

**Response to Comments on the Draft Final Design for PCMC**  
**Mark Fitch, University of Missouri-Rolla**

**General Response:**

This response is offered in regards my design, not in regards larger issues of ownership, control, or policy. In regards the design, there were a number of common concerns that I will address here instead of in the detailed responses:

1. **Meeting effluent standards:** The design was not based on meeting a proposed effluent standard, rather on substantially reducing the metal load due to the Prospector outfall. This proposed cell is envisaged as the first of two or three, with subsequent units being larger; however, I believe the authority over the areas that would serve well is currently not PCMC. I feel obligated to leave addressing these issues to the City.
2. **Influent:** It was apparent that several reviewers were not familiar with the specifics of the water to be treated; I had incorrectly assumed the stake holders knew the specifics in this case. Particularly relevant in Table 1 at right is that pH is 6.2 on average, such that I would say this is not an acid mine drainage, but rather a neutral metal-tainted water. The concentration of dissolved metals is low when compared to acid mine drainage, 7 mg Zn/L, 0.04 mg Cd/L and 0.3 mg Fe/L. The hardness is very high and sulfate is significant. Note that the iron is low enough that iron oxyhydroxide formation will be very slight and minimal armoring of solid surfaces is expected.
3. **Vertical flow:** To my knowledge, nobody has built a full-scale horizontal-flow system as proposed, a relatively thin strip of organic-rich substrate, but a significant number of vertical-flow systems exist. Being first in engineering solutions is sometimes considered to be “the bleeding edge” of progress. The horizontal flow system does offer advantages in terms of controlled flow and access to selected parts of the substrate. My understanding is that no vertical-flow system has run more than five or six years without requiring complete rebuild, and thus the promise of the horizontal-flow system as proposed is being able to do maintenance at a small scale. If a short-circuit develops, tracer tests using samplers across the wetland can isolate the area of the failure, and substrate can be added at that location and compacted to decrease the short-circuiting.

Table 1. Water Composition

	Mean	St. Dev
pH	6.2	0.3
TSS (mg/L)	3.6	3.6
TDS (mg/L)	1770	205
Hardness (mg/L)	910	125
DO (mg/L)	6.0	1.0
Sulfate (mg/L)	650	50
As (mg/L)	0.001*	0.0003
Cd (mg/L)	0.04	0.01
Fe (mg/L)	0.21	0.26
Hg (mg/L)	BDL	
Pb (mg/L)	0.02*	0.04
Zn (mg/L)	6.8	2.3

Based on data provided by PCMC.  
 BDL = Below detection limit.  
 \* Many values were below detection limit.

**Detailed responses:**

Comments by David J. Reisman, USEPA ORD ETSC: Mr. Reisman’s comments showed insight and understanding, and ORD offered a great critique. I have tried to excerpt major points from the comments (quoted in italics below) and address them in order.

4. *A manure and wood-chip-based reactor is not a permanent solution to the treatment of zinc, cadmium and other metals found in these waters.* The proposed design includes that maintenance and monitoring are necessary. The organic will decay, with replenishment at some rate by senescent plant matter. Depending on relative rates, the organic content might increase or might decrease. Therefore, if sulfate removal decreases (reflecting a decline in organic), fresh media shall be added. I find the idea of a permanent treatment process troubling; given that 20-year design lives are standard in engineering, I would think very few treatment processes can be considered as permanent.
5. *Changing the type of wood-chip will make little difference in the results.* The specification of a low lignin wood as the organic was the result of a suggestion that some of the locally available woody materials are fairly non-biodegradable (i.e. Douglas fir, a redwood-like material).
6. *The pilot scale results shown in the graph of the PowerPoint presentation show zinc removal seldom exceeding 60 %. We have an existing wetlands-bioreactor that eliminates zinc at greater than 95 %, and has done it during the warmer months for approximately 3 years.* I suspect that a detailed comparison would show that the EPA reactor has a longer residence time/lower loading rate and possibly a higher concentration of Zn. Higher concentrations give better % removal, as do longer residence times. Therefore one might ask: shouldn't this system thus have a longer residence time? Ideally, the proposed bioreactor (aka constructed wetlands in my opinion) is the first treatment cell. Additional treatment is dependent on demonstrated success of the first cell and availability of both suitable a site and resources for construction. Additional wetland cells will give longer residence times and greater removal.
7. [On manure:] *they will add manure to provide carbon while the wood chips are decomposing. There is very little data to show that this will work, and for how long ... In fact, adding manure may introduce other bacteria that may interfere with the existing microbiological structure.* The large fraction of manure was based on the suggestion of the third-party reviewers who were concerned about kick-starting the system. Although I am confident that the proposed mixture will work, a pilot test of the proposed mixture might be good. I strongly disagree that other bacteria would be introduced that interfere. The manure is the microbial inoculum! Coming from cattle, the manure will include cellulosic degraders and sulfate-reducing bacteria. I found in researching this response that cow manure was recommended as an optimal substrate for metal-treating bioreactors by a study funded as part of EPA's Mine Waste Technology Research (Activity III, Project 24).
8. *The microbiological community must be developed and include other functional bacteria, such as fermenters, degraders, and "cellulose providers."* Several years ago, two other researchers in this area, Dr. Miller and Dr. Tsukamoto from the University of Nevada-Reno, stopped working on a bioreactor of wood chips and manure similar to what this proposal is trying to achieve. My impression, based on their *Water Research* publication, was that these investigators were using wood chips as a solid matrix and supplementing with alcohol, and I gather they are doing something similar at the Leviathan Mine; I'd appreciate knowing where they published the failure you allude to. In contrast to their results, our lab-scale reactors have operated for six years on the original substrate mixture of wood chips, sand, manure, straw, sludge, and gravel. We seem to have large numbers of SRBs (not measured since 2001, but apparent in sulfate reduction and sulfide

