Study of Water Flow Rates in the Soil around Sino Metals Tailings Dumps (Pollution Control)

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Abstract
The hydrological characteristics of ground water around the Sino Metals Leach tailings dumps area were studied by determining the water table elevations in boreholes, the gradient of the water table, flow directions, the water flow parameters such as – coefficient of permeability 'K', Flows speed. This was with a view to establish extent of pollution of ground water and dispersion of pollutants at Sino Metals Leach tailings dumps facility
It was found that the general flow direction of ground water is from West to East. (West – East flow), The average permeability for the soils is between 0.00718m/day to 0.0137m/day and generally dispersion of any pollutants is very slow and that the acidic waters from the tailings is not reaching the subsurface soil.

Key words: *Hydrological, Water table, Gradient, Permeability and Pollution*

INTRODUCTION

Sino Metals Leach (Z) Limited is located within NFC – Africa Mining, Surface and Mining rights area. Its main operations are the processing of tailings and oxide ore to produce copper through leaching and electro-winning. The residual tailings are dumped in a designated dump on the western side of the Leach Plant.

The residual tailings have elevated acidity levels hence, the likely risk of contaminating ground water in the event that the HDPE membrane fails or there is an overspill.

In order to monitor ground water contamination, Sino Metals Leach (Z) Limited drilled six (06) boreholes around the dumps. Additionally, three (03) more boreholes located within Chambishi Metals are also monitored. Figure1a shows the location of the borehole around the tailings dump complex facilities and figure1b is the google location map. Though the monitoring has been going on for more than five (05) years, the ground water flow regime is not known.

