# Construction, Instrumentation and Preliminary Results of Field Leach Pads for Scaling Reaction Rates and Assessing Field Performance

**Keith Mountjoy[1], Annetta Markussen-Brown[2], Vivian Ferrera[2] and Tyson Kaemffer[3]**

1. *Klohn Crippen Berger, Peru*
2. *Klohn Crippen Berger, Canada*
3. *Site C Engineering, BC Hydro, Canada*

**ABSTRACT**

The construction of a large-scale hydroelectric project will result in the excavation of approximately 8 million cubic meters of sulfidic bedrock that will be permanently stockpiled. As part of a comprehensive geochemical characterization program, two Field Leach Pads were constructed to gain an understanding at a field scale of the relationship between physical and geochemical processes that may affect differences water quality between compacted and un-compacted material, during and after construction.

The Field Leach Pad 1 (West) is 2.4 meters high and was constructed in two 1.2 meter compacted lifts. Field Leach Pad 2 (East) is 2.1 meters high and was construction in two 1.05 meter uncompacted lifts. The sulfidic bedrock material used for Field Leach Pad construction was obtained from fresh excavated material. The lift height was selected based on engineering design at the time of Field Leach Pad construction. Both Field Leach Pads were instrumented with continuous multichannel tubing (CMT) multilevel systems (for oxygen and carbon dioxide monitoring and porewater sampling); temperature probes; water content sensors; and matric potential sensors. Information gained from the instrumentation will be used to evaluate site-specific factors and properties on sulfide oxidation rates and seepage chemistry.

This paper describes Field Leach Pad construction, instrumentation, and the preliminary results that includes: two leachate sampling events that (May 2013 and September 2013), one oxygen and carbon dioxide monitoring event that (September 2013), and the results from the sensors spanning the time period of August 2013 to April 2014. The preliminary results support the benefit of placing and compacting excavated shale. The gas concentrations and moisture content values suggest that the compacted Field Leach Pads should show lower reactivity over time and lower loading rates to the environment.

**Keywords:** Field Leach Pad, kinetic tests, instrumentation, scaling, loading rates, water quality

## INTRODUCTION

The complexities of physiochemical processes that occur at the field-scale in waste rock piles and the scaling of laboratory reaction rates has been the subject of intensive and extensive research. At the 2012 ICARD conference, for example, many papers were focused on presenting on this subject (Andrina et. al., 2012; Kempton, H, 2012; Shaw and Samuels, 2012; Smith et. al., 2012a; Smith et. al., 2012b). While considerable debate remains on what methods are most appropriate for scaling, what is recognized is that field scale kinetic tests, at varying scales, can provide insights into key site-specific factors affecting the geochemical behavior of sulfidic waste materials and the subsequent loading rates and water quality.

A geochemical characterization program was established in 2009 to assess the potential for acid rock drainage and metal leaching (ARD/ML) from sulfide-bearing bedrock. As part of this program, Field Leach Pad (FLP) testing was undertaken as part of a larger effort to inform waste management strategies. Two FLPs were constructed in late 2012 using excavation sulfidic shale with minor siltstone (hereafter referred to as shale) with the objectives of:

- Assessment leachate quality generated under site-specific field conditions during the first year of operation,
- Comparison of leachate quality to kinetic tests at other scales,
- Gaining an understanding of the physical processes acting within the FLPs, and
- Asesssment of the initial effectiveness of placing and compacting materials in 1 m lifts on oxygen ingress and water infiltration as an engineered management strategy to mitigate ARD/ML.

Preliminary results are presented for the FLPs that include:

- two leachate sampling events that occurred in May 2013 and September 2013,
- one oxygen and carbon dioxide monitoring/sampling event that occurred in September 2013, and
- data and results from the instrumentation sensors from August 2013 to April 2014.

## METHODOLOGY

The types of sampling, measurements and testing carried out for the FLPs were: sampling and analysis of leachates; measurement, sampling and analysis of gases; measurement of changes in moisture content, and temperature measurements. Analytical testing of leachates and gases were carried out at Maxxam Analytical in Burnaby, British Columbia, Canada.

