PERFORMANCE OF A FULL-SCALE HORIZONTAL-FLOW WETLAND FOR ZINC[1]

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Abstract. Park City Municipal Corporation (PCMC) long before being recognized as an Olympic venue was known as one of the great American silver mining towns. As a result, during a century of active mining, the Park City mining district produced millions of ounces of silver in addition to a substantial amount of mine tailing waste. As a result, the City since 1985 has been remediating these impacts with state and federal oversight. One particular challenging CERCLIS site, that was previously a historic mine tailings pond is known as Prospector Square Development (CERCLIS Listing Silver Creek Tailings UTD98051404). This site has been very challenging due to the metals that impact shallow ground water that eventually drain into the Silver Creek Watershed. To address the water quality impairment the City and Missouri University of Science and Technology teamed-up to investigate the feasibility of constructing a horizontal-flow wetland to treat this pollutant source. This effort comprised of building a pilot cell in June of 2004, leading to the construction of a full scale horizontal-flow wetland in the fall of 2008. The design of the pilot and full scale biocell was based upon lab-scale research conducted by the Missouri University of Science and Technology. In October of 2008, the Prospector Drain effluent was introduced to the system and to date analytical results reveal that the biocell is treating the Prospector Drain outfall below the Silver Creek Total Maximum Daily Load (TMDL) endpoint goals for zinc .39 mg/L and cadmium .00075 mg/L. The water chemistry of the influent, that originates from the historic silver mine tailings pond, is impaired with zinc and cadmium and has low iron with a pH of roughly 6.5. The construction of this unit encountered many challenges related to constituent relations, regulatory scrutiny, constructability, and start-up. Nonetheless, this unit since implementation is considered a success for improving water quality within the Silver Creek Watershed.

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Introduction

Park City, now renowned for skiing, was a major silver mining town during the nineteenth century. As a result, during a century of active mining, the Park City Mining District produced millions of ounces of Ag as well as a substantial amount of mine tailing waste. Mine tailing waste is known to contain elevated levels of heavy metals, which pose a threat to the environment and human health. Because of these historic impacts a modern Park City is fringed with former mines and has extensive mine tailings deposits (660 acres) throughout the city limits. One of these areas is known as Prospector Park Development (CERCLIS - Silver Creek Tailings UTD98051404), which is a residential community that was developed in 1985 and is situated on top of a mine tailings pond. To accommodate the development a dewatering line was installed to convey shallow ground water from the site. Geographically the development is located on the eastern side of Park City at an elevation of 6,700 feet and is adjacent to Silver Creek, which spans the southern boundary of the development. Park City has done extensive research to determine the lay of the dewatering line that contributes to the Prospector Drain. However, this research revealed little in regards to the layout of the dewatering line and clear geological identity as to how the line was installed. Nonetheless, similar to other mine intensive areas, Park City has environmental issues related to its history that has led to water quality impacts that are scrutinized under the Clean Water Act. The City therefore investigated passive treatment schemes such as biocells, previously referred to as constructed wetlands, which take advantage of naturally occurring geochemical and biological processes to improve the water quality with minimal operation and maintenance requirements (Gazea and Kontopoulos, 1996). In the past two decades, constructed wetlands have been employed with varying success to treat acid mine drainage as well as urban runoff and industrial outfalls (Neculita et al., 2007). Research at the Missouri University of Science and Technology (formerly the University of Missouri-Rolla) has focused on quantifying removal mechanisms in bench-scale horizontal flow wetlands (Fitch et al., 2008). One result of this bench-scale work was to successfully removed Pb and Zn from circum-neutral mine water. During this study, fourteen lab-scale constructed wetlands were set up treating synthetic mine effluent for up to seven years. The results of this research revealed more than 90% removal of Pb and 65% removal of Zn observed at hydraulic residence times of 0.45 to 4.5 days (Song et al., 2001).

Recognizing these research results, this particular bench-scale work along with the favorable results of a pilot system that was operated for four years, translated into the construction of a full-scale unit in 2008. This paper summarizes the pilot-scale results, design and construction, and the results of the first several months of operation. The objective of this work was to reduce the Zn and Cd load to Silver Creek by treating the Prospector Drain outfall effluent. The Silver Creek watershed is a Clean Water Act Section 303 (d) listed stream being impaired for high concentrations of Zn and Cd. The TMDL endpoint thresholds for the Silver Creek Watershed is Zn .39 mg/L and Cd set at .00075 mg/L.

Related to the Prospector Drain outfall characteristics this information is summarized in Table 1. The water composition is fairly constant and does not correlate to season, but flow is seasonally affected. This is assumed to be due to the influence of Silver Creek being a losing stream along Prospector Park.

Table 1. Characteristics of water from the Prospector outfall

Parameter	Unit	Average [a]	Range
Flow	gal/d	140,000	117,000-252,000
pH		6.27	6.0 – 7.1
Zn	mg/L	7.05	2.68 – 14.137
Cd	mg/L	0.045	0.01 – 0.083
Pb	mg/L	0.055[b]	BDL[b] – 0.58
Fe	mg/L	1.67	0.02 – 17.4
Sulfate	mg/L	650	590 – 760
Hardness	mg/L as $CaCO_3$	978	630 – 1170
TDS	mg/L	1926	1420 – 2270
TSS	mg/L	36	1 – 64[c]

[a] Based on monthly sampling between June 2003 and June 2007.