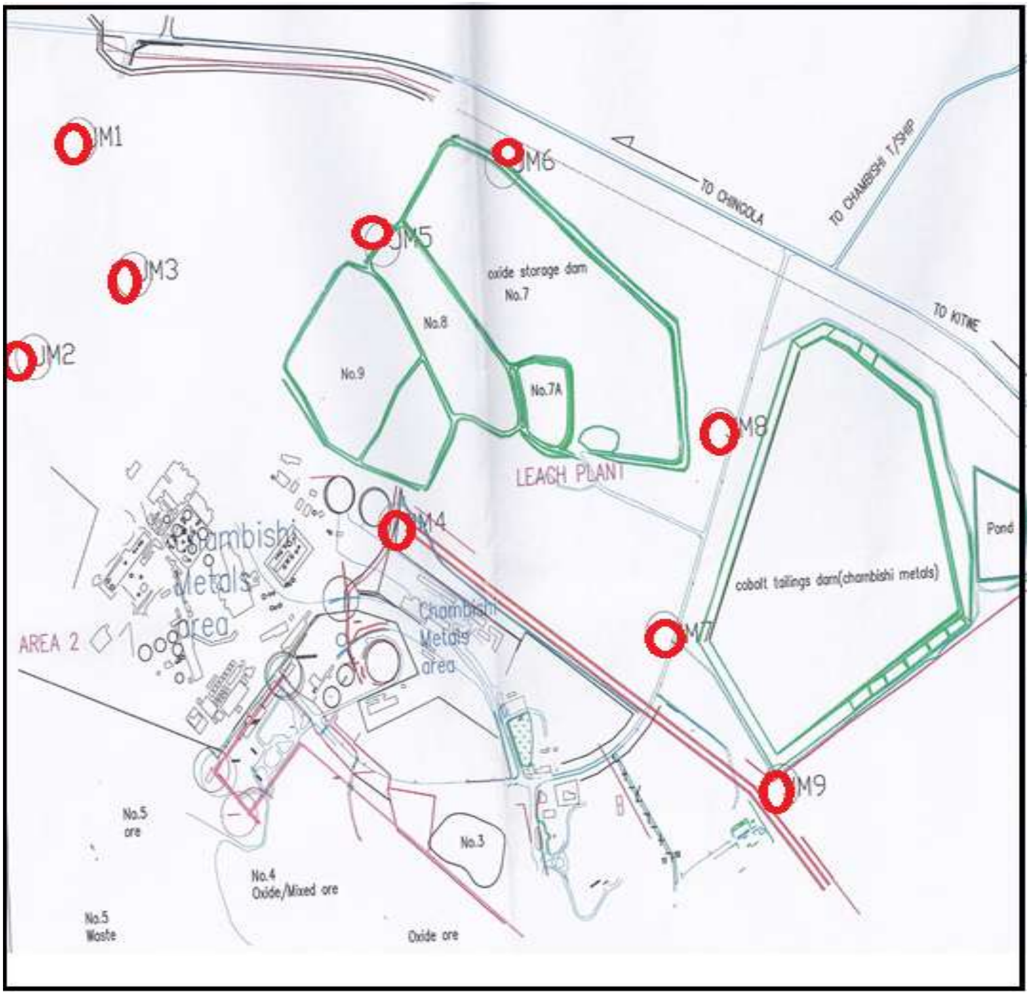

Figure1a: **Location of test borehole relative to Tailings dumps complex for Sino Metals**

Figure 1b: Google map of the taings dump complex facilities

Ground water contamination has been noted in one of the boreholes (JM5) adjacent to Tailings Dump No.8 and Chambishi metal plant. The extent of contamination beyond the tailings dumps is not known. The failure to know the extent of contamination was due to the lack of knowledge on the ground water flow parameters.

This paper presents the results of ground water flow regimes' studies carried out.

METHODOLOGY OF THE STUDY

The methodology of study involved surveying the borehole location in space (determining the coordinates and elevation of the borehole caps) using a total station. Determining the water table using an electric water meter and water flow rates by pump tests; falling head method through well recovery.

The other preferred method of flow rate study was die-cast but this was not due to limited time and resources.

GEOLOGIC SETTING OF THE AREA

Before the study could be undertaken it was important to establish the geology of the area, i.e., types of soils and the rocks beneath the soil layer around the Tailings Dumps.

The location of the tailings dumps is on the left side (Southern side) of Kitwe – Chingola Road – figure 1 (a&b).

The geologic setting for the area is defined by in-situ Lateritic Clay Sandy soil. This is underlain by Granitic Gneiss rocks. The soil is a direct product of the weathering (in-situ) of the Granitic Gneiss. The Granitic Gneiss forms part of the intrusive rock into the Basement Complex Schist. The Basement Complex forms the Kafue anticline with East-West trending structural features including fracturing – Figure 2

