Cesium Residue Leachate Migration in the Tailings Management Area of a Mine Site: Predicted vs. Actual

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ABSTRACT
A Cesium Products Facility (CPF) adjacent to a mine manufactures a cesium-formate drilling fluid. Residue from this process is dry-stacked in the old Tailings Management Area (TMA). Elevated concentrations of calcium, sulphate, strontium, cesium, and rubidium are used to identify the leachate. Groundwater monitoring indicates that, as predicted, leachate has affected near-surface porewater quality within the TMA. Porewater at the base of the tailings and in the overburden beneath the tailings has not been affected. A geochemical investigation has been initiated to determine how the leachate behaves in the groundwater/tailings porewater system.

RÉSUMÉ
Une Facilité de Produits de Césium (CPF) adjacent à un mien les fabrications un césium-formate forant du liquide. Le résidu de ce processus est sec-empilé dans la vieille Région d'Administration Tailings (TMA). Les concentrations élevées de calcium, sulfate, strontium, césium et rubidium sont utilisées pour identifier le leachate. La nappe phréatique contrôlant indique que, comme prédit, leachate a affecté la quasi surface porewater la qualité dans le TMA. Porewater à la base du tailings et dans le fait de surcharger au-dessous du tailings n'a pas été affecté. Une enquête geochemical a été lancée pour déterminer comment le leachate se comporte dans le groundwater/tailings porewater le système.

1 INTRODUCTION

A Cesium Products Facility (CPF) that manufactures a non-toxic cesium-formate drilling fluid, and other specialty cesium chemicals, from pollucite ore, operates adjacent to pollucite/tantalum/spodumene mine. The CPF was developed as a closed system, with the tailings slurry from the CPF process discharged to one of two double-lined containment cells (CPF Containment Cells 1 and 2; Figure 1). The tailings solids settle out in the containment cell, and the decant is returned to the CPF for reuse in the process. The containment cells are used alternately. When one cell is full, the discharge is transferred to the second cell while the residue in the first cell is dewatered, removed, and dry-stacked in a designated location of an inactive tailings management area (TMA). The drystacking location was selected to minimize the effect of residue leachate on discharges to receiving waters by (Agassiz North, 2001):

- minimizing the residue pile footprint because the effect of residue leachate on groundwater quality in the TMA is a function of pile footprint;
- maximizing distance from a discharge point, primarily the Main Dam, along groundwater flow lines to maximize travel time and dilution; and,
- locating the stockpile near a groundwater flow divide so that seepage may be divided among multiple discharge points.

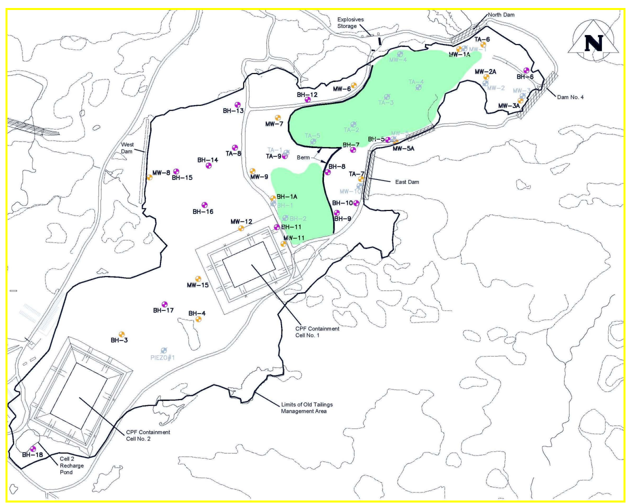

Figure 1. General Site Plan

To date, Cell 1 has been emptied of residue four times, the first time over the period between August 2001 and spring 2002, the second time between June and September 2004, the third time between June and August 2006, and the fourth time between July and August 2008. Cell 2 has been emptied of residue three times, the first time over the period between August and November 2002, the second time from May to September 2005, and the third between June and August 2007. The originally approved placement area of 22,000 m^2 reached its maximum allowable height in 2006. In 2007 the placement area was increased to 49,500 m^2.