production). The wood chips seem to continue to degrade with a low rate of organic utilization. One of my students just determined (handed me his document an hour ago as I write this!) that the six-year old wetland shows an organic decomposition rate of 0.04 mg VS/g original TS/day, while brand-new wetlands have a rate of 0.09 mg VS/g original TS/day. This would indicate exhaustion at about 30 years. Perhaps as the reviewer suggested the pH makes a huge difference in our results vs. Drs. Miller's and Tsukamoto's.

9. *Other issues with this substrate that might occur: varying rates of decomposition, non-homogeneous mixtures and decomposition, eventual preferential flow, compacting, clogging, precipitation and lodging on the bottom of the reactor.* The proposed design specifies that the substrate must be well-mixed to avoid issues of non-homogeneity, and preferential flow (short circuiting) and compaction (which would result in surface subsidence) must be monitored. I don't understand what is meant by 'precipitation' in the above, perhaps that organics will precipitate out in the gravel layer? Such will occur, and would result eventually in excessive head loss and preferential flow to a non-clogged location.
10. *Will Dr. Fitch be able to denote this event [cellulose limitation] in your reactor prior to failure (i.e., lack of the right form of the food from the substrate)?* Eventually something will fail and the system will require maintenance. If the hydraulic elements (pipes, pump, valves, berms) don't fail, then most likely the organic will become depleted. The proposed design does not suggest monitoring the volatile solids, which in the long term may be an oversight. As the organic (electron donor) is depleted, the rate of electron acceptance will decrease, and as a result the reduction of sulfate will decrease. Thus regular monitoring of the decrease in sulfate across the bioreactor should show when the rate of electron donation slows and available organic is depleted, assuming that plants do not replenish the organic at a greater rate. Park City might also annually sample some of the substrate and determine volatile solids to monitor the (presumed) decline in organics.
11. *Limestone rock should be used in place of gravel in the area of the reactor that will be covered by the water, preferably upfront.* The draft final design did strongly suggest limestone.
12. *As far as the plants dying and adding organics to the reactor, we have seen little data on this development and would like to see the references that provide this data.* I admit it has been an assumption that when the plants growing in the wetlands become senescent at wintertime the dead plant mass will fall to the sediment surface and decay. I also have assumed that growth and any death of rhizomes result in net organic addition to the substrate (sediment). We have not carried out long-term studies of organic content in planted vs. non-planted reactors to determine how much organic deposition, if any, occurs.
13. *In certain areas of the proposal, I was confused as to whether the system would be anaerobic or aerobic.* The substrate itself will be anaerobic aside from the top few millimeters of the saturated substrate and the front few millimeters where water flows in. The influent gravel zone I expect to be aerobic (the influent water has a moderate DO) and the effluent gravel zone may become aerobic.
14. *Construct sampling ports at the various levels of the reactor in different places.* I concur. Sampling tubes were suggested in the draft final design but not in great detail.

