A WETLAND FOR ZINC REMOVAL FROM THE PARK CITY PROSPECTOR DRAIN.

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Wednesday, January 18, 2006

This document communicates the draft final design for a wetland based on research conducted at UMR and in Park City, incorporating input from the third-party reviewer, Nature Works Remediation Corp. and from the stakeholder's meeting of 13 January 2006. It should be noted that this is not an engineering design based on widely accepted standards, but rather a design for a full-scale facility based on the research. It also should be noted that the plan view drawings in this draft do not show the piping, gravel and substrate trenches, or open pond; these drawings will be modified as soon as possible.

This design is for phase one of three proposed to the stakeholders. This wetland was not designed to comply with the proposed TMDL effluent standards for zinc (.39 mg/L) or cadmium (.00076 mg/L). Nonetheless, it would be the best case scenario if the biocell effluent met or exceeded the proposed TMDL standards, and distinctly possible that Phase II could exceed such goals. However, unlike typical best available control technologies (BACT), wetland systems have unknown variables that could potentially affect the treatment success. EPA has funded research at UMR aimed at better understanding these systems and working toward design guidelines. The expectation is that this project will assist the City in their stated overall watershed annual TMDL Silver Creek target goal to reduce zinc and cadmium loading within Park City by 65% and 92%, respectively.

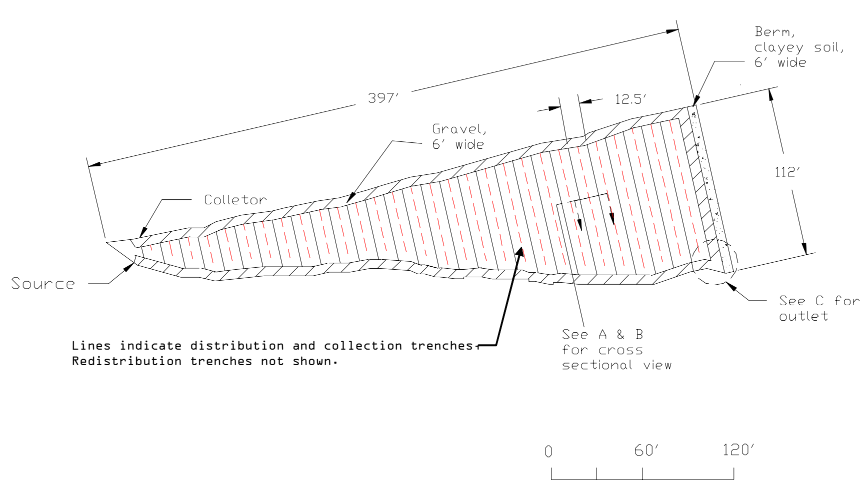
This document presents the design up front and then comments on potential issues relating to this design, many of which were raised by the stakeholders. The final portion of this document is the design methodology and calculations.

Design

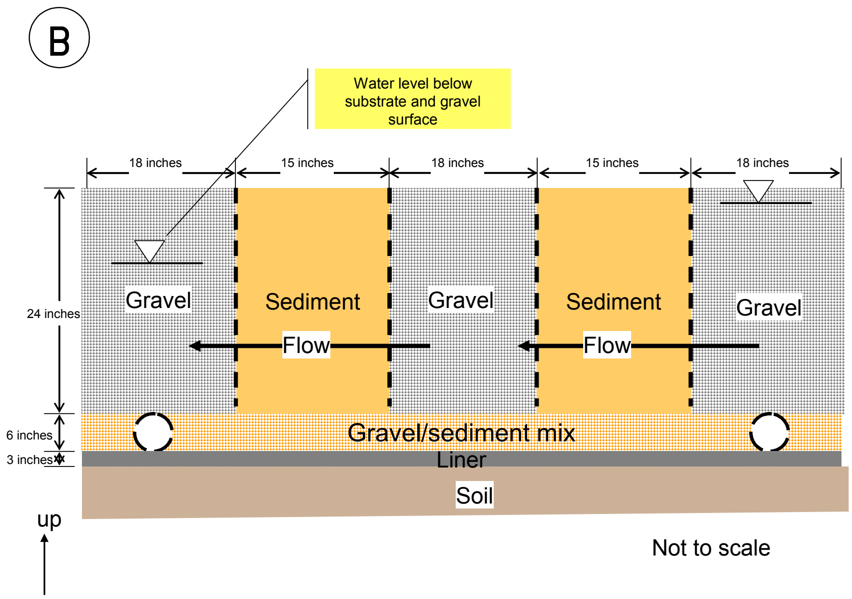
The design is summarized in the drawings included in this document. The basic element of the design is that water flows from the existing Prospector drain line:

1. into a 10-inch perforated pipe beneath a 6-foot wide gravel distribution channel,
2. from the wide channel into 4-inch perforated pipe under an 18-inch wide, 24-inch deep gravel trench which runs from the access road/earthen dam toward State Route 248 (see drawing A),
3. from the trench into a 15-inch thick, 24-inch deep layer of substrate,
4. from the substrate into another 18-inch wide, 24-inch deep gravel trench to redistribute flow before again passing into
5. another 15-inch thick, 24-inch deep layer of substrate, and
6. into a collection trench (18-inch wide, 24-inch deep, gravel filled, under which is a 4-inch perforated pipe) that drains into
7. a collector which is gravel filled, 6 feet wide and 24 inches deep and underlain by a 10-inch perforated pipe.
8. The collector channel abuts the slope up to the retaining wall for State Route 248, turning south (toward the Prospector park dam) at the east end of the area.
9. The end of the collector channel is a small open pond.