The Environmental Approval for placement of the CPF residue in the TMA requires monitoring of groundwater quality within the TMA. The objective of the monitoring program is to verify the predicted effect of the CPF residue leachate on groundwater quality in the TMA, and eventually on the quality of dyke seepage and discharges. This report summarizes pre-placement site investigations, post-placement monitoring results with to October 2008, and introduces future work.

2 PRE-PLACEMENT SITE INVESTIGATIONS

General TMA stratigraphy includes fine sand to silt tailings, intermixed organics and silt, silty clay, sand and gravel, and felsic bedrock (UMA 2001). Groundwater flow in the north basin of the TMA is primarily directed to the West and East Dams with a smaller area of the TMA draining towards the North Dam. Groundwater in the southern portion of the TMA is directed to the Main Dam. UMA (2001) estimated the bulk hydraulic conductivity of the tailings as 10^{-5} m/s, and of the clay as 10^{-8} m/s. Hydraulic gradients were measured to be 0.003 to 0.009 around the North Dam, 0.015 around the East Dam, and 0.013 around the West Dam (UMA, 2001). Annual seepage and travel time estimates were respectively 200 to 1,700 m^3 and 35 to 65 years around the North Dam, 1,000 to 2,500 m^3 and 10 to 15 years around the East Dam, and 2,000 to 2,500 m^3 and 40 to 50 years around the West Dam (UMA, 2001).

Agassiz North (2001) developed a method to dewater and remove residue from a Cell, and to reactivate the Cell once placement activities were complete. Additionally, Agassiz North (2001) used the information provided in UMA (2001) to conduct an Environmental Effects Assessment and develop the Operational Environmental Monitoring Plan described herein. The Environmental Effects Assessment for placement of the CPF residue in the TMA estimated that dilution of the residue leachate by the tailings porewater would provide adequate attenuation of leachate concentrations before the porewater reports to any surface water. This report resulted in regulatory approval to place residue in the TMA.

3 METHODS

3.1 Groundwater Monitoring

The operations (Agassiz North, 2001) monitoring program involves physical and chemical groundwater monitoring around the CPF residue dry-stack. The program initially involved 6 groundwater monitor wells with wells added as the residue dry-stack has accumulated.and expanded such that 40 wells are currently involved. Wells are sampled twice yearly for water level and for field pH, conductivity, and temperature, and once yearly for these parameters along with chemical parameters including: total and extractable cesium and rubidium, dissolved metals, sulphate, total dissolved solids, alkalinity and major ions.

Monitor wells involved in the program have changed as wells were destroyed by equipment operation or residue burial and to provide coverage of the expanding residue dry-stack footprint. In addition, some wells periodically could not be incorporated in the monitoring plan due to flooding and/or low groundwater elevations.

The monitor wells installed in the TMA are of two types: nested wells and single wells. Nested wells are identified with a TA designation. In most cases, three wells are installed in each of the TA boreholes, with the uppermost well (TA-X-1) installed with the screen in the tailings directly below the water table, the second well (TA-X-2) installed with the screen at the base of the tailings, and the third well (TA-X-3) installed with the screen in the underlying overburden. The MW-series wells are 1.5" drive-point steel monitor wells, installed by direct push, in which the well screen fitted to the end of the well pipe is installed in the tailings slightly below the water table. The BH-series wells are 2" schedule 40 PVC monitor wells, installed by hollow stem drilling methods, in which the screened section of the well is also installed slightly below the water table.

In 2008, 17 monitor wells were installed to replace destroyed or unusable wells (Figure 1). Nested monitor well TA-7 was installed to replace MW-10 and provide a means of monitoring groundwater quality through the tailings and into the overburden below the tailings adjacent to the East Dam. Nested monitor wells TA-8 and TA-9 were installed to replace TA-1 and maintain/increase the monitoring of groundwater quality through the tailings and into the overburden below the tailings to the west of the residue pile. Wells MW-5A and BH-2 were replaced by wells BH-5 and BH-11. All replacement wells were placed as close as possible to the original wells to allow continuity of the monitoring program at these locations. Well BH-6 was installed to increase monitoring coverage northeast of the residue pile. Wells BH-7 to BH-10 were installed to increase the monitoring coverage between the 2007 residue placement area and the East Dam. Wells BH-12 to BH-18 were installed to increase monitoring coverage southwest of the residue pile.