15. *Look at other metal concentrations.* The data provided by PCMC, monthly monitoring reports of the outfall, is summarized far above in Table 1. I do not have data about aluminum, but I suspect there is very little in the water. [Jeff?]
16. *As noted in my first set of comments, I suggest that you do not use sand.* The first set of comments did not reach PCMC; we would be pleased to have a copy. [Jeff?]
17. *In our recent study, we found that the bugs did not “use or like” the sand as a media. It will also affect the hydraulic conductivity in this project.* The sand is to be well-mixed in with the other substrate components as a solid, high-permeability component to help limit compaction and increase permeability. I do not have proof that sand performs these functions in the substrate, but I understand sand does perform such functions in soils.
18. *Eventually, the proposed reactor will become more compacted (after 5 years or so). ... Short-circuiting will come into play, and may cause part of the system to become aerobic unless many dollars are spent to tear apart and re-build parts of the reactor.* The issue of compaction and short-circuiting is indeed a concern and I believe a frequent cause of problems in vertical-flow wetlands. The periodic tracer tests recommended in the design should be analyzed to show changes in hydraulic conductivity, and locations with higher conductivity can have substrate added from the top and be compacted slightly to decrease the conductivity. Unfortunately, the utility of such an approach has not been, and possibly cannot be shown conclusively at lab-scale or at modest pilot-scale, and so it is a reasonable idea rather than a proven maintenance technique.

Comments by Dr. Brian Caruso, USEPA ORD Hazardous Substance Technical Liaison:

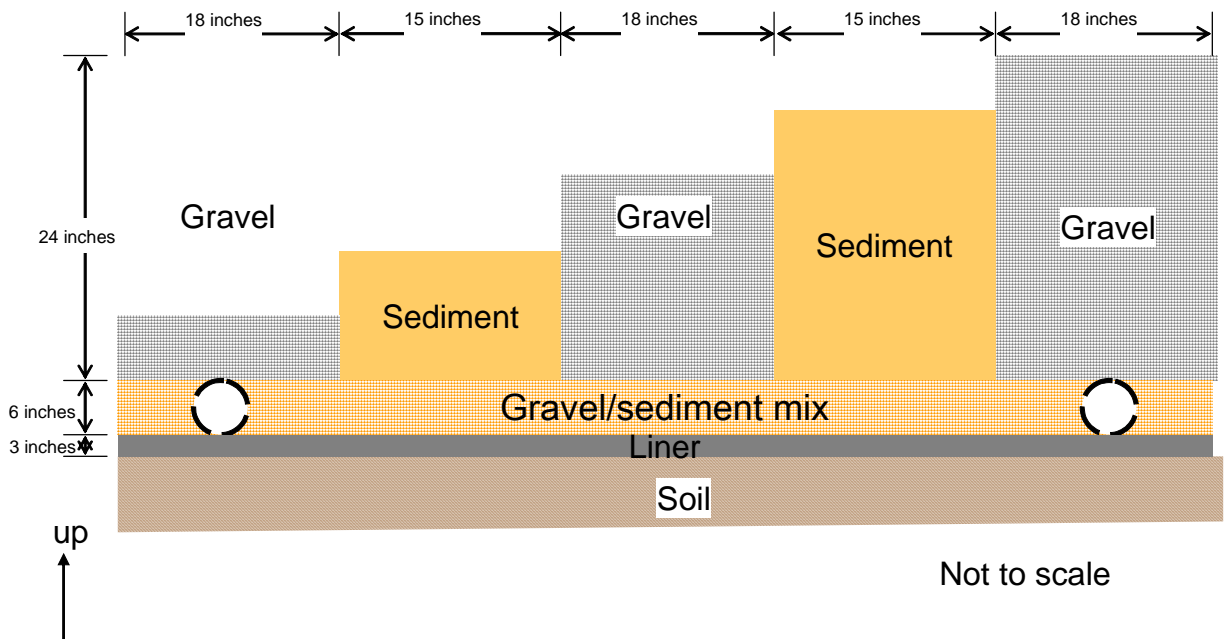
19. *Vertical flow SRBs are generally regarded as more effective with less potential short-circuiting than horizontal flow reactors, if designed and operated properly. We believe that the basis for selecting a horizontal flow reactor is flawed.* I am not aware of studies showing Dr. Caruso's claim that horizontal-flow systems have more short-circuiting than vertical-flow systems. I suspect that the orientation of flow to the gravity field has little to do with short-circuiting.
20. *The cost of the additional flow distribution and collection piping required for vertical flow would be less than the cost of the gravel proposed in the current design, and the reactor would achieve greater metals removal efficiency with less short circuiting.* I don't agree on cost: a similar amount of gravel would be required to overlay the additional pipes and assure good vertical distribution, and I believe a layer of gravel on the top would be needed to prevent flotation. The costs are likely similar. All this would indeed provide more substrate volume and thus more treatment. However, my understanding is that maintenance on vertical-flow systems is to completely reconstruct the cell, whereas I believe the horizontal-flow system as proposed allows for small fixes because the substrate is directly available.
21. *...gravel is not needed and may provide too coarse a material and too much porosity for precipitated metal sulfides, thereby allowing colloidal precipitates to flow through and exit the system to Silver Creek.* Gravel, or some other highly permeable material, is need to distribute flow evenly across the site. The sulfides will be generated in the substrate and are expected to be retained in the substrate rather than the gravel. Colloidal material, particularly NOM, may indeed exit the system, and thus additional cells would further removal.