### Field Leach Pad Construction and Instrumentation Installation

Field Leach Pad 1 (West) is 2.5 metres (m) high, and was constructed with sulfidic shale placed and compacted in two 1.25 m high lifts. Field Leach Pad 2 (East) is 2 m high and was constructed with the same material but uncompacted in two 1 m high lifts. Table 1 provides a summary of the instrumentation installed. Figure 1 shows a cross-section of each FLP and the location of the wells and instruments.

Continuous multichannel tubing multilevel piezometers (CMTs) were installed to monitor oxygen ($O_2$) and carbon dioxide ($CO_2$). Two CMT were installed in FLP 1 (West) with seven ports in each. Two CMTs were installed in FLP 2 (East) with six ports each. Temperature probes were attached to the CMTs to monitor temperature. Three probes were installed per CMT and, where possible, were attached at the same depth as a CMT port. Campbell Scientific model CS650-L water content reflectometers were installed to measure the volumetric moisture content. A total of 10 reflectometers were installed in each FLP.

**Table 1** Field Leach Pad Instrumentation Installation Summary

| Instrument | Description | Supplier | Parameter |
| --- | --- | --- | --- |
| CS650-L | Soil water content reflectometer | Campbell Scientific | Volumetric water content |
| 229-L | Water matric potential sensor | Campbell Scientific Canada Corp.; calibration O'Kane Consultants | Water flux |
| 109-L | Temperature probe | Campbell Scientific | Temperature |
| CMT Multilevel System | Continuous Multichannel Tubing piezometer | Solinst Canada Ltd. | Porewater quality, $O_2$, $CO_2$ |
| CR1000 Datalogger | Measurement and control system for data acquisition | R.S.T. Instruments Ltd./ Campbell Scientific. | - |
| Remote Multipexer | Increases number of sensor inputs. | R.S.T. Instruments Ltd. | - |
| Weather Station | Provides meteorological measurements | R.S.T. Instruments Ltd./ Campbell Scientific Canada Corp. | Precipitation, temperature, barometric pressure, wind speed/direction |

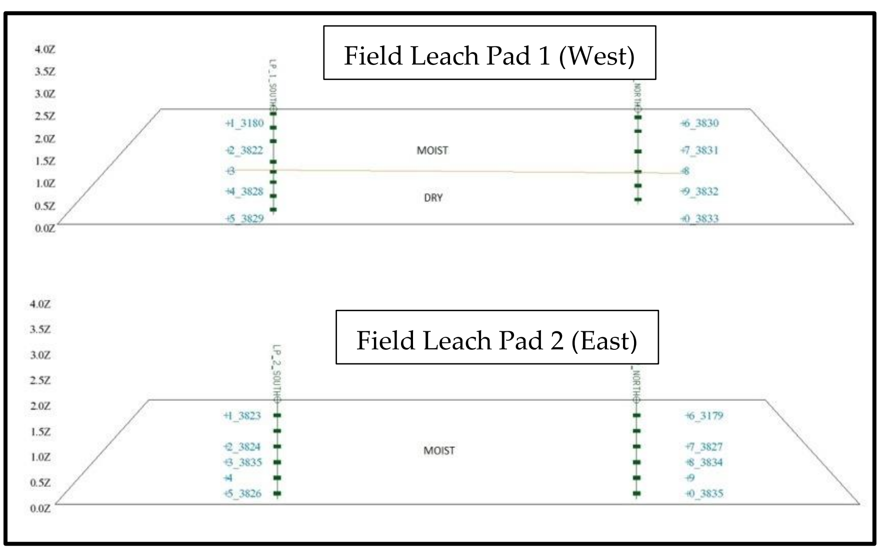


**Figure 1** Field Leach Pad Sections: Green bars represent CMT ports. Blue crosses represent 650 and 229 sensors.

**Surface Runoff and Infiltration Seepage Sampling**

Leachate samples were collected from two locations: collection barrels (designed to collect infiltration seepage only) and collection ponds (designed to collect surface runoff and infiltration seepage). The following parameters were measured or analyzed: pH, electrical conductivity, oxidation-reduction potential, acidity, sulfate, total alkalinity, fluoride, chloride, total suspended solids, total dissolved solids, turbidity, and 54 total and dissolved metals suite. The CMTs were installed to collect porewater samples from within the FLPs; however, no porewater was present during the first year.