3.2 Groundwater Sampling

Sampling methods used in previous years are documented in UMA (2001). Since October 2002, the groundwater sampling protocol at each well included measurement of the depth to water, well purging, water level recovery, and sample collection. Depth to water was measured using a Solinst Model 101 Water Level Meter. Samples were collected using dedicated Waterra inertial pumps and tubing. All wells were purged by removing 3 well volumes. Samples for the measurement of dissolved parameters were field-filtered through 0.45 µm pore size in-line Waterra© filters. All samples taken in 2004 and earlier were submitted for analysis to Norwest Labs. Samples taken from June 2005 through 2008 were submitted to Maxxam Analytics Incorporated. Field parameters including temperature, pH, and conductivity were measured with a calibrated YSI MS650 meter and 600QS sonde.

3.3 Hydraulic Conductivity and Gradients

Hydraulic conductivity was measured in all wells following their installation. After purging and before analytical sampling, groundwater recovery was measured at known time intervals in 11 wells for hydraulic conductivity analyses. Wells were selected based on their location and screened stratigraphic unit. These wells included BH-7, BH-9, BH-10, TA-7-1, TA-7-3, TA-8-1, TA-8-2, TA-8-3, TA-9-1, TA-9-2, and TA-9-3.

Hydraulic conductivity values for the aquifer formations based on drawdown versus time plots were determined using Waterloo Hydrogeologic Inc., AquiferTest Pro version 4.0 graphical analysis software. The Hvorslev curve matching analytical method was selected for use on the Wardrop collected monitoring data sets given the point-type aquifer access and the unconfined tailings and confined overburden aquifer conditions.

Horizontal hydraulic gradients were calculated between multiple pairs of monitor wells, using water level data from June and October 2008.

3.4 Quality Assurance/Quality Control

Trip blanks are analyzed after every sampling period to assess sample integrity. From 1998 through 2004, water quality sample analyses were completed by Norwest Labs. From 2005 through 2008 Maxxam Analytics Inc. was assigned this responsibility. To ensure analytical consistency, two water samples were taken in June 2005 from the same location and submitted to each lab for identical analytical requests.

4 RESULTS AND DISCUSSION

4.1 Pre-Placement Groundwater Quality: June 2001

Considerable spatial variability was evident in TMA groundwater quality, prior to residue placement, which most likely reflects variations in the composition of tailings solids over the approximate 25 years of tailings deposition. Over this period, the mining focus has varied among three primary ore types to reflect market conditions and overall project economics, leading to corresponding variations in tailings composition. The observed spatial variability in TMA groundwater quality is likely to contribute to temporal variability within the TMA, as groundwater influenced by the different tailings sources slowly migrates within the tailings porewater. Further analysis of spatial variation in the TMA can be found in SEACOR (2004).

4.2 Post-Placement Groundwater Quality: 2008

4.2.1 Quality Assurance/Quality Control

The trip blanks contained near detection limit concentrations of cesium, rubidium, alkalinity, bicarbonate, hardness, sodium, chloride, arsenic, iron, lead, molybdenum, nickel, tin, titanium and zinc. They also contained slightly elevated calcium, strontium, aluminum, barium, copper, lithium and manganese. This indicates that some trace contamination occurred during the 2008 field sampling, but relative to the concentrations measured in the groundwater, the trip blank values indicate that monitoring results have not been influenced by contamination in handling or transport.

The majority of 2005 analytical results from Norwest Labs and Maxxam Analytics are in agreement, with iron and aluminum being the only exceptions. The iron and aluminum concentration discrepancies can potentially be attributed to the order in which the two samples were extracted from the monitoring well.