[b] Including 17 samples below detection limit (BDL, method detection limit reported as 0.001 mg/L), averaged as zero. Without samples BDL included, average is 0.094 mg/L.

[c] Excludes August 2006 sample reported as 960 mg/L.

Examination of Table 1 shows that from a mine water remediation perspective, the water is unusual. There is negligible iron but substantial Zn, and the pH is near neutral. Considering the water as typical acid mine drainage would not be highly successful when designing a treatment strategy.

Site Description

The Prospector Park Drain outfall conveys shallow ground water from the development that was previously a historic mine tailings pond that contributes to the Silver Creek Watershed. The dewatering line is thought to span the length of the development that eventually empties into a manhole, and continues within a ten-inch concrete pipe, then outfalls on the eastern edge of the park and property line that is shared by the Bureau of Land Management (BLM). The area is shown in Fig. 1 and depicts the bypass vault, sampling ports, Agri-Weir, and the location of the outfall. The highway to north is State Route 248 and the gravel road on the south is a popular bike/walk path known as the Rail Trail. Additionally, the Prospector settling pond is bordered on the north side by a berm that separates the biocell from this unit. With that, the biocell area is a triangular area bounded by highway, berm, and the BLM property line. The triangular parcel noted is the location used for the biocell footprint and is approximately 0.52 acres. The city owns additional property to the east (down the watershed) separated by BLM property.

Samples and Analytical Techniques

Discrete water samples for metal analysis were collected following EPA procedures, with the analysis being done at a state certified lab known as Chem-Tech Ford Laboratory (Salt Lake City, Utah). Specifically the lab used United States Environmental Protection Agency (EPA) methods for metals and other parameters employing EPA Methods 200.7, 200.8, 160.1 and 160.2. Outfall samples were collected from water originating from within the manhole and the pilot outfall. After the by-pass vault was constructed for the biocell, such outfall samples (influent to the biocells) were collected within that vault. Effluent samples from the pilot cells were collected from the end of the effluent pipe. Effluent samples for the biocells were collected from the Agri-Weir, which feeds the outfall pipe. Flow rate was measured by a flow meter inside the manhole and another within the by-pass vault. Conditions within the biocell were measured using a Hach Field Monitor with probes for pH, ORP, D.O. and temperature.