This flow pattern is illustrated in drawing B. The overall distribution and collection system can be thought of as a



pair of interlaced combs separated by substrate, implied in the plan view. This design, rather than long channels, was chosen to allow easy access for maintenance. The spacing of gravel trenches is such that typical construction vehicles (namely a backhoe or small trackhoe) can drive atop the gravel trenches in order to go to any point in the wetland for any repair needed in later years. The wide distribution and collection channels were sized to minimized head loss through these channels for the total anticipated flow and assuming the channels are gravel-filled. Open channels would be less wide, but would not be able to be driven across.



The design uses the existing elevations to form the walls of the wetland (along the berm over the existing outfall pipe and State Route 248), but requires a new berm along the east end of the property to act as the end of this 'bathtub'. The soil for the berm should be relatively low permeability (a clay or silty soil, not sandy soil), and perhaps could come from leveling the wetland basin area (to approximately 6492 feet of elevation; but no specific elevation is required). From the approximately level base, a liner (low permeability, clayey soil) will be laid, followed by piping, six inches of a 50-50 mix of gravel and substrate, and then two feet of gravel or substrate (Table 1). The anticipated water level is thus approximately at elevation 6495 feet, and the berm shall be not less than one foot above the anticipated water level. The width of the gravel trenches and substrate were chosen such that a typical bucket should be able to readily deliver a full width of material in a single scoop, but this design does not presume to specify construction technique; more suggestions on construction are found later in this document.

Drawing C at right shows the outlet for the wetland. To prevent freezing, a 4-inch or 6-inch PVC pipe in the gravel collector channel and above the base of the wetland at least two inches transports water through the berm and into a small, insulated structure. The water flows to the top of the pipe (note tee with cleanout cap as elbow) and spills out onto the soil and into a gravel trench. This gravel trench shall be built to drain into Silver creek at the dam and to be below water level (preventing freezing in the trench).

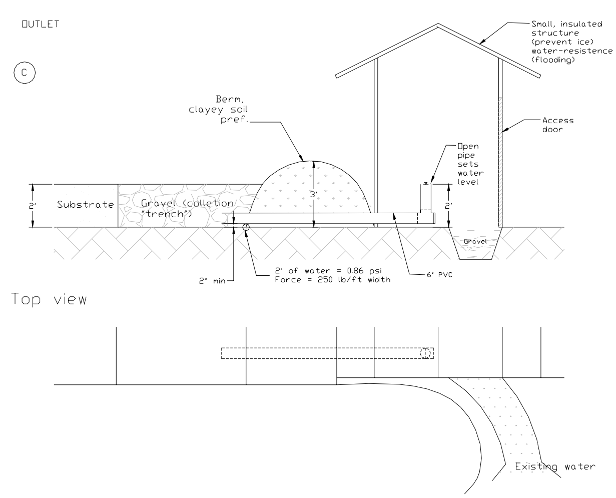


Table 1. Substrate Composition

Component	%v/v	Role
Wood shavings or	50	Long-term organic source

chipped wood		
Manure and sewage sludge	30	Bacterial inoculum and easy-to-degrade organic
Sand and gravel	20	Increased hydraulic conductivity

The outlet pipe level may be used to control water level in the wetland. The wetland water level should be below the surface at all times to prevent surface flow and, during winter, freezing.

The structure is not specified here; it shall allow access and be of water-resistant materials (the area is known to flood to several inches or more above the existing ground surface). Insulation is required to prevent freezing of the pipe outlet or within the exposed pipe.

The substrate components listed in Table 1 are chosen for local availability and low cost. Based on metals analyses given in Table 2 in a section below, manure is preferred to sludge. The substrate shall be well-mixed prior to placement.

Not shown in the drawings but strongly suggested is the inclusion in selected spots of the gravel of samplers. The samplers are to be upright two-foot long sections of PVC pipe with holes drilled in the sides to allow water to flow through from the gravel. Non-glued caps for the samplers are suggested. These sections can be used to determine water level in situ and to take samples of the water for analysis.