22. *It would probably be better to have 2 SRBs in parallel so that when one needed maintenance or repair, flow could be diverted through the other unit.* Agreed, but this assumes the unit needs to be shut down for maintenance rather than PCMC being able to add substrate at the surface. The ability to divert is planned at the inlet structure, but if only one cell is built, diversion would be directly to Silver Creek.
23. *The variability of seasonal and peak flow rates from the drain have not been adequately defined in the design proposal.* As noted in the general comments, I was surprised that the reviewers were not familiar with the situation. As reported by PCMC, the Prospector Drain produces  $90 \pm 15$  gallons per minute regardless of season.
24. *In addition, flows and high water levels in Silver Creek, which is directly adjacent to the SRB site, have not been defined in the design proposal.* The issue of high water level and the berm height is well-noted. Anecdotal evidence is that high water levels don't exceed 1-2 foot below the proposed berm height. However, PCMC has been asked for further information on the maximum flood stage of Silver Creek.
25. *Sewage sludge is not needed and could potentially add or release previously bound metals to the system.* Agreed.
26. *30% manure is too much and not needed.* Some evidence supporting this critique would be appreciated. As noted above, cow manure was recommended as an optimal substrate for metal-treating bioreactors by a study funded as part of EPA's Mine Waste Technology Research (Activity III, Project 24).
27. *Bark does not provide a good substrate or food source for the SRB and should not be used.* The SRBs that have been reducing sulfate for six years in my lab-scale chip bark-based bioreactors would be surprised. From a theory point of view, I don't know that anyone has isolated wood-degrading SRB, but this doesn't mean they cannot exist. More likely, though, and acceptable by bacteriologists, is that cellulose degraders produce organics which are used by SRBs.
28. *Vertical piping for sampling and flow and potential short-circuiting monitoring could introduce too much oxygen to the system preventing anaerobic conditions from developing in certain areas.* I disagree. The vertical piping, which will be small pipes widely separated across the wetland, should be water-filled and also loosely capped, limiting oxygen input to the top of the pipe and creating a stagnant water column. The diffusion rate of oxygen in water is low and no advection will occur, so I just can't believe this critique is correct.
29. *The metals removal rates achieved in the bench and pilot testing are relatively low. SRBs developed by EPA ORD can achieve >90 to 95% removal efficiency for most metals.* I believe that the ORD systems have lower hydraulic loading, treat higher metals concentrations (easier to hit higher % removal), 'benefit' from being acidic such that raising pH results in simple chemical precipitation, and remove iron as an oxyhydroxide which co-precipitates (or adsorbs) other multivalent cations. Additional cells will address the hydraulic loading, and PCMC is happy not to have the other factors in the water.
30. *EPA ORD and our Engineering Technical Support Center should work collaboratively with Park City and Dr. Fitch to modify and improve the SRB/wetlands design.* I think this is a lovely idea.

Comments by Henry Maddux, FWS Utah Field Supervisor:

I wanted to note that I enjoyed the thoughts shared and questions asked by the FWS representative at the stakeholders meeting at which the design was presented. Many of the written comments seemed to me to be addressing larger watershed issues rather than the design. One issue related to effluent concentrations, addressed in #2 far above.

31. *Feasibility in terms of construction and operation & maintenance, with specific questions about how the alternating layers of gravel and active biological “substrate” will be laid down.* The suggested construction method is to lay down a short lift, 4-6 inches deep, illustrated below. During construction, the various levels will be ziggurat-like, and strings can mark the edges of each lift/layer. A skid loader or small dozer (something with a 5-6 foot reach with a bucket) can pour the material (gravel or mixed substrate) onto the layer followed by manual dress up to roughly level that layer. The individual lifts will slump only a small amount because the exposed height is only a few inches.