**Instrumentation Monitoring and Data Logging**

Instrumentation data logging commenced in August 2013 following installation and consisted of temperature, soil water content and soil matric potential. Monitoring data collected from August 2013 to April 2014.

**Oxygen and Carbon Dioxide Sampling**

The CMTs were used for the purpose of monitoring $O_2$ and $CO_2$. The first gas sampling/monitoring event took place from September 17th to September 18th, 2013. A GEM2000 gas monitor was used to take in-situ readings at each CMT port. Samples were also collected at select CMT ports to confirm in-situ readings. The samples were collected in Summa canisters and sent for analysis of gas composition.

## RESULTS AND DISCUSSION

When sulfide minerals such as pyrite are exposed to water and oxygen; acidity, sulfate and elevated metals concentrations of are produced. Understanding the physical characteristics and processes acting on the material on site, can aid in scaling the laboratory water quality results and loadings to the field, and inform the waste management strategies. These physical processes include water infiltration, oxygen transport, multiphase flow and heat transfer (Lefebvre et. al., 1998; Wels et. al., 2003; Lahmira & Lefebvre, 2007).

The key parameters monitored by the instrumentation in the FLPs include oxygen, carbon dioxide, temperature, moisture content and matric potential. It is important to evaluate the relative influence of these parameters on sulfide oxidation and weathering reaction rates. For example, an oxygen supply is required for sulfide oxidation. Oxidation is an exothermic reaction and results in increased temperature. Changes in temperature and/or pressure may modify the oxygen transport mechanism from diffusion to advection (Wels et. al., 2003). Advection is more efficient at supplying oxygen and sustains higher oxidation rates at greater depths (Lahmira & Lefebvre, 2007).

**Comparison of Cumulative Loadings**

Precipitation that falls onto the FLPs eventually reaches the collection ponds either as infiltration or runoff. The collection ponds are open to the environment and, as a result, receive additional precipitation and also undergo evaporation. The leachate collection barrels are closed to the environment and only receive seepage that infiltrates through the FLPs.

The flows into the collection barrels and ponds were not measured therefore a number of methods for estimating output volumes for both the collection barrels and the sumps were investigated based on measured and theoretical values. Loadings were calculated using the different outputs and compared. The most appropriate methods were selected and used to calculate the loadings presented here. The parameters presented here are based on previous shake flask extraction, humidity cell and Field Leach Barrel results for the shale unit.

The results show that the seepage loadings are up to one order of magnitude less than the runoff and seepage loadings combined. It can be inferred from this comparison that an increase of water volume from runoff will increase the loadings in the runoff and seepage combined while the concentrations will decrease.

As discussed earlier, the FLPs were constructed predominantly shale (Unit A) with minor siltstone (Unit B). Cumulative loadings for sulfate, calcium and magnesium over the first year of operation are presented for humidity cells, FLBs, and the seepage and combined seepage and runoff loadings from both FLPs in Figure 2. Overall, there was a clear decreasing sequence of cumulative loadings from humidity cells, to FLBs to FLP runoff and seepage to FLP seepage only (Figure 3 and Figure 4). Differences in cumulative sulfate loadings between humidity cells and FLPs were 4 to 7 times lower. Cumulative calcium loadings between humidity cells and FLPs were similar to sulfate and cumulative calcium magnesium loadings were up to 19 times lower (Figure 2a).

The differences in key metal cumulative loadings was more pronounced, with cumulative loadings up to more than one order of magnitude lower for aluminum, arsenic, cadmium, iron and zinc (Figure 2b).

This relative behavior is expected as the humidity cells have the smallest particle size (more surface area available for reacting), the highest water to solid ratio, and humidity cells are flushed weekly. The FLPs have the largest particle size overall, the lowest water to solid ratio, and are subject only to natural precipitation.

Both FLPs showed similar cumulative loadings. The compacted lifts of Field Leach Pad 1 (West) do not appear to have had a significant impact on cumulative loadings relative to Leach Pad 2 (East). However, it can be observed that seepage only cumulative loadings from Field Leach Pad 1 (West) were lower for sulfate, iron and aluminum.