Plants

The wetland should be planted with native to the area shallow-rooting wetland (emergent) plants such as cattails. It is suggested that one cattail rhizome be placed roughly every square yard. UMR's measurements have shown that plants do not have a direct affect on metal removal of any significance. However, deep rooting plants could clog the gravel channels and affect flow, possibly causing short circuiting. While not directly contributing to treatment, plants will contribute to the organic layer and given enough time form a soil layer atop the wetland, which should not negatively affect operation. The plants UMR has grown in wetlands, largely bulrush and cattails, are excluders of metals (no biomagnification) and likely act as long-term sources of further organic carbon. Further, roots of these plants do not seem to affect hydraulic conductivity in the substrate based on 7 years operation at lab scale.

Materials

Gravel: Graded and washed limestone gravel shall be used. Grading is needed because even size results in open pores for flow. Limestone helps to raise pH due to the dissolution of the carbonate and consequent buffering, so other stone yielding alkalinity could substitute.

Pipe: PVC pipe with perforations is needed. The pipe shall be of sufficient schedule (wall thickness) to withstand three foot of gravel atop the pipe while also having perforations (holes) sufficient for free flow of water out at any point along the length.

Liner: The design assumes a liner, and the next section includes a on the rationale for inclusion of such a liner. The liner shall have a hydraulic conductivity of less than 2×10^{-9} m s^{-1} (clay) and thickness more than 3 inches or equivalent combination of conductivity and thickness. If a high-clay soil is used, the layer thickness should be increased to balance the increase in hydraulic conductivity.

Wood shavings or chips: Bark is an entirely acceptable component of the wood material. The wood should be reasonably biodegradable, so a high-lignin wood is not preferred. Thus hardwood such as poplar is better than softwood, although pine and spruce should be acceptable (while cedar and redwood would be very poor choices).

Inflow and Interception

The expected water level in the wetland is 6945 ft without head losses. The elevation of the water surface in the manhole is not known and must be determined. If lower than 6945 ft, a pump may be required to lift the water to the wetland. The wetland shall be fed by a 10-inch non-perforated pipe connecting to the perforated pipe in the source channel. The two cases for flow are:

1. No pump required: the existing outfall shall be used as the overflow/bypass for excess flow. Head level at the manhole shall be set by an adjustable gate to be installed in the existing manhole. The excess flow thus will travel over the gate and to Silver Creek down the existing pipe.
2. Pump required: if a pump is required, a submersible self-priming pump shall be installed before the existing manhole (power will be required) able to lift 200,000 gallon/day above the top of the existing berm (estimated head of 10 feet). The pump will discharge to the existing pipe flowing into the manhole. The manhole is to be modified as above.

Issues

Expected outflow concentrations and toxicity

The existing pilot scale wetland gives 4.0 ± 1.5 mg/L of zinc (excluding the questionable samples during flooding last year; with the samples, 5 ± 3 mg/L) and 0.011 ± 0.007 mg/L of cadmium. The ± values are one standard deviation based on 17 samples over 19 months. Influent concentrations over the same period were 8 ± 2 mg/L of zinc and 0.05 ± 0.01 mg/L of cadmium. The proposed wetland will receive one-third the hydraulic load of the pilot unit and thus greater removal. Given that lab-scale as well as the Teck Cominco wetlands, operated at lower hydraulic loadings than the pilot unit, remove ~50-65% of zinc per stage, the outflow of this wetland should be on average 3 mg/L zinc and 0.01 mg/L of cadmium. The zinc and cadmium loadings to Silver Creek therefore will decrease by approximately 2,200 g Zn/d and 18 g Cd/d.

Limited measurements from wetlands receiving and discharging higher concentrations have shown negligible effluent toxicity. The same is expected of this effluent, that full-strength effluent will have 100% survival of fathead minnows, and 50-100% survival of the much more sensitive *Ceriodaphnia dubia*.

The proposed second phase is a larger wetland and is expected to remove a further 60% or more of the metals, yielding an effluent of at most 1.2 mg/L zinc and 0.004 mg/L of cadmium.

Soils and grading

The soil at the site has not been characterized, and clearing, grubbing and leveling will result in some movement of soil, and such soil may include tailings. Appropriate disposal, is to be performed as required by the law. The leveling shall produce an area which is generally flat, with flat meaning that no obvious humps shall remain, but grading as for a gravel road surface is not required.

Construction

The designer does not presume to tell the contractor how to do their job, but constructability has been a consideration of the design. This is not an easy unit to construct due largely to the small trenches.

Creating the rows of gravel and substrate will be a challenge compared to many common construction operations. Two suggestions are offered:

1. Use a skid loader to place material and manual clean up.
2. Define each face of the trench by a sturdy netted material (not silt fence or other material which will plug with silt) such as chicken wire or snow fencing, and fill between the netted material. Essentially a mesh like that used in gabion secured with posts could hold the gravel, and the substrate could be filled between rows of gravel.

The substrate will have to be well-mixed, such that pockets of sand or manure do not exist. This is also true of the first six inches of 50-50 substrate and gravel. A soil mixer or concrete mixer would be likely to produce acceptable results.