4.2.2 Key Parameters

Leachate movement through the TMA groundwater is traced using the leachate signature (SEACOR, 2004 which is represented by parameters: conductivity, total cesium and rubidium, dissolved calcium, dissolved strontium, and sulphate. The signature was identified by comparing the results of 20-week laboratory leach test (Table 1) with background groundwater quality in the TMA. Although the monitoring program examined many more parameters, the following discussion will focus on those comprising the leachate signature.

Table 1. Maximum, minimum, and stable mean leachate chemistry in the 20 week CPF residue leach test. L - laboratory. D - dissolved. T - total.

Parameter	Units	Max	Min	Mean
Key Parameters				
Cond_L	µS/cm	3230	2080	2300
Calcium_D	mg/L	680	558	600
Sulphate_D	mg/L	1880	1300	1500
Cesium_T	mg/L	1926	18	25
Physico-Chemical				
pH_L		7.46	6.57	7.3
Alk_T	mg $CaCO_3$/L	19	10	11
Dissolved Metals				
Aluminum_D	mg/L	0.63	0.19	0.4
Antimony_D	mg/L	<0.05	<0.02	<0.05
Arsenic_D	mg/L	<0.05	<0.001	<0.05
Barium_D	mg/L	0.020	0.015	0.018
Beryllium_D	mg/L	<0.001	<0.001	<0.001
Boron_D	mg/L	0.02	<0.01	<0.01
Cadmium_D	mg/L	<0.005	<0.002	<0.005
Chromium_D	mg/L	<0.02	<0.004	<0.02
Cobalt_D	mg/L	<0.01	<0.004	<0.01
Copper_D	mg/L	0.005	<0.003	<0.005
Iron_D	mg/L	0.008	<0.003	<0.02
Lead_D	mg/L	<0.02	<0.002	<0.02
Magnesium_D	mg/L	3.24	0.34	0.88
Manganese_D	mg/L	0.11	<0.001	<0.002
Molybdenum_D	mg/L	0.086	<0.02	<0.02
Nickel_D	mg/L	<0.02	<0.01	<0.02
Phosphorus_D	mg/L	<0.80	<0.03	<0.10
Potassium_D	mg/L	1.86	0.10	0.13
Selenium_D	mg/L	<0.10	<0.005	<0.10
Silver_D	mg/L	<0.05	<0.003	<0.005
Sodium_D	mg/L	114	0.9	1.02
Tin_D	mg/L	<0.10	<0.02	<0.10
Zinc_D	mg/L	0.028	<0.004	<0.01

Leachate movement was tracked in one of two ways depending upon data availability. For wells which were installed prior to residue placement, a leachate effect was identified by comparing measured concentrations of the signature parameters in the monitor wells with the pre-placement mean. For wells installed after the first residue placement, baseline conditions were inferred from the mean pre-placement concentrations at nearby wells monitored during the baseline study. In all cases, a significant change was interpreted as a difference from the applicable baseline mean concentration of ± two standard deviations (s.d.).

4.2.3 Wells beneath and North of the Residue Pile

Residue leachate affected shallow groundwater beneath the residue pile shortly after the initial residue placement. Increased concentraitons of key parameters were first evident in TA-3-1 in 2002 and these elevated concentrations continued to be meseaured through 2005, after which the well was destroyed by residue placement (Figure 2). The deeper tailings groundwater at the same location was not significantly affected. Slight increases of strontium and sulphur were evident in TA-3-2, at the base of the tailings pile, between 2002 and 2006 but these could not be attributed to the resiude leachate in the absence of complete signature increases. Similarly, a slight increase in calcium was evident at TA-3-3 from 2002 to 2006. In 2006 nearby well MW-6 was sampled in place of TA-3-1. MW-6 is located approximately 15 m farther from the original residue pile footprint than TA-3-1. The key parameters in MW-6 were elevated with respect to pre-placement conditions in 2006, but to a lesser degree than TA-3-1 in 2005. Concentrations of key parameters decreased in MW-6 from 2006 to 2007, with only calcium, sulphate and sulphur occurring in slightly elevated concentrations relative to pre-placement conditions. In 2008 there was a decrease in TDS, calcium, sulphate, strontium and sulphur but an increase in dissolved cesium and rubidium. Of these parameters, only sulphate, sulphur and cesium were elevated relative to pre-placement conditions.