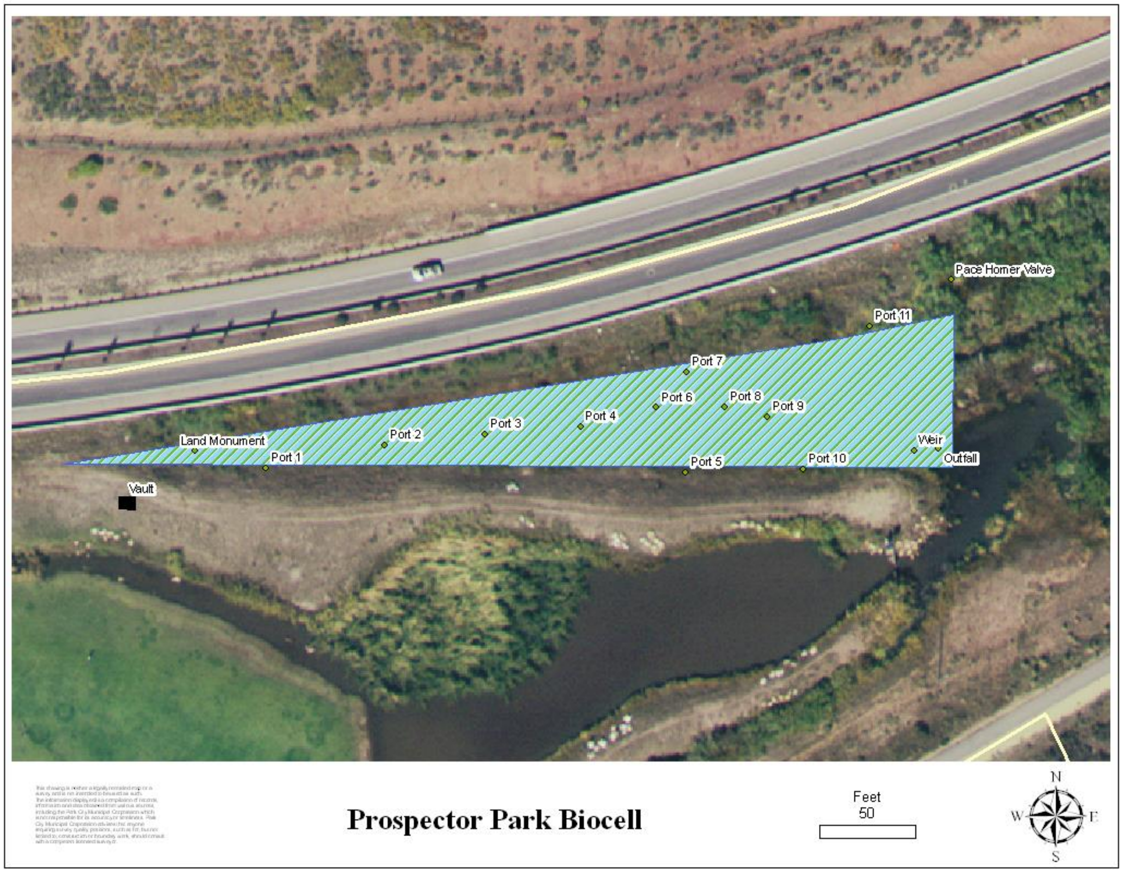

Figure 1

Regulation and Decision Process

EPA and the Utah Department of Environmental Quality (UDEQ) have been investigating and evaluating mine sites within the Park City area since the early 1980's. During these evaluations, Prospector Park was investigated extensively to determine potential environmental impacts. As a result, USEPA proposed listing the Prospector Park area on the National Priorities List (NPL) in 1985. This resulted in a controversial scenario with the community, since much of Prospector Park was being developed into a residential subdivision within the City. USEPA's concerns with the development of the area were based on exposure risks of residential households being situated within an area known to contain mine tailing waste. The hazardous constituents of concern that were known to be within the mine tailing waste are Pb, As, and Cd.

The proposal to list the site generated a great deal of controversy within the community. Park City Municipal Corporation (PCMC) and most city residents were opposed to NPL listing, while EPA maintained the site should be NPL listed. Furthermore, PCMC believed the situation at Prospector presented only minimal risks and could be remedied with local corrective actions resulting in the city capping vacant properties in 1985. Also, during this time, PCMC sought congressional intervention to ensure the site was not listed on the NPL. As a result, a line item was included in the 1986 SARA amendments (Section 120 pg. 666), which removed the site from consideration from the NPL and precluded future considerations to the NPL unless significant new information was discovered. The following is the language contained within the SARA amendment:

> (p) Silver Creek Tailings.—Effective with the date of enactment of this Act, the facility listed in Group 7 in EPA National Priorities List Update #4 (50 Federal Register 37956, September 18, 1985), the site in Park City, Utah, which is located on tailings from non-coal mining operations, shall be deemed removed from the list of sites recommended for inclusion on the National Priorities List, unless the President determines upon site specific data not used in the proposed listing of such facility, that the facility meets requirements of the Hazard Ranking System or any revised Hazard Ranking System.

To allay the controversy and seek consensus based technical information regarding the situation at Prospector, PCMC, EPA, and UDEQ developed a series of scientific studies that focused on air, water, and health. These studies were very broad with the Agency for Toxic Substances and Disease Registry (ATSDR) conducting the health and blood Pb assessment, EPA conducting the ambient air study, and UDEQ/United States Geological Survey (USGS) conducting ground and surface water quality study. While these studies were being conducted, PCMC also began developing a local ordinance to ensure effective capping of the area. These actions culminated in 1988 with two EPA letters giving qualified approval of PCMC proposal for a local ordinance and the subsequent enacting of the ordinance. As a result, PCMC is committed to the remediation of historic mine tailing impacts and controlling the environmental and human health risks with institutional controls. These institutional control obligations can be found within PCMC Annual reports that are posted at http://mapserv.utah.gov/ParkCityGIS/.

Nonetheless with this type of historical scrutiny with Prospector Development, the regulatory driver for the Prospector Outfall was the Silver Creek Total Maximum Daily Load (TMDL) drafted by UDEQ, which mandates a 50% reduction in Zn and Cd within the watershed. As defined within the Silver Creek TMDL, the endpoint threshold for Zn is set at 0.39 mg/L and the threshold for Cd is limited to 0.00075 mg/L. The watershed approach used in setting the TMDL values melded well with the approach generally used in the area for environmental concerns, namely to involve all constituents. For the Prospector Outfall, the regulatory stakeholders included the EPA, UDEQ, U.S. Fish and Wildlife, and BLM, which owns land adjacent to the site. In addition to regulatory agencies, Park City and mining corporations are included in the stakeholder group. The Upper Silver Creek stakeholder group meets as needed to discuss problems and arrive at agreements, with meetings scheduled by the EPA, who kindly provide a professional facilitator.

Park City is a significant tourist destination, and given its history as a mining town, has benefitted from approaching pollution issues as problems to be solved. In the case of the Prospector Outfall, the joint concerns of Zn and Cd load to Silver Creek and Park City's environmental approach led the City to examine various potential solutions and decide on a biocell. After discussions with Missouri S&T (previously named the University of Missouri-Rolla) about research on horizontal flow wetlands (Fitch et al, 2008; Song et al, 2003), the City decided to test a biocell at small pilot scale. In May of 2005 the results were presented to City leaders and met with approval and consequently a budget. Furthermore the Upper Silver Creek Stakeholders group met in January of 2006 and indicated no objection to construction of a small full-scale biocell on City owned property as a demonstration.

<u>Pilot-scale Biocells</u>

A small pilot-scale biocell was constructed at the site in May of 2004. A hole of approximately six foot by four foot and three foot deep was excavated by backhoe. The hole was then lined with consumer grade 'pond liner' plastic and filled by hand. Small berms were formed atop the liner at ground level around the wetland with excavated soil. The pilot-scale wetland design is shown in Fig. 2. The pilot-scale biocell received inflow from a small submersible pump installed in an existing manhole. A garden hose equipped with a ball valve delivered the water to the unit. To prevent freezing during the winter months, the garden hose was buried under a few inches of soil. Influent flowed into a foot-and-a-half-thick (in the flow direction) gravel lens to allow equal distribution of water into the substrate. Similarly, a gravel lens on the effluent side of the substrate led to the effluent pipe, which was a short length of two-inch PVC. The effluent lens was roughly three foot in length. The substrate came from local sources, which was a foot-and-a-half-thick and was a mix of pine wood shavings (60% v/v), sand

and gravel (combined 35%), and sewage sludge and cow manure (combined 5% v/v); percentages given are approximate. The substrate was mixed in a wheelbarrow by shovel and then deposited in the biocell in layers, which included gravel to maintain roughly vertical abutment between gravel and substrate. The manure and sewage sludge quantities were limited, so the upper quarter of the substrate lacked for these components.