Construction of an adjustable gate in the manhole may require diversion of flow.

Liner

Exchange between the wetland and the soil beneath the wetland is a concern. The soils in the area for this wetland may include tailings, such that water passing into the existing soil might mobilize metals into groundwater. Alternately, seepage from the soil to the wetland might introduce an additional metal load to the system beyond the design value. This latter seepage seems unlikely, given that the wetland will add several feet of head to the soil. On the other hand, seepage from the wetland to the soil would introduce water with some degree of sulfide present, forming metal sulfides in the soils and immobilizing metals. Visual evidence at the site indicates the soil is permeable to some degree – the plants present include some willows and grasses associated with wetlands, but also upland plants. Upland plants imply adequately drained soil. Movement from the influent channel to the soil would largely prevent or avoid treatment of water in the wetland, and that water would not have high sulfide content.

The exhaustive approach would be to determine whether such water exchange will occur, by measuring the permeability of the existing soils (percolation tests) and determining the composition of the soils in the area. The easy, more expensive and possibly unnecessary approach is simply to line the system. In the design, therefore, a liner is included.

Winter

As much as six inches of ice may form at the top of the wetlands, based on ice thickness on lakes and reservoirs. The third party reviewer has suggested allowing an ice surface to form and then lowering the water level such that an insulating layer of air is under the ice.

Head loss and hydraulics

The design calculations below show the estimated head loss as 0.9 ft at full flow. The reviewers and stake holders have indicated some concerns about piping and slope. Because flow is essentially from south to north and head losses primarily occur in the substrate layers, sloping the wetland will not assist flow and might result in surface flow, which is failure. The hydraulic profile will be controlled by the set level of the inlet bypass and the outlet pipe.

Start-up

The wetland should be started by slowly filling the wetland (at half flow, approximately 1-2 days) without outflow. To provide for no flow, the wetland outlet pipe should be at the same elevation as the manhole gate, slightly below the surface of the wetland. The wetland should be allowed one to two weeks to develop an effective anaerobic community, and then flow should begin.

The wetland should be run at a low flow rate, initially, slowly ramping up flow as the outlet concentrations are found to be acceptable. The higher the flow, the greater the effluent metal concentration.

Maintenance

<u>Plants</u> should be monitored; as noted above, deep-rooting wetland plants might cause problems of plugging over years of operation. Plants will contribute to the organic layer and given enough time form a soil layer atop the wetland, which should not negatively affect operation. One minor concern would be occasional assay of metal content in representative plant samples from the wetland. No wetland plant species is known to accumulate metal in the stems and shoots at high concentrations, but some upland

plants certainly do, and the aerobic zone near wetland plant roots can have high concentrations of metals. Although biomagnification is not of much concern, occasional assay is suggested.

Short circuiting is the most likely issue to arise. The wetland should be checked on an occasional basis (monthly) for proper flow patterns. Extreme evidence of channeling would be obvious washing away of substrate into gravel trenches. Any such channeling should be patched by adding additional fresh substrate (low on sand content is suggested). Such inspection also shall identify any areas which are consolidating and require added material. An annual tracer test is suggested as a component of this operating process (and UMR would be delighted to be involved or at least to use the resulting data from this wetland system for years to come).

Surface flow is unacceptable, and the water level can be maintained by adjusting the level of the outlet pipe (drawing C). It is suggested that the samplers suggested above be checked routinely for water level; a significant rise or fall in one location will indicate short-circuiting (e.g. a rise on the collector side is due to short circuiting). The samplers will ease locating short-circuiting.

Design methodology

Basis of values: The full-scale wetland design is based on the lab-scale wetlands evaluated at UMR for lead mine drainage over the past eight years and the pilot-scale process receiving drainage from the Prospector outfall at Park City which was constructed in June of 2004. Hydraulic conductivity was based on values in various texts or measured in the thesis of Chad Ross at UMR, 2001. The applicable values are shown at right.

Material	Hydraulic conductivity (m/sec)
UMR substrate	$0.03 – 7 \times 10^{-4}$
Gravel	0.003

The hydraulic conductivity of the substrate made at Park City for the pilot-scale wetland appears to be higher than UMR's substrate due to the nature of the wood shavings, which appeared to form a loose sediment with significant void space. Consolidation is thus a long-term maintenance concern in term both potential surface flow and decreased hydraulic conductivity. The hydraulic conductivity is thus the largest unknown factor in this design and will be the limit on flow possible to the system.

Flow Direction: Vertical and horizontal flows are possible. Many wetlands for metals removal favor vertical flow, but horizontal flow is proposed for this design. The reasons for vertical flow are largely related to cost. Both vertical and horizontal flows give good removal, and vertical flow allows for higher loading (flow per area) because added head (pressure) results in more flow. Too much head on horizontal flow results in surface flow (flooding). Vertical flow, however, requires a network of pipes at the bottom to distribute or to collect flow, a significant cost for this case. Vertical flow also increases the likelihood of hydraulic short-circuiting due to the higher flow rates possible. Short-circuiting is addressed with reconstruction of the substrate layers, a significant cost. The horizontal flow wetland may have short-circuiting, but the horizontal design allows the specific location to be determined and fixed without taking apart the entire wetland cell.