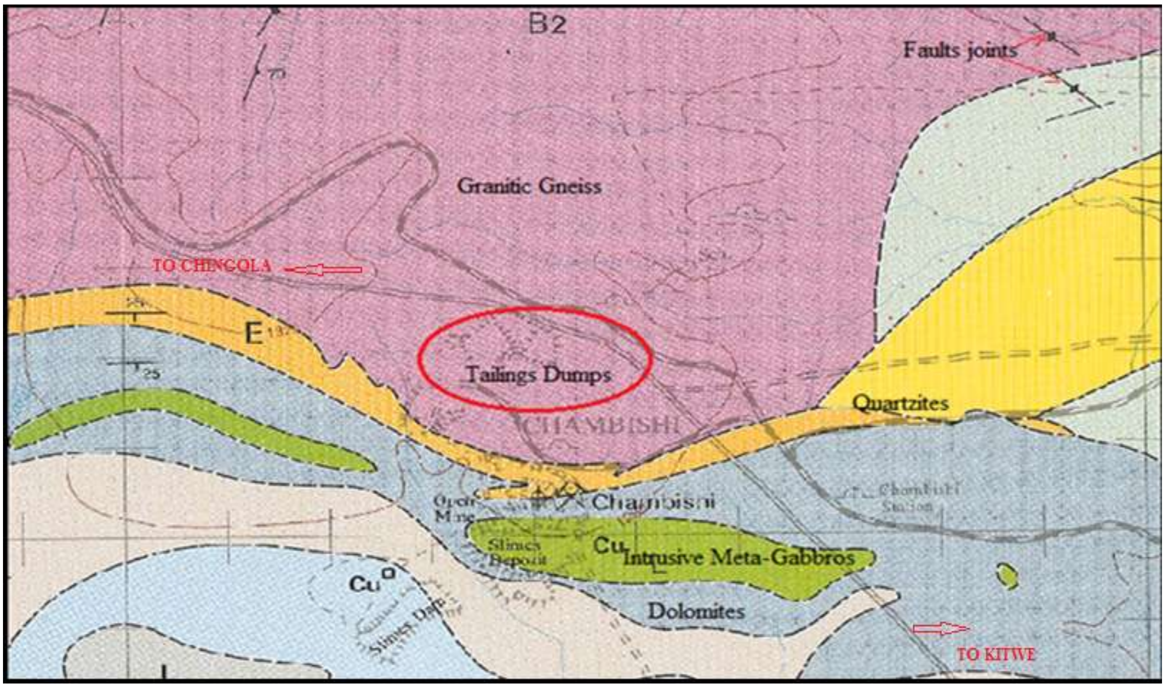

Figure 2: Geology of the study area.

RESULTS

The results from the study done are given below

BOREHOLES USED FOR GROUND WATER MONITORING

All the boreholes used for this study had been drilled to a depth of 50m and cased with perforated steel casings. The internal diameter of the boreholes is 150mm. The boreholes were surveyed to define the location in space. The table below gives the obtained co-ordinates – Table 1

The water table elevations were calculated after taking the depth measurements using an electric water meter. The calculated water elevation is metres above sea level.

Table 1: Borehole coordinates and water table elevations (above sea level)

BH No.	CORDINATES	IN UTMs	BORE HOLE CAP	WATER DEPTH FROM	WATER TABLE
PT NAME	Y	X	Z- ELEVATION	BORE HOLE CAP	Z-ELEVATION
JM1	612882.392	8602560.196	1316.823	9.2	1307.623
JM2	612757.271	8602168.044	1307.391	3.75	1303.641
JM3	612996.241	8602306.44	1314.486	3.87	1310.616
JM4	613578.383	8601814.126	1312.345	3.17	1309.175
JM5	613575.22	8602332.464	1311.379	3.09	1308.289
JM6	613864.41	8602461.445	1299.317	0.58	1298.737
JM7	614186.558	8601582.322	1304.287	3.04	1301.247
JM8	614336.209	8601948.633	1301.38	1.64	1299.74
JM9	614440.501	8601288.018	1300.614	1.85	1298.764

WATER TABLE MEASUREMENTS AND WATER FLOW DIRECTION

The depth of water table in each borehole was measured. The elevation of the water table with reference to sea level was then calculated as earlier indicated. Figure 3 shows the plot of boreholes in space showing cap level, water table and the base of the borehole.