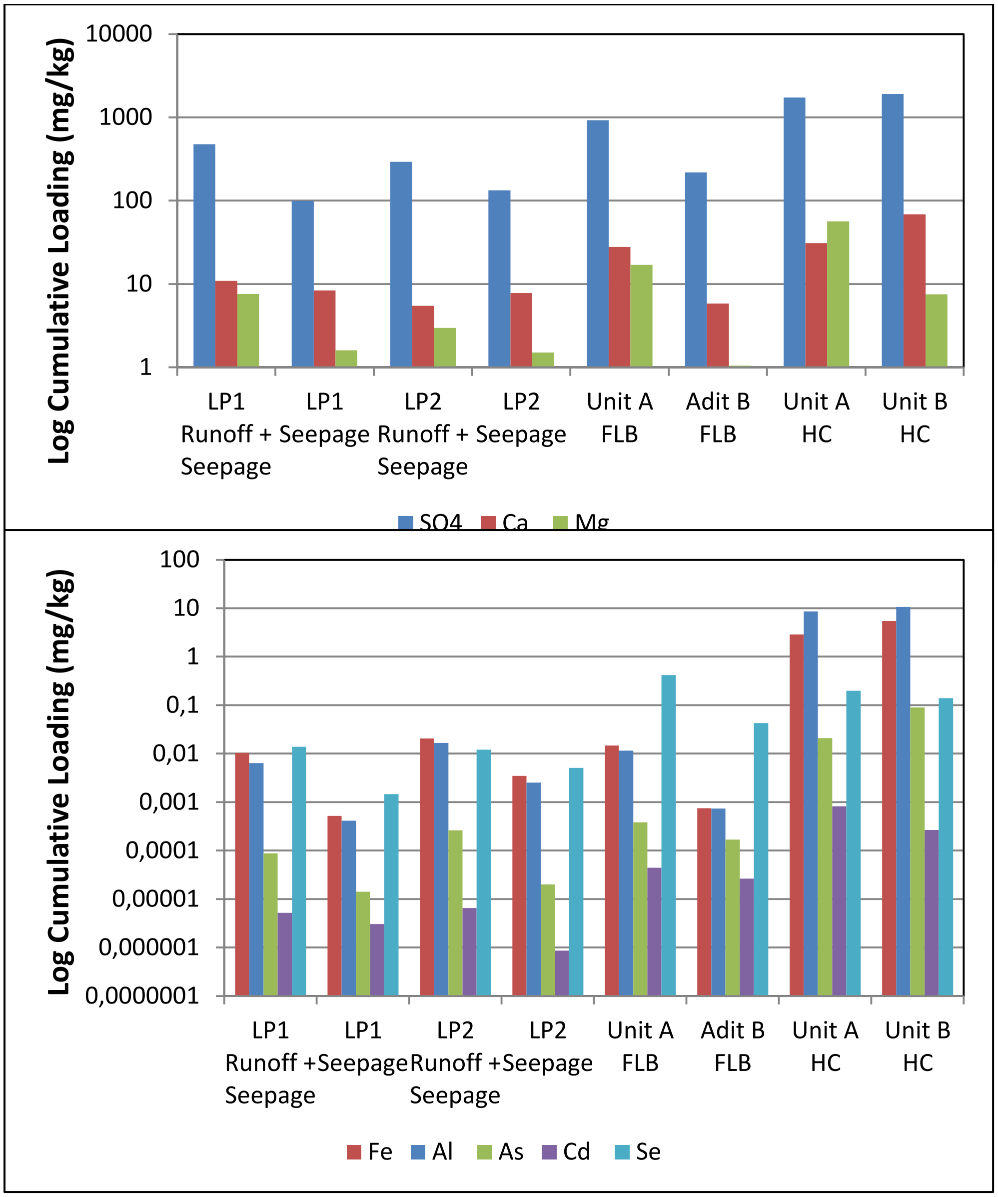


**Figure 2** Summary Comparison of Kinetic Loading Rates: **a)** sulfate, calcium and magnesium **b)** iron, aluminum, arsenic, cadmium, selenium.

Notes: LP = Field Leach Pad, Unit A = shale, Unit B = siltstone, FLB = Field Leach Barrel, HC = Humidty Cell

## Instrumentation

### Oxygen and Carbon Dioxide

Sulfide oxidation consumes oxygen ($O_2$) and produces sulfuric acid, which can react with carbonate minerals, if present, to produce carbon dioxide ($CO_2$) gas.