TA-2 was destroyed in July 2007 by residue placement activities; however, with the exception of elevated dissolved calcium in June 2007, there was no evidence of an effect of residue leachate on key parameter concentrations at TA-2-1 or TA-2-2. Concentrations of key parameters in both wells were not significantly different from the pre-placement baseline, other than depressed strontium in TA-2-2. Notably, dissolved sulphate was only detected once since 2001 in these wells.

Historically and in June 2008, there is no evidence of residue leachate at TA-5. Concentrations of key parameters at TA-5-1, with the exception of relatively small elevations in conductivity, and TDS, and a slight depression in pH, were not different from the pre-placement baseline. In 2008, both calcium and strontium exceeded pre-placement concentrations. At TA-5-2, all of the key parameter concentrations were within two s.d. of the baseline mean with the exception of elevated pH in 2008. The marginally depressed pH that has been evident at TA-5-3 since October 2002 continued to October 2008. Conductivity at TA-5-3 continued to be elevated compared to pre-placement conditions. The slightly elevated TDS found in 2007 decreased to concentrations within pre-placement conditions in 2008. Concentrations of all other key parameters at TA-5-3 were not significantly different from the pre-placement baseline. Nested well TA-5 was buried by residue in August 2008.

4.2.4 Wells in Northeast Portion of the TMA

In 2008, concentrations of several key parameters in TA-6-1 continued to increase higher than two s.d. from the inferred baseline, including calcium, sulphate, strontium, and sulphur. A decrease in pH also continued in 2008. Conductivity, cesium, and rubidium concentrations increased in 2008, but remained within pre-placement conditions. Given that the complete residue leachate signature is not expressed because some concentrations remained well within the pre-placement range measured in the surface tailings wells, the concentration increases that did occur are most likely a result of natural variation within the tailings groundwater system. In TA-6-2, all parameters were within inferred baseline conditions with the exception of elevated pH. In TA-6-3, pH, sulphate and sulphur were elevated relative to inferred baseline conditions. There is no indication that residue leachate has affected deeper groundwater. With the exception of the elevated pH from both wells and elevated sulphur in the overburden, all of the key parameters measured in TA-6-2 and TA-6-3 occurred at concentrations within 2 s.d. of the inferred baseline mean values for the well.

Leachate has affected shallow groundwater north of the residue pile. Conductivity, TDS, dissolved calcium, strontium, sulphur and sulphate, and total cesium and rubidium concentration increases, that initially appeared in MW-1/1A in late 2002 continued, peaked by 2007. These concentrations decreased in 2008, but still were present above pre-placement conditions.

Elevated conductivity, TDS, dissolved calcium and strontium were evident at MW-3A from 2006 to 2008. In 2008 dissolved cesium and rubidium increased above baseline conditions. These increases coincided with a decreased pH. Sulphate and sulphur have not been detected above baseline levels since 2002.

BH-6 was installed in 2008 and contains elevated conductivity, TDS, calcium, strontium, cesium and rubidium, and a depressed pH relative to inferred baseline conditions. Both sulphate and sulphur were not detected.

4.2.5 Wells between Residue and the West Dam

Both TA-1-1 and TA-1-3 contained elevated pH and TDS relative to pre-placement conditions. TA-1-3 also contained depressed sulphate and cesium relative to pre-placement conditions. Nested well TA-9 was installed to replace TA-1. Elevations of conductivity, TDS, dissolved calcium, dissolved sulphate and sulphur, dissolved strontium, and total cesium along with a depression of pH reported from TA-9-1 in 2008 indicated residue leachate migration. Concentrations of key parameters were not significantly different from pre-placement conditions in TA-9-2 or TA-9-3.