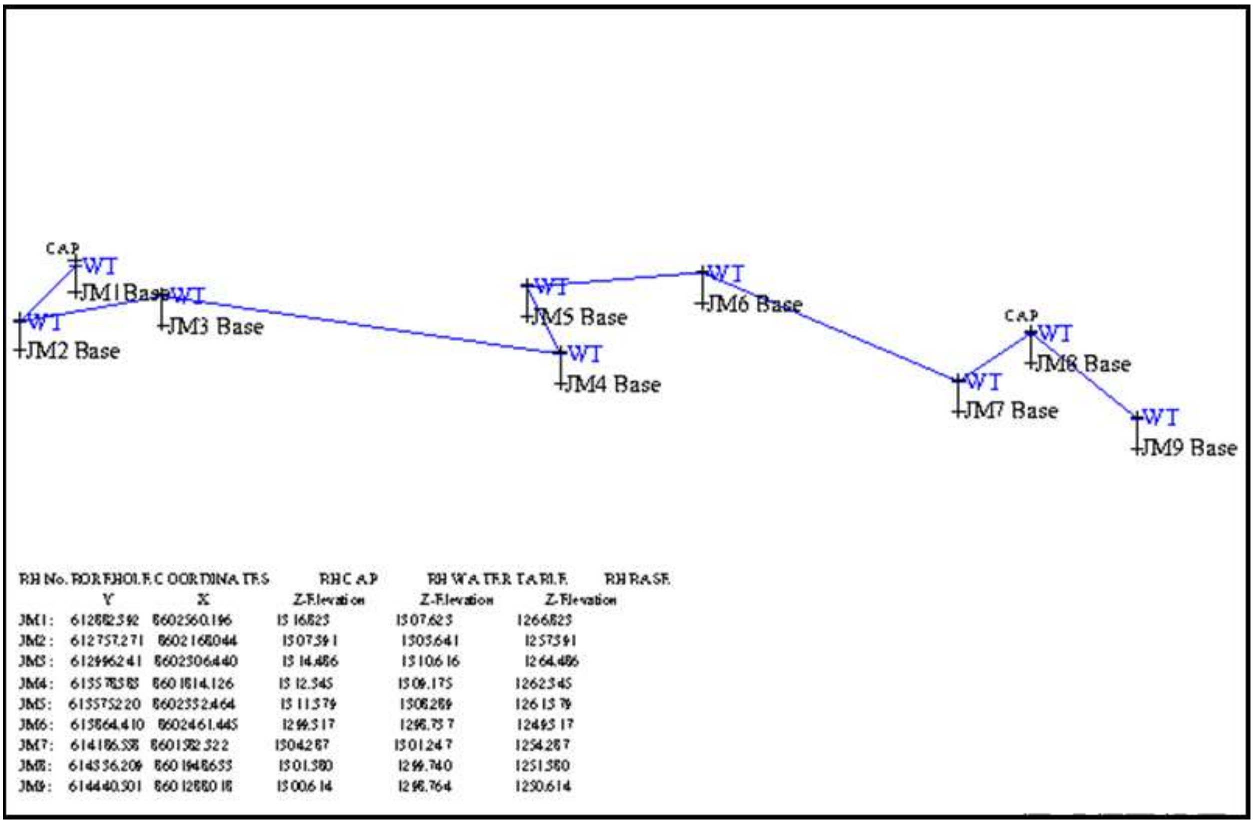

Figure 3: Plot of boreholes in space – Base and cap elevations (generated by Surpac)

The resulting information was then used to estimate gradient between boreholes and this information was used to determine the follow direction. Figure 4 shows the contour plots of the water table and the gradient between boreholes and water flow direction (as constructed) from the gradients.