There is a good correlation between $O_2$ and $CO_2$ readings (Figure 3). In 3 of 4 CMT's there was a corresponding decrease in $O_2$ with increasing $CO_2$. Overall, the FLPs represent an oxidizing ARD environment where $O_2$ is being consumed via pyrite oxidation, which produces acid that reacts with carbonate minerals to produce $CO_2$ gas.

The $O_2$ and $CO_2$ profiles for the north CMT of FLP 1 (West) suggest that compaction has not had a significant effect on oxygen infiltration. The $O_2$ and $CO_2$ concentrations at the bottom of the FLP may have been the result of oxygen flow through the dry zone located between 1.4 and 2.2 m depth. Overall, there was an increasing $O_2$ consumption and $CO_2$ production with depth to 1.8 m depth. The moist-dry contact observed during installation does not appear to have had any effect on the $O_2$ and $CO_2$ concentrations. Overall there was an $O_2$ consumption and $CO_2$ production to a depth of 0.8 m depth, below which concentrations remained constant.

The $O_2$ and $CO_2$ profiles for the north CMT of FLP 2 (East) suggests no compaction has not had a significant effect on limiting oxygen infiltration. Overall there was steady $O_2$ consumption and $CO_2$ production to a depth of 1.8 m depth, the maximum depth monitored. However, both profiles suggest that rapid surface weathering of the shale may have results in a weathered skin that may act as a cover at limiting $O_2$ consumption and therefore $CO_2$ production.

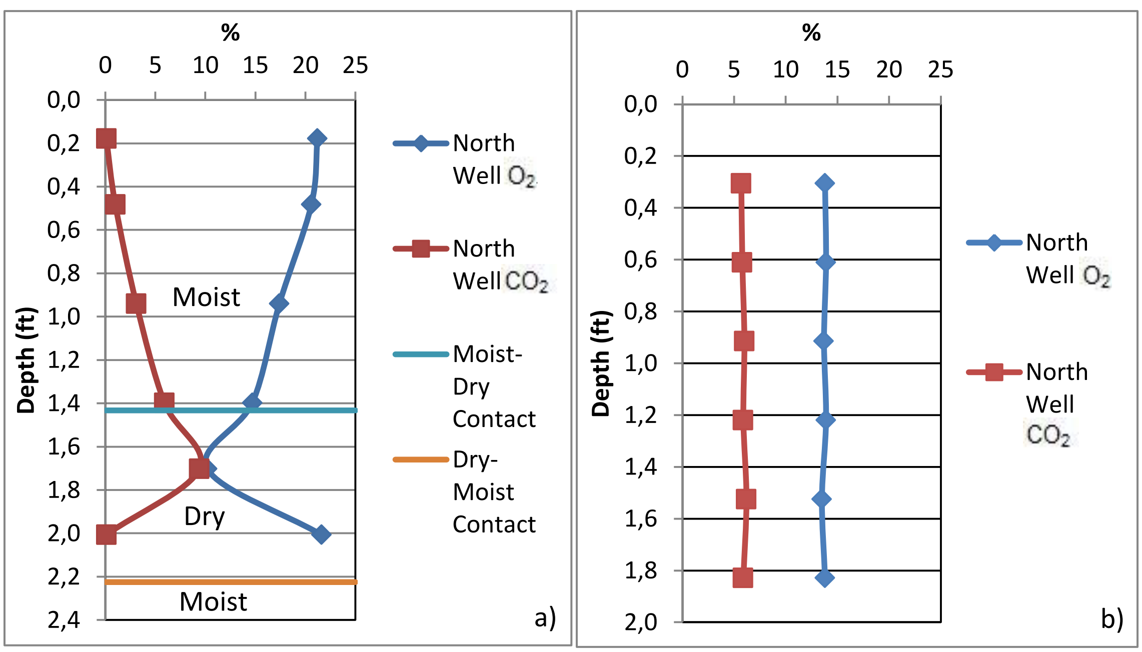


**Figure 3** Oxygen ($O_2$) and Carbon Dioxide ($CO_2$) Profiles: **a)** Field Leach Pad 1 **b)** and Field Leach Pad 2

Notes: Moist and dry zones were observed at the time of installation and are included for reference only. It is unknown if they have changed.