Design Loading: A lower hydraulic load than the original ~0.15 gal/min/ft^2 used in the pilot-scale wetland was used to give a greater removal percentage. Hydraulic loading in this case is the flow into a horizontal cross section of the wetland, related to the velocity, not the flow per surface area. The lab-scale wetlands have been studied at 0.001 - 0.013 gal/min/ft^2, with surface flow observed at the higher loading value. The difference in loading between the lab- and pilot-scale units reflects both the difference in media (the Park City unit used fir shavings, the UMR units use chip bark, largely oak and contain less sand) and that the pump available in Park City had a minimum flow around one gallon per minute.

Given the pilot-scale results, the design flow is based on a hydraulic load of 0.05 gal/min/ft^2.

Design Area: Park City identified the area between State Route 248 and the Prospector outfall piping/lake berm as the design area. UMR understands this area to be owned by PCMC. This is roughly a triangle of 400 foot along two legs and 110 foot at the third leg (22,000 ft^2 of surface area).

Elevations: The area for the wetland is broadly at an elevation of 6492 feet; which was taken as the base of the wetland cell. The wetland shall be two feet deep, so the existing slopes along the south and north sides will contain the wetland, but a berm of not less than three feet height above the level of the wetland floor (~6492 feet) is required along the east end.

Trenches: As noted above, the trench dimensions were chosen in part to allow vehicle access. The basic gravel → substrate → gravel design is the same as use in the lab-scale and pilot-scale systems. The redistribution trenches and a second layer of substrate were based on the somewhat limited removal observed in the pilot scale wetland and to decrease the effect of any single short circuit across one layer of substrate.

Substrate: the substrate has three major elements: (1) organic to act as an electron donor, (2) bacterial seed from which the microbial ecology develops, and (3) filler to increase hydraulic conductivity. The fundamental idea of wetland treatment for metals is that electron donor is used by sulfate reducing bacteria with sulfate as an electron acceptor and the resulting sulfide cell waste forms insoluble metal sulfides. Past lab-scale analyses using materials provided by PCMC showed ample formation of sulfide. More to the point, the substrate in the wetland is clearly anaerobic and sulfide rich at a depth of less than one foot. The substrate in the top foot of the wetland had a negligible sludge content as mixed, which likely is the reason that sulfide is only removed at depth at the current time. Therefore the substrate mixture specified here for the full-scale wetland has a higher manure (readily degradable organic) content than the pilot-scale unit.

UMR analyzed samples of the components for extractable iron, lead, and zinc, as shown in Table 2. The values in the table are ppm by weight. Sewage sludge is known to contain elevated metals concentrations (it is good sorbent); no other component appeared to be a possible source of significant levels of zinc or lead.

Table 2. Substrate component extractability.

	Zn			Pb			Fe		
Extractant:	H_2O	$MgCl_2$	HNO_3	H_2O	$MgCl_2$	HNO_3	H_2O	$MgCl_2$	HNO_3
Wood shavings	4.1	8.3	6.8	0.0	BDL	BDL	0.2	12.7	38.7
Sludge	33.2	38.7	336.3	BDL	BDL	35.7	42.4	71.1	1151.7
Manure	3.8	6.1	153.5	0.0	BDL	3.7	6.0	20.0	426.7
Sand	0.8	7.0	63.6	0.0	BDL	14.4	0.7	3.3	521.5
Gravel	0.1	0.7	4.0	BDL	BDL	2.7	0.1	1.4	194.4

All values are µg metal/g component. Extractants: H_20 – deionized water; $MgCl_2$ – 1 M $MgCl_2$ at pH 7; HNO_3 – concentrated nitric acid. BDL = Below detection limits; values reported as 0.0 were measurable but less than 0.005 microgram/gram.

Calculations

Design flow:

Given

1 Hydraulic loading of 0.05 gal/min/ft^2 (= 0.002 m/sec = 176 $m^3/m^2/d$),

2 Total length of distribution channels is 1526 ft (465 m, measured by hand from drawings, includes ends of channels), and

3 Substrate depth of 2 feet, but only 1.5 feet flowing due to compression on bottom,

then the available flow cross sectional area = 1526 × 1.5 = 2290 ft^2. The design flow = 2290 ft^2 × 0.05 gal/min/ft^2 = 114 gal/min = 165,000 gal/day.