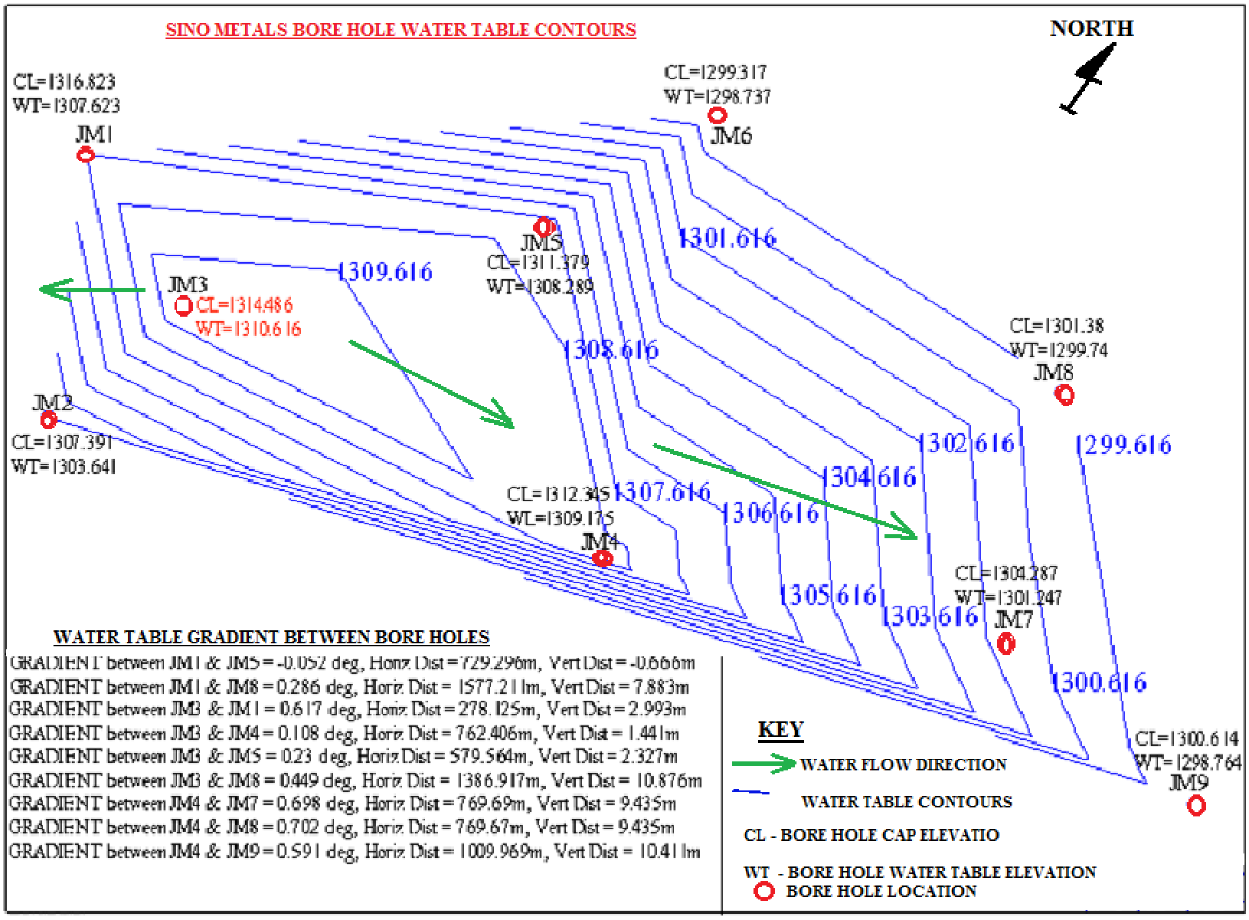

Figure 4: Water table elevation as generated by Surpac software

From the contour plots, it is clear that the water table high is at borehole number MJ3 (1310.616m elevation). The general trend or gradient is towards borehole number MJ 7, MJ8 and MJ9. This trend seems to represent the natural trend. There is a possible South West trending gradient (toward MJ2 and MJ1). This western gradient is likely to be influenced by mining activities (ID 15 and West Ore body). However, the study indicates that major flow direction is West-East in line with major trend in the faulting system as defined by the Lufirian arc (a major structural trend on the Copperbelt and North Western Provinces). This trend was also noted by NFC – Africa Mining on the water monitoring project for the South East orebody (February report by Applied Science and Technology Associates, March, 2013).

GROUND WATER FLOWS

Having established the water table level and major flow direction, it was possible to establish the flow velocities.

There were two options of studying the flow of velocities and these were:

- Borehole Pump tests
- Dye Cast tests (tracer element method using manganese peroxide)

The soil is that of lateritic Clayey Silt Sand. The theoretical permeability 'K' is in the order of 0.05 to 0.25 cm/hr. With this in mind, it was decided, given limited time, to use the borehole pumping tests method.