## Temperature

Temperature can be an indicator of sulfide oxidation. The temperature profile in a waste stockpile depends on the rate of heat produced from pyrite oxidation (an exothermic reaction), on ambient temperature changes at the surface of the waste stockpile and by heat diffusion (Ritchie, 1994; Lahmira et. al., 2007). If there are temperatures significantly higher than ambient within the waste stockpile, this suggests that rates of sulfide oxidation are high.

Figure 4**¡Error! No se encuentra el origen de la referencia.** shows an example of the monthly average temperature profiles within the FLPs. The temperatures within the FLPs were generally warmer than the ambient air temperatures at surface, primarily due to sulfide oxidation. In the summer months, temperatures decreased with depth, but overall were warmer than ambient air temperature. The highest temperatures within the FLPs occurred in August with a maximum of 20 °C. In the winter months, temperatures increased with depth with up to 20°C difference between the ambient air temperature and the base of the FLPs.

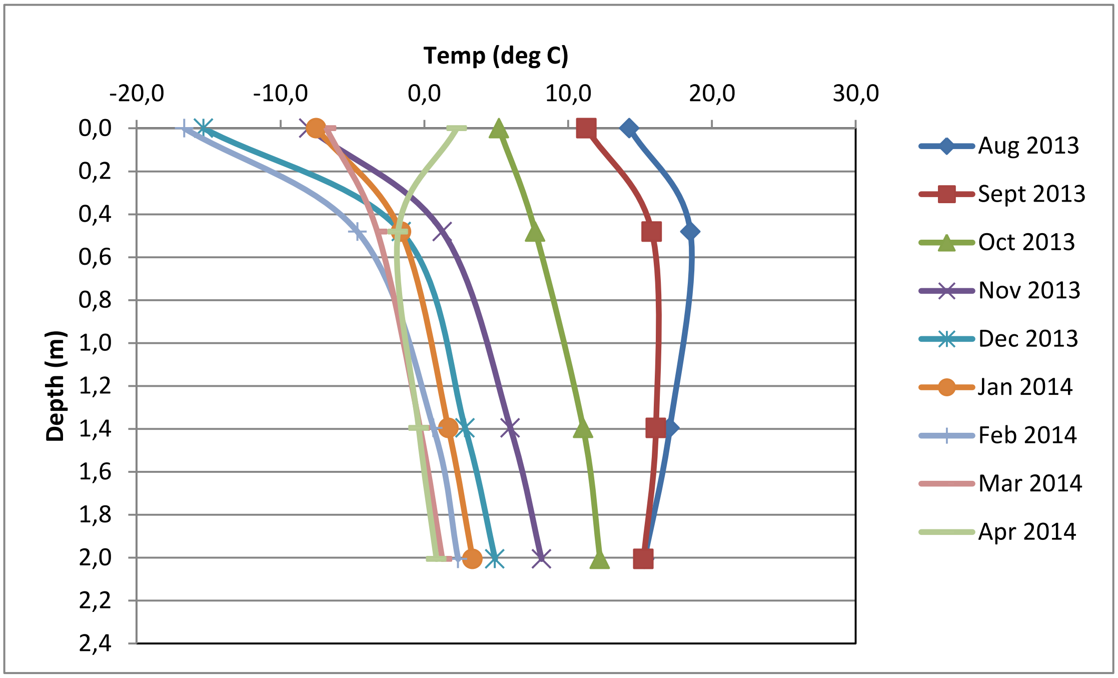


Figure 4  Average Monthly Temperature Profile for Field Leach Pad 1 (West) North CMT

**Moisture Content**

Moisture content can be used to evaluate the degree of saturation and the permeability of the material in response to precipitation events and seasonal variation.

Figure 5 shows the average monthly moisture content profiles. At the north end of FLP 1 (West), the water content increased with depth until the upper contact of the observed dry zone at 1.37m and then decreased slightly. In FLP 2 (East), water content increased with depth at both the north and south ends. In both FLPs, the uppermost sensors showed greater seasonal variability and the lower-most sensors were relatively stable throughout the year.