32. *How flow paths within the wetland will be established and maintained, and how “short-circuits” (when the water takes a flow path around the substrate treatment cells) will be identified and repaired.* Short circuiting has been addressed above in comments #3 and 18.

33. *How overflow volumes will be dealt with.* The inlet structure is to have a bypass to the existing drain/outfall.

34. *How overland run-on will be controlled and prevented from entering the treatment unit.* I believe that only a small area drains into the proposed bioreactor area, namely from the berms. The highway also may runoff to the area. This all amounts to very little water. However, one concern is an existing outfall underneath the highway (shown as ‘steel pipe’ in the survey, halfway along the proposed length of the cell. PCMC has indicated this outfall is valved off and controlled by the highway dep’t? [Jeff?]

35. *How the unit will be “taken down” for maintenance (i.e., will the whole system have to be taken off-line, with untreated water going into the creek, in order to perform maintenance, and if so, for what length of time).* As noted in above responses, the expectation is that most maintenance can be done without diversion. Eventually some

major maintenance will be required (best case – pipes will fail after some number of decades) and major portions of the cell will have to be excavated and rebuilt, which I believe will require weeks. If additional cells are constructed, the bypass can go to those downstream cells, mitigating the impact of one cell going off-line.

36. *The proposal's contention that "Limited measurements from wetlands receiving and discharging higher concentrations have shown negligible effluent toxicity" references direct acute toxicity ... not necessarily ... chronic toxicity ..., nor, importantly, does it address the issue of zinc or cadmium loading and accumulation in sediments downstream.* Agreed; I apologize that my wording was not more specific. I would note that our WET tests used not fathead minnows but *C. dubia*, which I believe are considered to be more sensitive organisms to direct toxicity. It seems to me to be reasonable to expect that a decrease in the metals load to the creek should decrease any putative toxic effects, but I am not a toxicologist nor in any way familiar with the specific food web of the creek.
37. *In general, the Service does not approve of the use of natural wetlands for water treatment. In this case, an absence of an evaluation of other treatment alternatives (or ways to minimize the amount of wetlands needed for treatment) would make it more difficult for the Service to approve this approach.* Other treatment alternatives were considered and listed in both of the presentations I gave at Park City. I believe the wetlands are the least-cost treatment technology.

Comments by Dan Wall, USEPA:

A substantial fraction of Mr. Walls' comments concerned effluent quality which I am not addressing (comment #1 above). The largest single issue, in my opinion, is whether the pilot wetland should be reconstructed and tested for another year (to get trustworthy winter data), delaying by a year implementation of the proposed cell.

38. *I support this effort but I think that the pilot wetland was only marginally successful. I think it would be prudent to see the pilot wetland be modified to approximate final biocell conditions and retested before significant money is spent.* This sounds wise to me. I am modestly concerned at changing slightly the design, particularly the substrate mixture, without a pilot test. I am also interested in a better-insulated and isolated pilot wetland outlet allowing for increased confidence in sampling during the winter. At the same time, the substrate composition is a slight change, and choosing to do additional pilot testing would almost certainly delay implementation of treatment by a year. It's a difficult choice, and I leave such a choice to the stakeholders and/or PCMC.
39. *Will the system of biocells be considered complete if the effluent standards are not met? Can the effluent standard be considered a performance criteria? What will be the measure of success of this system of biocells?* Although this comment partially concerns effluent standards, measures of success I will address in the negative: I would consider failure to be less than 50% removal of the zinc load (on an annual average) by this proposed first cell. Based on research at UMR, an outstanding success would be greater than 70% zinc removal. As to cadmium, 80% removal would be an outstanding success.
40. *I don't think there has been presented sufficient information that the wetland is functional in the winter. It appears that the biocell actually becomes a source when temperatures drop.* Jeff has stated that he believes the effluent samples were poorly obtained, which relates to my response to #38 above that additional pilot-scale testing should be better

insulated and isolated from flooding. ... *wouldn't the Cd also have risen from contamination of the sample?* Not necessarily, the Zn might be from the gravel itself (small particles), which might have much lower Cd content. Even if these possible excuses are correct, performance still was not as good as expected. As to winter, some biocells for AMD have been reported to give consistent good performance at very low temperatures, but others exhibit poor performance in winter. Such conflicting reports are quite irritating, and a better pilot effluent system run over another winter might establish the truth of the matter for this location.