In the borehole pumping tests, the most accurate method is the steady state method. However, given the distance between boreholes, type of soil and the rock below it, this state could not be reached as the bore hole would culvert since the distance in between adjacent bore holes was large and the soil yield is naturally low. It was then decided to use the modified Boutwell permeameter equation: $K_1 = \frac{\pi d^2}{\pi D(t_2 - t_1)}$ Ln $\left(\frac{h_1}{h_2}\right)$.

Making an assumption that d = D as the diameter of the Borehole and top cap are the same.

This equation reduces and converting log base 10 becomes simpler.

$$K_1 = \frac{2.303d}{(t_2 - t_1)} \log\left(\frac{h_1}{h_2}\right)$$

If the soil is not stratified and assumed uniform, then $K_1 = K_2$ = 'K'.

Hence $K = \frac{2.303d}{(t_2 - t_1)} \log\left(\frac{h_1}{h_2}\right)$

To achieve this objective, borehole recovery method was adopted to get the necessary parameter t_1, t_2 and h_1, h_2.
The table below gives the values calculated in the 5 boreholes selected (security issues in Chambishi metals did not allow pump test). Borehole MJ7 gave erroneous value as water seems to have been gushing from a crack or fissure. The table below gives 'K' values for the other borehole tests done.

Table 2: Calculation of coefficient of permeability for the soils

BOREHOLE No.	WATER TABLE ELEVATION (m ASL)	PUMPED WATER TABLE LEVATION (m ASL)	COLUMN RECOVERY HIEGHT (m)	RECOVERY TIME (minutes)	CALCULATED 'K' VALUE - m/day
JM4	1309.417	1307.175	2.0	34.417	0.00960
JM5	1308.29	1307.16	1.13	35.167	0.00718
JM7	**1301.247**	**1291.247**	**10.0**	**2.40**	**0.694***
JM8	1299.74	1288.74	10.0	48.53	0.0378
JM9	1995.00	1292.11	3.89	35.167	0.0137

* Water gashing through a cavity intersected by the bore hole

Figure5: Pumping test at borehole MJ7

Fugure6: Pumping tests in borehole MJ8

WATER QUALITY TESTS

Before the pump tests could be done samples of the water in each borehole were taken for analytical test to determine the quality and compare with the set limits by WHO and Zambia Environmental Management Agency. The tests were done at the Copperbelt University Environmental laboratory.

The table below gives the results of the water quality tests. From the table it is evident that the Dissolved 'Fe' are slightly elevated in boreholes No. JM3, JM7 and JM9. The cause of 'Fe' elevation is not deduced, this could mean that acidic water from the tailings could be responsible for the increase in the dissolved iron in the ground water around these boreholes. However this cannot be ascertained as pH values indicate otherwise and that that intervention measures of covering the tailings dumps base with HDPE and liming are working (Table3).

Table3: Water quality monitoring average results for 2012

B/Hole No.	pH	T Cu	DCu	T Co	DCo	TMn	DMn	TFe	DFe	TNi	DNi	S/S	D/S.	SO_4^{2-}
JM 1	7.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.6	0.5	<0.1	<0.1	6	530	470

JM 2	7.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	0.3	<0.1	<0.1	9	668	472
JM 3	7.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.9	2.4	<0.1	<0.1	10	420	250
JM 4	7.2	<0.1	<0.1	<0.1	<0.1	0.3	0.2	1.0	0.8	<0.1	<0.1	4	286	205
JM5	7.4	<0.1	<0.1	<0.1	<0.1	0.5	0.3	1.3	1.0	<0.1	<0.1	4	230	194
JM 6	7.9	<0.1	<0.1	<0.1	<0.1	0.2	0.1	1.2	1.1	<0.1	<0.1	4	311	287
JM 7	7.5	<0.1	<0.1	<0.1	<0.1	2.1	2.0	3.4	2.8	<0.1	<0.1	6	273	232
JM 8	7.3	<0.1	<0.1	0.2	0.1	0.1	<0.1	0.2	0.1	<0.1	<0.1	9	310	246
JM9	7.6	<0.1	<0.1	<0.1	<0.1	2.1	1.1	2.9	1.8	<0.1	<0.1	9	380	325
WHO - TRADE	**6.0 – 9.0**	**1.5**		**1.0**		**1.0**						**100**	**3000**	**1500**
LDW	**6.5 – 9.0**		**1.0**		**0.5**		**0.7**		**1.5**			**100**	**1500**	**600**