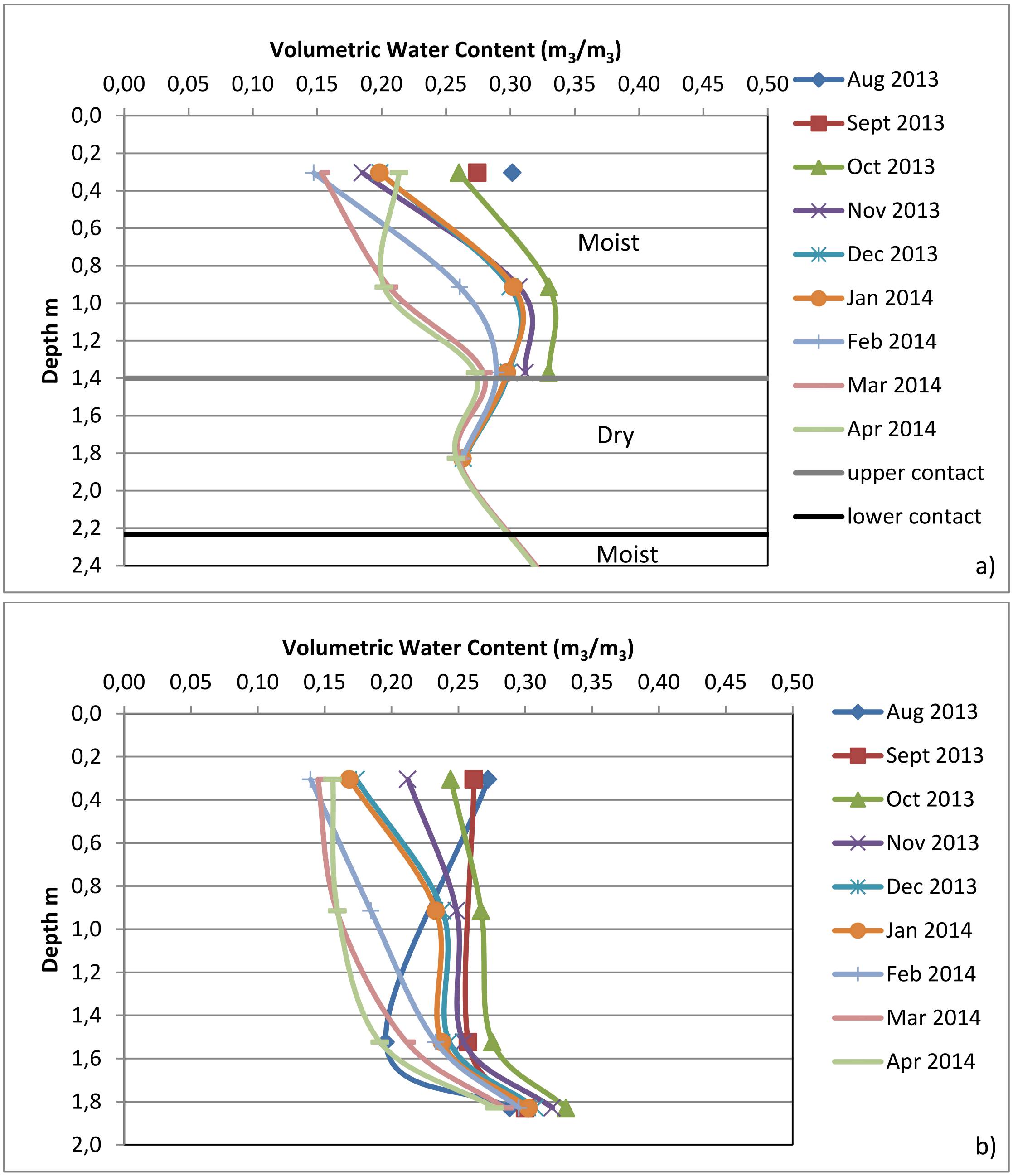


**Figure 5**: Average Monthly Volumetric Water Content Profile: a) Field Leach Pad 1 b) and Field Leach Pad 2

## CONCLUSION

The compacted lifts of FLP 1 (West) does not appear to have had a significant impact on water infiltration or influenced corresponding water quality and cumulative loadings in the first year of monitoring. Both FLPs show similar water quality and cumulative loading rates, despite field observation of moist and dry zones at the time of instrumentation installation. However, the cumulative loadings of sulfate, iron and aluminum from FLP 1 (West) were notably lower than for

FLP 2 (East) Therefore there is some indication that compaction may result in measurable performance change over time.