TA-8-1, TA-8-2, and TA-8-3 were installed in 2008 and do not contain evidence of leachate migration. TDS was elevated in TA-8-1, pH, sulphate and sulphur were slightly elevated in TA-8-2, and pH, TDS, and sulphur were elevated in TA-8-3. Additionally, 2008 concentrations of sulphate and strontium were less than the inferred pre-placement conditions in TA-8-3.

Elevated dissolved calcium, strontium, and cesium were reported at MW-7 in 2008, while sulphate, sulphur and total rubidium were within the pre-placement ranges. Compared to baseline conditions, groundwater from MW-8 contains a depressed pH, conductivity, TDS and cesium, and elevated calcium and strontium. MW-9 contains a depressed pH, and elevated conductivity, TDS, calcium, strontium, sulphate and sulphur.

BH-11, BH-12, BH-13, BH-14, BH-15, and BH-16 were all installed in 2008. BH-11 contains elevated conductivity, calcium, strontium, sulphate, sulphur, cesium and rubidium relative to inferred baseline conditions. BH-12 contains elevated calcium, sulphate, sulphur and cesium, along with depressed conductivity and TDS relative to inferred baseline conditions. BH-13 contains elevated conductivity, TDS, calcium, strontium and rubidium relative to inferred baseline conditions. BH-14 contains elevated calcium, strontium, sulphate and sulphur relative to inferred baseline conditions. BH-15 contains elevated TDS, calcium and strontium relative to inferred baseline conditions. BH-16 contains elevated calcium, strontium, sulphate and sulphur, along with depressed conductivity relative to inferred baseline conditions.

4.2.6 Wells between Residue and the East Dam

Relative to pre-placement conditions, increased conductivity, and concentrations of TDS, dissolved calcium, dissolved sulphate and sulphur, and total cesium were reported in TA-7-1. This coincided with a depression of pH. Elevated TDS along with dissolved sulphate and sulphur were reported in TA-7-2 in 2008, whereas key parameter concentrations were not different from pre-placement conditions in TA-7-3.

BH-5, BH-7, BH-8, BH-9, and BH-10 were all installed in 2008. BH-5 was installed adjacent to the residue pile to replace MW-5A, which has not produced water since July 2006, and had only been monitored for groundwater level. Relative to inferred baseline conditions, BH-5 and BH-7 contain high concentrations of conductivity, TDS, calcium, strontium, sulphate, sulphur, cesium and rubidium, along with depressed pH. These analytical results represent the complete leachate signature. BH-8 contains elevated conductivity, TDS, calcium, strontium, sulphate and sulphate, along with depressed pH relative to inferred baseline conditions. With the exception of depressed pH, key parameters in BH-9 do not differ significantly from inferred pre-placement conditions. BH-10 contains elevated conductivity, TDS, calcium, sulphate, sulphur and cesium, along with depressed pH relative to inferred baseline conditions.

4.2.7 Wells South of Cell 1

BH-17 and BH-18 were installed in 2008. With the exception of depressed conductivity and rubidium in BH-18, key parameters in BH-17 and BH-18 do not differ significantly from inferred pre-placement conditions.

4.2.8 Summary

The monitoring data for MW-3/3A and TA-6 indicate that residue migration beyond the margins of the residue pile has occurred to the east-northeast. The monitoring data for TA-9-1 indicate that leachate is migrating either west of the primary residue placement area, or north or the 2007 residue placement area, but not as far as BH-12, MW-7, MW-9, or TA-8-1. The groundwater monitoring data for TA-7-1, BH-5, BH-10, and BH-11 indicate that residue leachate is present along the west side of the East Dam. Based solely on the analytical data, the source of this leachate influence is unknown; either from the original residue pile and/or the 2007 residue placement area.

The monitoring data from BH-11 indicates that leachate from the 2007 residue placement area is likely migrating southwest. However, BH-11 is located on the down-gradient side (and 1-2 m from) of the haul road used to transport dewatered residue from the cells to the drystacking area, and only about 25 m south of where the haul trucks are parked each night. Trucking activities and heavy equipment are potential sources of contamination.