Figure7: Water sampling – Borehole JM8

DISCUSSIONS

The studies conducted indicate that the flow of water in this area is west east more in line with the geological setting. The gradient is very low such that the flow of water is by oozing. The pump tests have indicated low velocities of the ground water. This can be attributed to the type of soil found around the Tailings Dumps (Lateritic clay silt).

All the holes except JM 7 showed similarities in the water flow. The gashing of water in JM7 indicated the presence of a cavity. Cavities of this nature occur in solid rockmass. The flow velocity of water is higher in the cavities. This could be the source of concern if some pollutants can get to the bedrock. The transmission of pollutants could be wide spread in a short time. However as it stands, the low permeability of the lateritic soils below the tailings dumps helps in slowing down the rate of pollution and in most cases the pollutants are trapped in the soil where they undergo degeneration over a period of time.

Originally, borehole No JM5, was said to have been polluted possibly from tailings dump No. 8 on the eastern side or refuse dump on the western side. However, this borehole after being flashed, there has been no indication of fresh contamination. This indicates that contaminating clay rich soil is difficult as the clay acts as a natural filter. The low levels of coefficient of permeability indicate how slow the water moves in the clay rich soils. Under natural conditions without any induced draw, water will move very slowly and its movement will only be induced by seasonal changes.

Study reviewed that the general water flow direction in the subsurface soils is West – East. This seems to be controlled by the natural geological structure (structural control of the Lufilian arc). This flow direction was obtained some 5Km near hybrid poultry farm in a similar study carried out by NFC – Africa Mining on the new project – South East orebody.

The flow speeds in ground water was found to be 0.00718m/day to 0.0137m/day. This seems fairly consistent with theoretical values. At this velocity, the lateral extent of pollution if it occurs, will be slow and could take 300years to cross the 1.0 Km distance if there is no induced flow as a result of pumping in a well within proximity.

CONCLUSIONS

The study revealed the following:

a) The general flow direction of ground water with Sino Metals Leach (Z) Limited dump operational area is from West to East. (West – East flow).
b) The average permeability for the soils is between 0.00718m/day to 0.0137m/day.
c) Some water may be flowing through fissures or rock cracks in the soil or rock below at much faster velocity as revealed in Bore hole MJ7 (0.693m/s).
d) Generally, unless the water finds a geological fissure or crack, dispersion of any pollutants is very slow. However, in the event that an active bore hole (pumping water on a daily basis) dispersion may be increased through increased velocity of water flow due to a negative pressure created by a pumping well.
e) Water quality monitoring shows that the acidic waters from the tailings is not reaching the subsurface soil.

RECOMMENDATIONS

Due to limited time, the dye cast test could not be done. It is therefore, recommended that the test be done in future to check the natural flow rate and mode of diffusion or dispersion of the dye (due representing pollution dispersion).

Given that the flow rates are within the theoretical values, the pollution of the soil from the tailings effluent is possible. It is recommended that pre-emptive intervention measures are done before the tailings water effluent reaches the soil. These should include:

- Covering the base of a new tailings dump with HDPE membrane must be done to prevent seepage of acidic waters to the underlying soil or ground water.
- Liming of the tailings discharged from the leach plant should be done to neutralize the tailings before disposal.