Pressure drops/head loss

Substrate: The expected head loss through a section of substrate 15 inches thick with a flow of 0.05 gal/min/ft^2 is:

$Q = K A \Delta h/\Delta L$ (Darcy's law) → $\Delta h = Q \Delta L / (K A)$

$Q/A = 0.05$ gal/ft^2/min = 0.0067 ft^3/ft^2/min (= 0.0020 m/min = 3.4×10^{-5} m/s)

$K = 1 \times 10^{-2}$ cm/sec (average value from Ross's thesis) = 2×10^{-2} ft/min

ΔL = 15 inches = 1.25 ft

$\Delta h = Q \Delta L / (K A) = (Q/A) \Delta L/K$ = (0.0067 ft^3/ft^2/min) 1.25 ft/ 2×10^{-2} ft/min = 0.42 ft.

Therefore the expected head loss through two layers of substrate is 0.84 ft at the design flow.

It is <u>strongly worthy noting</u> that hydraulic conductivity measured at UMR has varied over two orders of magnitude, and that if the substrate is highly compacted during placement or the wood chips are very fine, the head loss will be much greater than is calculated here. As a result, the maximum flow possible would be lower than designed due to simple hydraulic limitation.

Gravel: it is assumed that flow will travel down the pipes into the trenches, then follow the flow pattern shown in drawing B. Flow through gravel also will follow Darcy's law, with an expected hydraulic conductivity, K, of 0.3 cm/s (= 0.59 ft/min). Because pipes distribute the flow fairly evenly in the side-arm distribution trenches, the hydraulic loading, Q/A through the gravel is assumed to be 0.05 gal/ft^2/min. The total thickness, ΔL, of the gravel layers from pipe to pipe are 36 inches. Thus:

$\Delta h = Q \Delta L / (K A) = (Q/A) \Delta L/K$ = (0.0067 ft^3/ft^2/min) 3 ft/ 0.59 ft/min = 0.03 ft.

Piping: 69All piping head loss was calculated using Mannings equation for open channel flow (the pipe is not under pressure). The expected head loss through the 10-inch main pipes in the source and collection channels is:

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

Q = Flow, 165,000 gal/d = 0.255 ft^3/s,

n = coefficient of roughness, 0.013 (standard value for most smooth pipes),

A = cross-section flow area = πr^2 = 0.54 ft^2,

R = wetted perimeter = πD = 2.6 ft, so

$$S = \left(\frac{n}{1.49} \frac{Q}{A R^{2/3}} \right)^2 = \left(\frac{0.013}{1.49} \frac{0.255}{(0.54)\, 2.6^{2/3}} \right)^2 = 4 \times 10^{-6} \text{ ft/ft}$$

S is the slope of the hydraulic gradient. For the flow in the 10-inch pipes, that length is approximately 500 feet (partway along one side, picked up opposite on the other side and then down the berm), so a head loss of 0.002 feet is expected.

The same equation applies for the 4-inch distribution trench piping. In this case for conservatism in predicting head loss, it is assume that any given pipe (of the 28) might take 10% of the flow.

Q = 16,500 gal/d = 0.0255 ft^3/s,

n = 0.013,

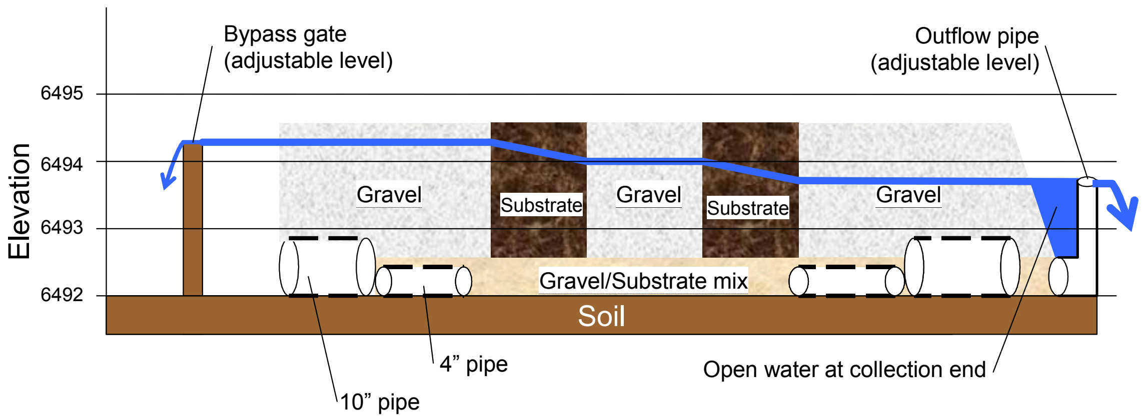
A = 0.087 ft^2,

R = 1.05 ft, so

$$S = \left(\frac{n}{1.49}\frac{Q}{AR^{2/3}}\right)^2 = \left(\frac{0.013}{1.49}\frac{0.0255}{(0.087)1.05^{2/3}}\right)^2 = 6\times10^{-6}\text{ ft/ft}$$

The longest distribution piping will be approximately 100 feet, so the highest head loss through such pipe would be 0.0006 foot.

The resulting hydraulic profile is shown below.