There is no indication of residue leachate at the base of the tailings or in the overburden beneath the tailings. Potential sulphate concentrations at the base of the tailings would be lowered by a reducing environment caused by the layer of organic peat between the tailings and underlying clay.

4.3 Groundwater Flow

The 2008 drilling program increased the amount of groundwater monitor wells in the Old TMA; this allowed the hydraulic conductivity and gradient data presented in UMA (2001) to be updated, and increased the accuracy of inferring seasonal groundwater contour plans.

4.3.1 Hydraulic Conductivity Analyses and Gradient Calculations

All of the 2008 tailings and overburden data sets were found to fit with theoretical responses. Using the 2008 data and the UMA (2001) data, the mean hydraulic conductivity of the near surface tailings is 9.31×10^{-6} m/s, at the base of the tailings is 8.25×10^{-6} m/s, and in the overburden is 3.06×10^{-6} m/s. The values respectively represent published ranges for silty sand tailings and sandy overburden aquifer formations (Freeze and Cherry, 1979). The tailings, peat, clay, sand/gravel, and bedrock stratigraphy is generally consistent in the TMA. Therefore, the mean 2001/2008 hydraulic conductivities can be considered representative of TMA conditions.

The average hydraulic gradient between the residue placements areas and the north dam is 0.0048, between the residue placement areas and the east dam is 0.0100, between the residue placement areas and the west dam is 0.0090, between the residue placement areas and the main dam is 0.0086, and on average across the entire TMA is 0.0085.

Water level monitoring in nested wells TA-5 to TA-9 indicate a downward vertical gradient between the tailings and underlying overburden. In addition TA-5 to TA-7 and TA-9 indicate a downward vertical gradient within the tailings; whereas TA-8 indicates an upward gradient in the tailings.

4.3.2 Groundwater Flow Plan and Travel Times

The 2008 groundwater elevations and inferred contours indicate that, similar to UMA (2001), groundwater within the TMA flows towards the Main Dam, West Dam, East Dam, and North Dam (Figure 2).

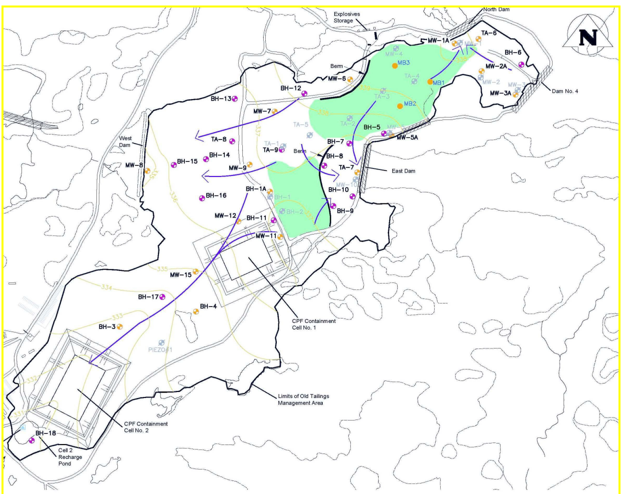

Figure 2. Inferred groundwater contour plan (June 2008)

Using the groundwater contours, an average near surface tailings hydraulic conductivity of 9.3 x 10^{-6} m/s, average hydraulic gradients presented for specific areas of the TMA, and an assumed average near surface silty sand tailings porosity of 45% (Freeze and Cherry, 1979), the *average linear velocity* (v) was calculated to estimate the following groundwater travel times:

$$v = \frac{Q}{nA} = \frac{-K}{n}\frac{\Delta h}{\Delta l} \qquad [1]$$

Between the main residue pile and the North Dam, groundwater would have an *average linear velocity* of 3.1 m/yr. Therefore, it will take groundwater approximately 11 years to travel from the main residue pile to the North Dam. Between both residue piles and the West Dam, groundwater would have an *average linear velocity* of 5.9 m/yr. Therefore, it will take groundwater approximately 43 years to travel from the 2007 residue pile to the West Dam, and 57 years to travel from the main residue pile to the West Dam. Between both residue piles and the East Dam, groundwater would have an *average linear velocity* of 6.5 m/yr. Therefore, it will take groundwater approximately 9 years to travel from the 2007 residue pile to the East Dam, and 7 years to travel from the main residue pile to the East Dam. Between both residue piles and the Main Dam, groundwater would have an *average linear velocity* of 5.6 m/yr. Therefore, it will take groundwater approximately 130 years to travel from the 2007 residue pile to the Main Dam, and 161 years to travel from the main residue pile to the Main Dam.