Figure8: Recommended HDPE lining for new tailings dumps (TD7)

REFERENCES

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APPENDIX

CO-EFFICIENT OF PERMEABILITY CALCULATION

The calculation of coefficient of permeability 'K' was done after the determination of relevant permeability parameters. The parameters involved were:-

a) Borehole recovery time – ∇t

b) Borehole diameter – D (internal)

c) h_1 and h_2– ground water levels in the borehole.

Though the recovery involved inflow of water into the borehole radically, the value calculated can be related to unidirectional flow. The values obtained were as anticipated in the type of soil the tests were carried out. The type of soil is lateritic clayey silt sand. The component of Clay is in excess of 28%. This amount of clay influences the permeability of the soil.

The total numbers of holes tested were five (05) out of the nine (09) holes available as logistical problems did not allow tests to be done in the other four (04) holes namely: JM 1, 2, 3 and 6. Below are the calculations results from the pump tests.

a) **BOREHOLE No. JM 4**

$K_1 = \frac{2.303\,d}{(t_2 - t_1)} \log\left(\frac{h_1}{h_2}\right)$

$(t_2 - t_1) = 34.417$min

D = 0.15m

h_1 = 1309.175m

h_2 = 1307.175m

$$\therefore K = 2.303x\frac{D.15}{34.417}x\log\left(\frac{1309.175}{1307.175}\right)$$

= 0.01003719 x 0.00066397

K = 6.664 x 10^{-6} m/min

K = 4.0 x 10^{-4} m/hr

K = 0.0096m/day

b) **BOREHOLE No. JM 5**

$K_1 = \frac{2.303\,d}{(t_2 - t_1)} \log\left(\frac{h_1}{h_2}\right)$

$(t_2 - t_1)$= 26 minutes

h_1 = 1308.29m

h_2 = 1307.16m

$$K = 2.303x\frac{0.15}{26}x\log\left(\frac{1308.29}{1307.16}\right)$$

= 0.013287 x 0.00037527

K = 4.986 x 10^{-6} m/min

K = 2.99 x 10^{-4}m/hr

K = 0.00718m/day

c) **BOREHOLE No. JM 7**

$K_1 = \frac{2.303d}{(t_2-t_1)} \log\left(\frac{h_1}{h_2}\right)$

(t_2-t_1) = 2.4min
D = 0.15m
h_1 = 1301.247m
h_2 =1291.247m

$$\therefore K = 2.303x\frac{0.15}{2.4}x\log\left(\frac{1301.247}{1291.247}\right)$$

= 0.1439375 x 0.003350415
K = 4.8225 x 10^{-4} m/min
K = 0.0289m/hr
K = 0.694m/day ?Water flowing through a crack (cavity).

d) **BOREHOLE No. JM 8**

$K_1 = \frac{2.303d}{(t_2-t_1)} \log\left(\frac{h_1}{h_2}\right)$

(t_2-t_1) = 48.53min
D = 0.15m
h_1 = 1299.74m
h_2 = 1288.74m

$$\therefore K = 2.303x\frac{0.15}{48.53}x\log\left(\frac{1299.74}{1288.74}\right)$$

= 0.007118 x 0.003691176
K = 2.6273 x 10^{-5} m/min
K = 1.576 x 10^{-4} m/hr
K = 0.0378m/day

e) BOREHOLE No. JM 9

$K_1 = \frac{2.303d}{(t_2-t_1)} \log\left(\frac{h_1}{h_2}\right)$

(t_2-t_1) = 35.167 minutes
D = 0.15m
h_1 = 1295.00m
h_2 = 1292.11m

$$K = 2.303x\frac{0.15}{35.167}x\log\left(\frac{1295.0}{1292.11}\right)$$

K = 0.009823 x 0.00097
= 9.531 x 10^{-6}m/min
= 5.718m/hr
= 0.0005718m/sec
K = 0.0137m/day