Hydraulic profile. Horizontal distances not to scale.

<u>Material [Values have not been updated as of yet, construction estimate will be complete by 25 Jan]</u>
Gravel: the distribution system and collection system 6-ft wide, 2-ft deep trenches are approximately 400 ft long and 520 foot long, respectively, containing (400+520)×6×2 = 11,040 ft^3 of gravel or 410 yards. For the distribution and collection trenches, each is 1.5 foot wide by 2 foot deep and the lineal trench length is 1500 foot for distribution, so assuming the same length for collection, (1500+1500)×1.5×2 = 18,000 ft^3 of gravel or 670 yards. The redistribution trenches willl require essentially the same amount of gravel, 660 yards. The total gravel needed is thus 1740 yards.

<u>Liner</u>
2×10^{-9} m/s hydraulic conductivity and 3 inch thickness over 0.5 acres with two foot of head yields (using Darcy's law) a flow of 0.0002 m^3/s or 4,510 gal/d. This assumes atmospheric pressure on the bottom of the liner, which is highly unlikely, so observed flow would be smaller.

Boilerplate

<u>Permissions</u> It is understood that PCMC will secure all required permits and waivers needed for the project (none of which are required for this design, but may impact chosen areas).

<u>Information</u> PCMC will share all available information requested by UMR in a timely manner, and UMR shall respond to all PCMC inquires in a timely manner.

<u>Liability</u> Dr. Fitch is not a P.E. in Utah, and mine water treatment wetland design is not yet developed to a state where there is one accepted design standard (indeed, design models are a goal of the research at UMR). This is a research effort for UMR, not an engineering design as would be produced by a (significantly more expensive) consultant.

Addendum follows, third party review:

Nature Works Remediation Corporation

Natural Processes for a Cleaner Environment

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Jeff Schoenbacher
Environmental Coordinator
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Dear Mr. Schoenbacher:

We are pleased to have had the opportunity to work with Dr. Mark Fitch and provide comments on his design for the phase one treatment for the Prospector Drain in the Silver Creek Watershed. As part of the process we have been working collaboratively with Dr. Fitch since September 2005, providing our field expertise and operating insights throughout this phase of his design process.

In this iterative process he has been receptive to our input and concerns. Dr. Fitch has addressed our initial concerns by further developing his explanations and by making design modifications based on our input where appropriate. We have collectively arrived at a point where we are in agreement on all major aspects of the final design proposal.

Our experience is based on 10 years of design and operation of a system that utilizes vertical sub-surface flow anaerobic bioreactors in series with horizontal sub-surface flow gravel substrate plant-based cells. Although some elements of our design differ from the design proposed by Dr. Fitch, there are sufficient similarities in concept to allow us to offer advice and to feel comfortable with the proposed design innovations that Dr. Fitch has developed.

The important elements of a biological removal system are well known. For a bacterially based biologically-driven system, it is important that the bacteria have sufficient quantities of an easily available carbon source and sulphate to produce the sulfide ion necessary to precipitate the divalent metals as metal sulphides. As well, sufficient residence or contact time is required for the metal sulphides to form and to be deposited in the bioreactor matrix.

The main issues that must be addressed in a semi-passive biologically based treatment design are the following:

- **The quantity of the biological substrate**
  - Based on our field experience and the generally accepted 'rule-of-thumb' of passive metal removal wetlands design (Gusek and Wildeman, 1997), we are comfortable with the quantity of substrate proposed by Dr. Fitch. There is also a considerable safety margin in his design.

- **The character of the substrate**
  - Because the carbon in wood chips is not as readily available initially as the carbon in other substrates it is important to include another material in the original mixture. Through discussions with Dr. Fitch we have agreed that it would be better to increase the initial concentration of manure to

30%. This will mean that bacteria will have a readily available carbon source from the onset. We have also agreed that the type of wood chips that are used be changed from the relatively more stable fir chips used in the pilot system to a combination of white wood chips that are more easily broken down by cellulose degrading bacteria.

- **The design must ensure even distribution of water with no short circuits**
  - We are in agreement that his design should ensure even and complete water distribution throughout the cell (if built as designed).
  - The horizontal design allows for easy access to the system for monitoring and maintenance of the system. This allows for early detection and correction of short-circuits should they develop.
  - Our agreement on this issue is based on assurances that the bottom of the cell will be level in all directions or sloped slightly downward from the input to the output side. As well, the distribution and collection pipes must be installed level with sufficient support to eliminate or markedly reduce sagging along their lengths.