(a) (b)

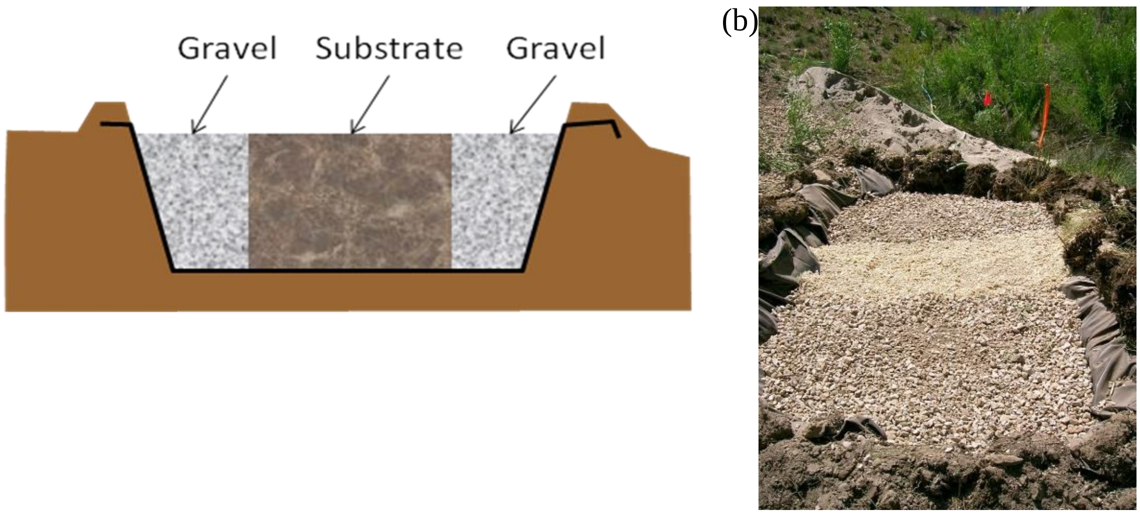

Figure 2. (a) Section showing first pilot unit design. (b) image of construction.

A second pilot-scale biocell, shown in Fig. 3(a), was constructed in late May of 2006 with a similar design but a differing substrate composition. Dimensionally, the second unit was seven foot by four and three feet deep. In addition to a different substrate, there were two significant differences in design: (1) the substrate was formed in two sections, each 18 inches thick with a separation of 18 inches of gravel, and (2) the second biocell had influent delivery and effluent collection each by the piping system shown in Fig. 3(b), which included an end cap to allow influent or effluent sampling. The substrate was again locally available material mixed by hand in a wheelbarrow, and the composition used was 70% v/v pine shavings, 20% v/v gravel, and cattle manure at 10% v/v. A six-inch layer of a 50-50 substrate and gravel mix was placed in the bottom of the cell, and above this was placed influent and effluent gravel layers sandwiching a foot-and-a-half thick (again, measured in the horizontal flow direction) substrate layer. The same garden hose was used to supply influent, but the hose was brought into the one-inch feed pipe shown in Fig. 3 such that the end of the hose was visible when looking down the vertical pipe. Flow was initiated immediately, and was maintained at about 0.3 gallons per minute.