The compacted cover of FLP 1 (West) may affect oxygen ingress. The north CMT showed oxygen gradually decreasing with depth as would be expected; but the south well shows a dramatic decrease at approximately 0.6m with a corresponding increase in carbon dioxide. This is likely attributable to the compacted cover or it may be the result of variability in grain size and material composition. In general, laboratory oxygen and field oxygen measurements were in agreement and support the observed field trends.

Both FLPs showed similar moisture content ranges, with greater seasonal variability near surface. However, the compacted lift in FLP 1 (West) may impact water content below the upper lift at approximately 1.2 m by impeding infiltration. This is seen by the decreasing trend in measured water content below 1.2 m. In addition, there were field observations of a dry zone at the time of instrumentation installation. FLP 2 (East) showed an overall increasing trend in measured water content with depth.

The preliminary results support the benefit of compaction and lifts. The gas concentrations and moisture content values suggest that the compacted FLPs should show lower reactivity over time and lower loading rates in seepage and surface runoff to the environment. The results also indicate that cumulative loadings are variable but more than one order of magnitude lower for aluminum, arsenic, cadmium and zinc than determined from humidity cells of the same material.

## REFERENCES

Andrina J., Wilson G.W. Miller, S.D. 2012. Waste Rock Kinetics Testing Program: Assessment of the Scale Up Factor for Sulfate and Metal Release Rates. *In* Proceedings 9th International Conference on Acid Rock Drainage (ICARD) 20-26 May, 2012. Ottawa, Canada.

INAP, 2011. The Global Acid Rock Drainage (GARD) Guide. Available online http://www.gardguide.com/index.php/Main_Page Accessed January 2011.

Kempton, H. 2012. A Review of Scale Factors for Estimating Waste Rock Weathering from Laboratory Tests. *In* Proceedings 9th International Conference on Acid Rock Drainage (ICARD) 20-26 May, 2012. Ottawa, Canada.

Lahmira, B., Lefebvre, R., Aubertin, M., Bussière, B. 2007. Modeling the influence of heterogeneity and anisotropy on physical processes in ARD-producing waste rock piles. *In* Proceedings of 60th Canadian Geotechnical Conference and the 8th Joint CGS/IAH-CNC Groundwater Conference (pp. 21-24).

Lefebvre, R., Smolensky J., Hockley D. 1998. Modeling of Acid Mine Drainage Physical Processes in the Nordhalde of the Ronnenburg Mining District, Germany. *In* Proceedings of the TOUGH Workshop 1998. May 4-6, 1998, Berkeley, California (pp. 228-233).

MEND, 2009. Prediction Manual for Drainage Chemistry from Sulfidic Geologic Materials Mend Report 1.20.1. NRCan.

Ritchie, A.I.M., 1994. The waste-rock environment. In: Jambor, J.L., Blowes, D.W. (Eds.), Short Course Handbook Volume 22, The environmental geochemistry of sulfide mine-wastes. Waterloo. May 1994.

Shaw S., Samuels A. 2012. An Empirical Comparison of Humidity Cell and Field Barrel Data to Inform Scale-Up Factors for Water Quality Predictions. *In* Proceedings 9th International Conference on Acid Rock Drainage (ICARD) 20-26 May, 2012. Ottawa, Canada.

Smith L.J., Macdonald, G., Blowes D., Smith L., Sego D.C., Amos R.T. 2012a. Davik Waste Rock Project: Objectives, Construction, Current Conclusions and Implications. *In* Proceedings 9th International Conference on Acid Rock Drainage (ICARD) 20-26 May, 2012. Ottawa, Canada.

Smith L.J.D., Moncur M.C., Neuner M., Gupton M., Blowes D., Smith L., Sego D.C. 2012b. Davik Waste Rock Project: Design, construction and instrumentation of field-scale experimental waste rock piles. Applied Geochemistry. doi:10.1016/j.apgeochem.2011.12.026

Wels, C., Lefebvre, R., Robertson A. 2003. An Overview of Prediction and Control of Air Flow in Acid Generating Waste Rock Dumps. *In* Proceedings 6th International Conference on Acid Rock Drainage (ICARD) 12-18 July 2003. Cairns Australia (pp. 639-650).