- **Sufficient residency time**
  - This is essential. Bacteria must produce sufficient sulphides in contact with dissolved metals in the water to allow for the formation of metal sulphides. Although the kinetics for formation of zinc sulphide (sphalerite) are rapid there is still a measurable time requirement. Therefore, the design must incorporate features that ensure that water flows through sufficient substrate in all directions to ensure this contact.
  - In recent conversations with Dr. Fitch we have proposed that he increase the size of the plugs in some areas of his substrate channels to provide more even distribution and increased substrate contact.
  - Further we have suggested that he include a layer of specially mixed substrate that covers the entire bottom of the cell to a depth that at least covers the complete collection pipe. This mixture would be approximately 50% gravel and 50% wood chips. The additional gravel material ensures that compaction, when it takes place will not be severe enough to impede water flow. It also increases the amount of substrate in contact with metal containing water and finally acts as a filtration layer to remove metal sulphides that exist as fine colloidal particles.
  - Residency time is also important because it allows the fine particles to settle out. This may be the ultimate limiting factor of this design. At higher flows the velocity of water through the cell may push fine sulphide particles through the cell and out and at high enough flow velocity wash out bacteria. The impact of insufficient residency time can be detected through monitoring both the total and dissolved output metal concentrations. A large difference between the total and dissolved metal concentrations may indicate the need for increased residency time in the bioreactor. If bacteria are washed out the treatment rate will decrease dramatically.

The removal of zinc is greatly improved at a pH of 7.2 – 7.6. Although the pH of the influent is in the neutral range and bacterial activity will increase the pH through the formation of the bicarbonate ion, we recommend that limestone be included as an essential part of the gravel mixture. It is difficult to specify the percentage of limestone that would be ideal, but we feel that as high a percentage as possible be included within the constraints of the overall budget. Furthermore, we recommend that the gravel be graded and washed to eliminate as much of the fines as possible before installation.

From our field experience we know that multiple cell systems are the best method to use. A second cell in series with the first one has been shown to provide higher removal efficiency as the effluent has been pre-treated, primed biologically and provides fine metal sulphide particles that act as precipitation nuclei for the second cell. Hence, the biological and chemical activity is improved in the second cell. It also serves as a second stage filtering system removing any remaining fines from the effluent of the first cell.

A phased approach is also beneficial because each site is specific (i.e., availability of local organic substrates, types of local gravel sources, annual hydrograph, available land for the project and climate conditions). As well, the ideal treatment of the specific effluent may vary (due to pH, particular metals present, and sulphate/nutrient availability). When such systems are built in phases, it ensures that the designers can incorporate what was learned from the first phase into subsequent phases.

From our field experience it is extremely important that the system be constructed as designed. We recommend on-site monitoring during total construction period and that on-site monitoring be under the supervision of someone with wetlands construction experience. This includes both the quality of the material and its placement is as specified. It is also essential that substrate materials be completely mixed and that the final matrix meet the detailed design specifications.

From our experience it is not possible without considerable effort to ensure areas of the cell be plant free. Better to select the plants that you want and to plant them immediately following completion of the construction phase. We recommend that the cell be planted with native species (such as *Typha latifolia)* in sufficient density to preclude other undesirable plants (such as weeds or deeply-rooting plants) from invading the bioreactor. A vegetative cap may reduce potential freezing depth and will provide organic material to the system. It will however introduce dissolved oxygen to the surface layer and possibly reduce the treatment volume available. However, during active growing periods considerable water is evapo-transpired (100% treatment of this water) and during senescent periods only limited oxygen diffusion occurs. Deeply-rooting plants could interfere with water flow and need to be avoided.

While this cell was designed for an average flow of up to 170,000 gallons per day it is advisable that it be filled slowly and that the effluent is monitored frequently during this startup phase to ensure that designed removal efficiencies are established and maintained. Input should be controlled so that the final goal of treating the total mean flow is reached over time, with the excess untreated flow being directed through the existing discharge pipe. The input flow is started slowly and increased over time to the point where decreased treatment is observed.

It is our experience that treatment rates for Zn removal decrease during the winter and reducing the input flow rates can compensate for this effect. The total year-round flows that can be treated are generally defined by the winter treatment rates (i.e., if total year-round treatment is desired then the design is based on winter treatment rates). A second cell in series with the first cell can also address this issue.

Biological systems require a start-up period to allow the development of the bacterial consortia that work together to produce sulphides. During this critical period, we would recommend close monitoring by someone experienced in operating wetland/bioreactor systems. Once the system is established it will remain functional year-round and will remove metals, sequestering them as non-bioavailable metal sulphides. If the system is disturbed due to maintenance or for other reasons becomes aerobic, sequestered metals can be re-dissolved. To prevent this from happening, an operating manual should be developed and maintenance practices defined after a full season of operating experience.

Our field experience has shown the removal efficiency of these systems increases with time and with long periods of stable operation. Monitoring frequency can be reduced as the system matures and is run at or below its final determined treatment capacity.

We would like to conclude by saying that we are fully comfortable with the final design as an initial phase and with the working relationship that we developed with Dr. Fitch throughout this process. If we can be of further assistance in this matter, please do not hesitate to contact us.

Yours truly,

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Reference:

Gusek J. and Tom Wildeman, 1997, 4th International Conference on Acid Rock Drainage, Vancouver, BC. Canada