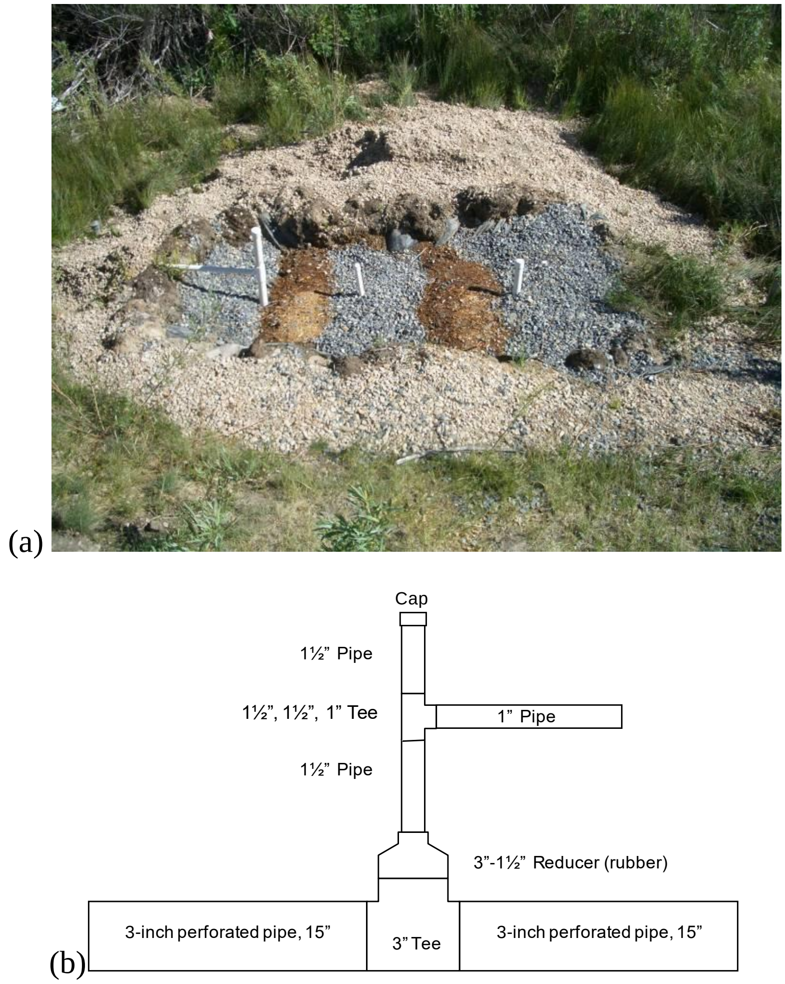

Figure 3. Second pilot-scale biocell. (a) image form construction. (b) effluent piping.

Design, Bidding and Full-Scale Construction

With the pilot-scale units considered as successful as described in the results, PCMC decided to proceed to full scale. In 2007 the existing manhole that was used to feed the pilot unit was replaced with a by-pass vault costing $71,000. This was required to control flow, as the area available was judged to be insufficient for complete treatment of the 0.14 MGD flow, instead the biocell was estimated as having a capacity for 0.05 MGD. The vault thus includes a flow meter to control flow to the biocell in a six-inch pipe and an overflow that channels excess flow into the original outfall pipe. Additionally, the bypass vault was connected to a SCADA system so that the flow to the biocell can be controlled remotely.

In 2008 plans were set forth to build the biocell and because the pilot-scale units treated water through 18 inches of substrate, the full-scale design for horizontal flow used the same dimension of substrate. The triangular area to be used presented a challenge, as the simplest design would be similar to a filter press, alternating layers of substrate with influent and effluent in a series of bands with one end acting as the supply and the other as the uptake. However, concern over hydraulic short-circuiting resulted in the basic design including not one but two layers of substrate separated by a gravel layer. In this way water might channel through one layer of substrate but then would have to flow through a second layer. Thus the water flow path was designed as gravel (influent), substrate, gravel (redistribute flow), substrate, gravel (effluent). This series of layers was applied to the filter press idea, resulting in a theoretical design as shown in Fig. 4.

The design was reviewed for Park City by Nature Works Remediation Corporation of Canada, and with their input the substrate was specified as 50% wood shaving or chipped wood, 30% cow manure, and 20% clean limestone gravel of size ¾ inch or smaller. Cow manure was the chosen inoculants because the bacteria are efficient in cellulose degradation. Gravel for the distribution channels was specified as one inch or larger. Due to possibly significant head loss in the gravel, pipes were placed in the bottom of the unit to improve the uniformity of water distribution. The main delivery and collection pipes, located in the channels in Fig. 4(a) on the left and right sides, respectively, were ten-inch plastic. These were joined to four-inch plastic perforated pipe, which ran down the center of each gravel 'finger' extending from the inlet or outlet side. The isolated gravel lenses for flow redistribution contained no pipes.

Effluent flows to a small, forty-foot by thirty-foot open-air pond at the southeast corner of the biocell. This pond has a ten-inch collector pipe, which goes through the five-foot clay-lined berm defining the east end of the biocell. Due to concerns expressed by the stakeholders group, the entire unit was lined with six inches of clay to prevent exchange of water to the underlying soil. The water level in the pond is controlled by a commercially available adjustable Agri-Weir that is installed in the berm. The placement of the weir was chosen to prevent freezing of the outlet structure.