5 CONCLUSIONS

The groundwater monitoring completed through 2008 indicates that leachate from CPF residue placed in the TMA has affected near-surface (2.4 to 3.7 m depth) groundwater quality up to 67 m south, <50 m southwest, and at least 17 m northeast of the residue pile boundary. Over the past 7 years of residue placement in the TMA, the footprint of the residue placement area has changed, making the comparison of predicted vs. actual rate of leachate migration very subjective and difficult to quantify. However, qualitatively leachate migration towards the North Dam has been faster than predicted by UMA (2001) and more in line with the 2008 predicted travel times, leachate migration to the East Dam is close to UMA (2001) and current predictions, and leachate travel to the West and Main Dam's appears to be slower or close to UMA (2001) and current predictions.

Additionally, near surface groundwater quality up to 8 m southwest and 12 m north of the 2007 residue placement area has likely been affected by residue leachate. Groundwater quality at the base of the tailings and in the overburden has not been affected by leachate.

Residue leachate is indicated by elevated conductivity, along with increased key parameter concentrations of dissolved calcium, sulphate, and strontium, and total cesium and rubidium. The monitoring data for MW-3/3A and TA-6 indicate that residue migration beyond the margins of the residue pile has occurred to the east-northeast. The monitoring data for TA-9-1 indicate that leachate is migrating either west of the original residue placement area, or because TA-2-1 and TA-5-1 did not contain the leachate signature before being buried, leachate is more likely migrating north or the 2007 residue placement area, but not as far as BH-12, MW-7, MW-9, or TA-8-1. Groundwater monitoring data for TA-7-1, BH-5, and BH-9 to BH-11, along with estimated leachate travel times, indicate that residue leachate from the original residue placement area is present along the west side of the East Dam. The monitoring data from BH-11 indicates that leachate from the 2007 residue placement area is likely migrating southwest. However, BH-11 is located on the down-gradient side (and 1-2 m from) of the haul road used to transport dewatered residue from the cells to the drystacking area, and only about 25 m south of where the haul trucks are parked each night. Trucking activities and heavy equipment are potential sources of contamination.

Residue leach test work along with water quality monitoring, indicate that a progressive reduction of concentrations over time is expected once residue placement has ended.

Groundwater elevations and inferred contours indicate that groundwater within the Old TMA flows towards the Main Dam, West Dam, East Dam, and North Dam. The mean hydraulic conductivity of the near surface tailings is 9.3×10^{-6} m/s, at the base of the tailings is 8.3×10^{-6} m/s, and in the overburden is 3.1×10^{-6} m/s. The average horizontal hydraulic gradient across in the TMA is 0.0085; vertical gradient is in the downward direction.

5.1 Ongoing/Future Site Investigations

For purposes of long term residue management, an investigation of the geochemical behaviour of residue leachate in the groundwater/tailings system of the TMA is currently underway as a M.Sc. project by the University of Manitoba's Department of Geological Sciences. The study is aimed at determining the mobility of cesium in the residue pile, and whether or not there is geochemical rate limiting effect on leachate migration. This will help better predict long term discharge concentrations reporting to surface waters.

With residue leachate reported adjacent to the North and East Dams in 2008, surface water sampling outside the TMA at these potential discharge points are being incorporated in the 2009 monitoring plan. The objective will be to determine whether or not mitigated actions are required to limit seepage concentrations outside the TMA.

Continued annual groundwater monitoring in the TMA is required.

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