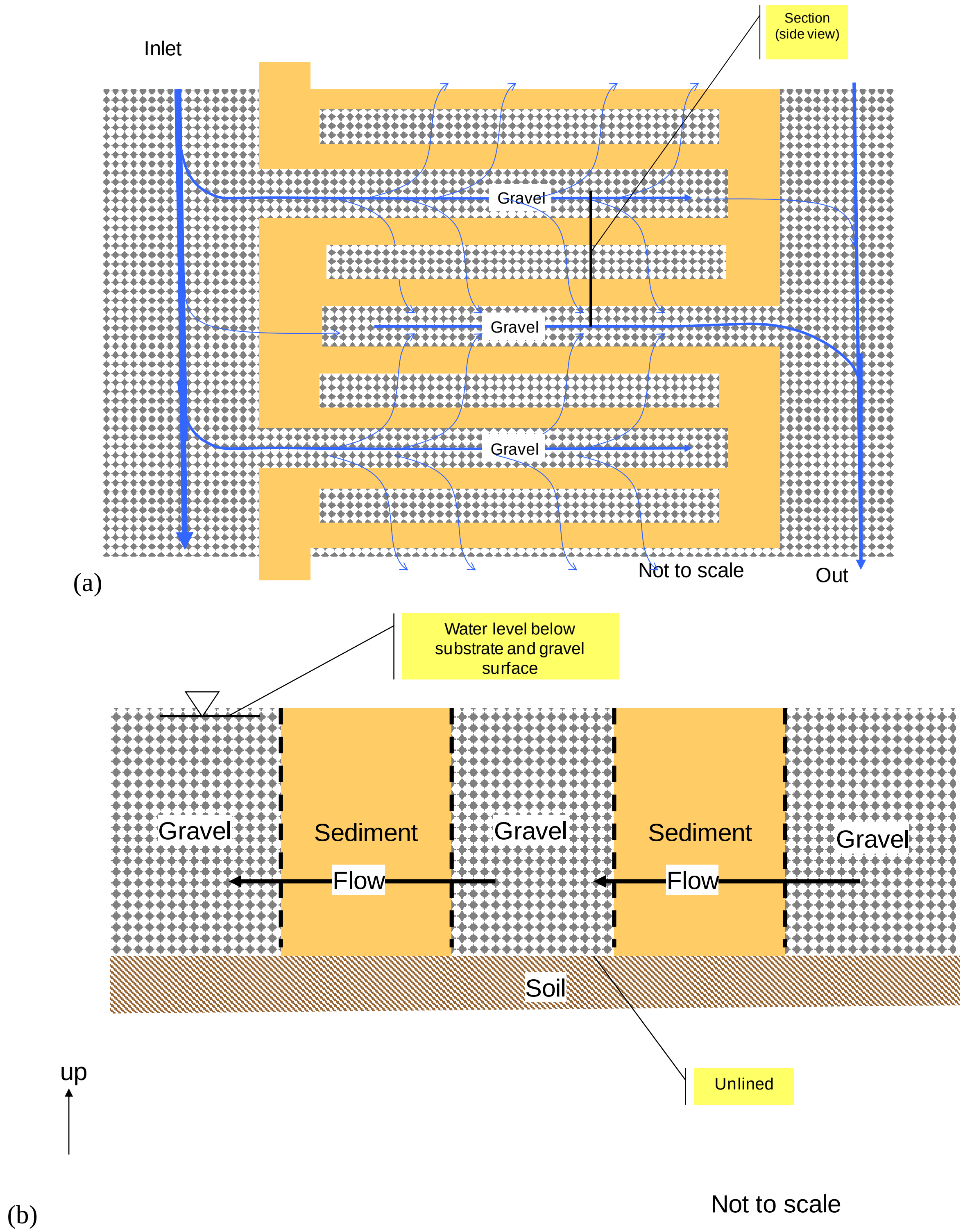

Figure 4. Theoretical layer design; (a) plan view, solid fill is substrate, (b) section view.

Sampling ports were installed in the cell, two-inch plastic pipe extending vertically to six inches above the clay layer and topped with an end cap. Sampling also is possible at the influent vault structure and the effluent pond or pipe.

Construction occurred in September of 2008. Cost estimation by Missouri S&T for the initial bid process in 2006 was significantly less than the bids received; the first RFP resulted in cost estimates ranging from $98,000 to $525,000. The biocell was rebid in 2008, and the successful bid was $325,000, awarded to Counterpoint Construction out of Lehi, Utah. One challenge for the contractor was how to place the alternating 'trenches' filled with gravel and substrate. The contractor's solution, shown in Fig. 5, was a wood and steel form lifted and filled by trackhoe with manual assistance. Because of concerns over potential winter freezing, the entire biocell was covered with a twelve-inch layer of wood chips. This was a change order resulting in another $86,000 cost for the final construction of the biocell.

(a) (b)

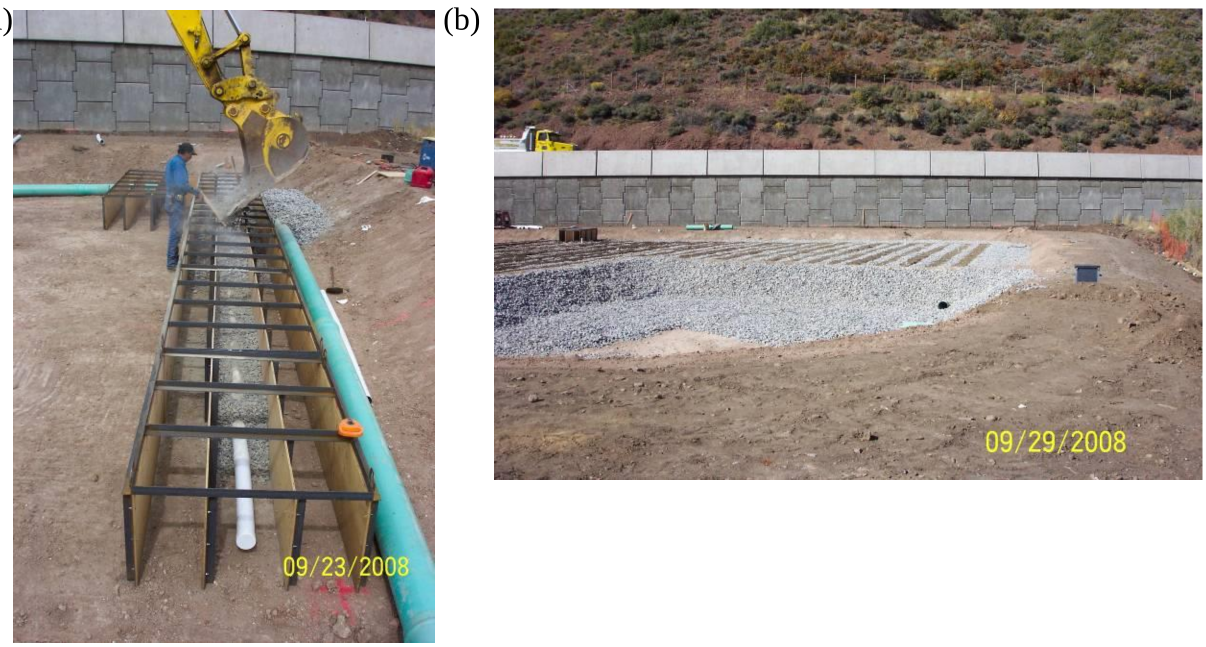

Figure 5. Biocell construction. (a) Placement of gravel and substrate in biocell. (b) View of construction showing effluent pond in foreground. Dark box atop berm at right is top of the water control structure.

Results

As described above, this work focused on the design and operation of a biocell for an unusual metal-tainted water of pH 6.5 containing negligible iron but significant Zn. Pilot scale units were operated for two years. The pilot cells showed promising removal, and the initial results from the full-scale biocell are encouraging.

Pilot-Scale Biocells

The first biocell operated from May 2004 to May 2006, with data collected monthly through November of 2005. One challenge was large snowfall limiting access to the unit without significant hand digging of snow. Both units were found to have formed a 'snow cap', with air space above the biocell surface, indicating sufficient heat came from the influent water, which is a consistent mid 50s ºF temperature, thereby preventing freezing. The second biocell, which had a higher content of organic (pine shavings) and bacterial seed (cattle manure) operated from late May 2006 until June 2007. Performance is summarized in Fig. 5 and Table 2. Broadly stated,

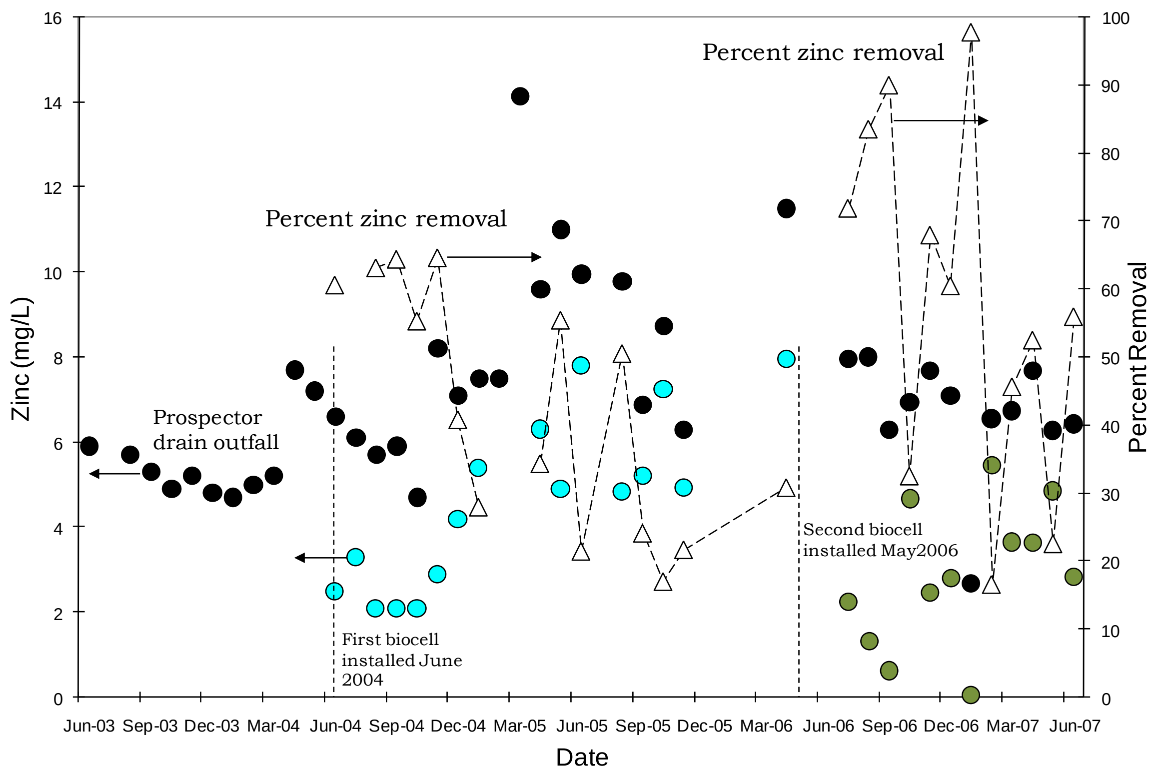

Figure 5. Pilot Scale Results. Solid circles are influent (Prospector outfall) Zn concentration (left axis), circles filled with blue are effluent concentration from first pilot scale

biocell, solid circles filled with green are effluent concentration from second pilot scale biocell, and triangles show calculated removal (right axis) through biocell.

both biocells showed significant removal of Zn during the full period of operation, with great variability in effluent concentration. Sulfate removal was demonstrated, but only small amounts in the first biocell, possibly related to the lack of bacterial seed (manure and sludge) in the top portion of the substrate of this biocell. The second pilot-scale biocell demonstrated greater sulfate removal during the first three months of operation (90 – 150 mg/L removed, rate of 520 $g/d/m^3$ based on estimated substrate volume of 0.38 m^3) that declined significantly thereafter to an average of 13 mg/L (56 $g/d/m^3$).

Table 2. Pilot-scale biocell performance.

Parameter and units	Biocell 1 average	Biocell 1 range	Biocell 2 average	Biocell 2 range
Influent Zn (mg/L)	8.2	4.7 – 14.1	6.7	2.7 – 8.0
Effluent Zn (mg/L)	4.0	2.1 – 8.0	2.9	0.06 – 5.46
Zn Removal (%)	45	17 – 98	58	17 – 98
Influent Cd (mg/L)	0.05	0.03 – 0.08	0.05	0.01 – 0.06
Effluent Cd (mg/L)	0.01	BDL[b] – 0.08	0.02	0.006 – 0.06
Cd Removal (%)	77	36 – 100	64	36 – 88
Sulfate removed[a] (mg/L)	24	-40 – 80	42	-10 – 150

[a] Influent sulfate averages 650 mg/L, range 590 – 760 mg/L.
[b] BDL – below detection limit, reported as 0.001 mg/L.

Biocell Start-Up

The biocell was filled slowly after construction was completed (mid-October of 2008) at a rate of 10 gal/min. Once the biocell was filled to a few inches below the substrate surface as determined from the water level in the effluent pond, flow was shut off and the ORP, pH, and D.O. were monitored at sample ports within the biocell. The reason the flow was shut-off was to allow the unit to become fully anaerobic and allow the redox potential to drop to that associated with the establishment of sulfate reducing bacteria. The influent water has an ORP of above 100 mV and has very high D.O. concentrations, generally above 20 mg/L.

The data in Table 3 shows that the biocell slowly went anaerobic; requiring approximately four weeks after water was added to reach consistently negative ORP values. Prior to this time, however, H_2S was detected at several sampling ports. Also, pH was monitored, and was found to increase slightly over the period of no flow from around 7.0 to 7.5.

Table 3. Biocell start-up to anaerobic conditions.

Date[a]	Sample port near inlet		Sample port near middle		Effluent pond or sample near end of biocell	
	ORP (mV)	D.O. (mg/L)	ORP (mV)	D.O. (mg/L)	ORP (mV)	D.O. (mg/L)
7 Nov	ND[b]	ND	-175	BDL	74	6.6
12 Nov	ND	ND	89	2.8	ND	ND
18 Nov	-82	3.4	20	2.7	-130	0.5
24 Nov	-196	0.2	-142	0.3	-187	0.2

[a] Biocell was filled as of 27 October. Flow was started on 24 November at 8.5 gal/min and declined to 5 gal/min by 3 December.
[b] ND – Not determined.

The biocell commenced operation on November 24, 2008, with an initial set at 8.5 gal/min. On December 3, 2008 water was observed flowing from the effluent the Agri-Weir. Sampling on that date showed ORP of 163 mV in the influent and -211 at the effluent pond. Temperature of the water dropped from 57 ºF in the influent to 42 ºF at the open effluent pond. The pH changed slightly, from 6.0 in the influent (vault) to 6.8 at the effluent. The water quality samples taken that date also showed good performance as demonstrated in Table 4.

Table 4. Biocell performance.

Date	Influent Zn (mg/L)[b]	Effluent Zn (mg/L)[b]	% Zn Removal	Influent Cd (mg/L)[b]	Effluent Cd (mg/L)[b]	% Cd Removal
3 Dec	6.83	0.19	97	0.053	BDL	98[c]
23 Dec	6.72	0.05	99	0.050	BDL	98[c]
12 Jan	6.60	0.05	99	0.050	BDL	99[C]
27 Jan	ND[d]	0.03	ND	ND	BDL	ND
6 Mar	7.07	0.02	99	0.056	BDL	98[c]

[a] Flow was started on 24 November and effluent flow was observed on 3 December.

[b] Values are for dissolved metal; total metal was slightly higher.
[c] Conservative, assumes effluent at reported detection limit, 0.001 mg/L.

Discussion

Currently the biocell is being fed 30 gallons per minute (0.043 MGD), which is near the design value. the flow will continue to be increased as long as the ORP values reflect an anaerobic environment. Based on studies of neutral lead mine drainage using similar biocells at lab scale (Fitch et al, 2008) it is likely that metal removal is through a combination of adsorption to the woody components of the substrate and also through precipitation as metal sulfide. The sulfide results from biological use of sulfate as an electron acceptor and organic sourced from the organic of the substrate. One interesting aspect of this continuing study will be observing whether there are changes in metal removal as the organic slowly decays. Tracer tests have been proposed to study changes in hydraulic residence time, as short circuiting has been seen to strongly affect efficacy of biocells.

From the perspective of the City, the biocell is meeting the effluent down to water quality standards, therefore solving a very important problem. The Prospector Drain was identified in the TMDL as contributing up to 22% of the Zn load into the Silver Creek watershed. The elimination of this pollutant load is a benefit to the whole watershed and the biocell concept has been identified as a best management practice within the TMDL. Of course, the unit will be tested when it receives the full flow of the Prospector Drain, which can be as high as 222,000 gallons per day (0.22 MGD) during the peak spring run-off period. Nevertheless, with the results that are currently being experienced, it justifies investigating the potential for another cell that would connect to the bypass and reside within a two acre parcel situated on BLM property. As the City continues to procure additional data that reflect promising results as the system matures, the City and Upper Silver Creek watershed group will perhaps discuss expanding the current cell onto adjacent BLM property.

Acknowledgements

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