J-948-02

HART CROWSER & associates inc.
GEOTECHNICAL CONSULTANTS

March 29, 1983

Kaiser Aluminum & Chemical Corporation
Mead Works
P.O. Box 6217
Spokane, Washington 99207

Attn: Mr. Dale Schmidt

Re: Groundwater Contamination Potential from Uncovered Pot-Lining Waste at KACC Mead

Dear Mr. Schmidt:

This letter presents our conclusions and a summary of our evaluations concerning the potential for contamination of groundwater by uncovered pot-lining waste located on the Mead Plant. Our analysis of the available data indicates that it is highly unlikely that the uncovered pot-lining represents a significant source (or potential source) of contamination to the underlying aquifer from natural precipitation for the following reasons:

- Natural recharge from precipitation is too low to allow significant migration of cyanide to the water table. We estimate that average natural recharge is likely less than 0.1 inches per year.

- The data indicates that the probable downward contaminant migration average rate is less than 0.2 feet per year.

- These conclusions are based on: 1) evaluation of unsaturated hydraulic conductivities based upon laboratory analyses of soil samples obtained from borings completed on the plant site; 2) previous work completed by Crosby et al (1968, 1971a, 1971b) who concluded that recharge from incident precipitation in the Spokane Valley was highly unlikely; 3) observed A-zone aquifer cyanide concentrations and a mass balance analysis. Aquifer cyanide concentrations of water samples taken from wells located down-gradient of the uncovered pot-lining do not significantly increase as compared to water samples taken from up-gradient wells. The mass balance analysis indicates that at higher recharge rates and downward migration velocities, increases of greater than 100 ppb total cyanide would be expected.

- Sampling of soil beneath the uncovered pot-lining and analyses for soil cyanide concentration indicate that cyanide has moved downward. However, it is highly likely that this movement was caused by man-induced recharge such as diversion of storm-runoff into the area coupled with past infiltration of water from Tharp Lake and the sludge bed.

The results of field sampling of soil beneath the pot-lining and a brief summary of the approach and analyses used in our evaluations are presented below.

Results of Field Sampling of Soil Beneath the Uncovered Pot-Lining

The uncovered pot-lining waste is situated over approximately a 200 x 200 foot area between the sludge bed and asphalt covered pile (Figure 1). A boring (HC-18) was completed to evaluate the geology, soil moisture conditions and soil cyanide concentrations beneath the pot-lining. The results are presented in Figure 2.

The data obtained from HC-18 indicate that the soils and soil moisture conditions are typical for the Mead Plant site. The soils consist predominantly of fine to coarse sand interbedded with relatively thin silt layers, and the moisture contents range from 2 to 19 percent by weight. The finer grained silts have a moisture content greater than 10% while the sands have a moisture content between 2 and 4 percent (by weight).

The sampled depth interval in HC-18 can be grouped into four zones based upon the distribution of soil cyanide concentrations:

Zone Number	Depth	Average Soil Cyanide Concentrations (ug/g)
I.	0 - 20	512
II.	20 - 59	136
III.	59 -125	22
IV.	125 -152	2

The data indicates that cyanide has migrated downward beneath the area. It is our opinion that this migration was caused by plant activities (such as diversion of runoff into the area, and past infiltration of water from the sludge bed and Tharp Lake) which caused recharge to be significantly greater than what could be expected from natural precipitation.

The predominant factor that controls the amount of contamination moving towards the water table from the uncovered pot-lining is recharge. We estimate that the majority of all recharge within the northwest portion of the plant has been eliminated by remedial actions such as stopping sewage effluent disposal into the sludge bed and abandoning Tharp Lake.

The distribution of soil moisture beneath the Plant indicate that some natural recharge probably occurs. Analyses of several hundred soil samples from borings completed in the vicinity for moisture content show a relatively constant soil moisture content with depth. If no recharge were to occur it would be expected that soil moisture would decrease at greater distances above the water table.

The amount of unsaturated zone water flow moving towards the water table, in the deeper portion of the soil colume, should be representative of the long-term recharge caused by natural precipitation under the prevailing climatic conditions. Seasonal precipitation events will cause the near-surface soil moisture contents to fluctuate. These fluctuations however, will be "dampened" with increasing depth and will likely be undetectable below a relatively shallow depth. As a moisture front moves downward, moisture begins to be distributed throughout the soil colume with the actual change in soil moisture being significantly less with depth.

If several hydraulic properties are known for the soil colume the amount of unsaturated zone water flow towards the water table can be evaluated. In our opinion, this flow should be representative of the current recharge conditions beneath the Mead Plant.

APPROACH AND RESULTS

Our approach to evaluate recharge and the potential for contaminant migration was as follows:

Step 1: We calculated migration velocity and the amount of water and cyanide flowing towards the water table using soil and A-zone aquifer data over a range of unsaturated zone hydraulic conductivities.

Step 2: We then evaluated the potential for aquifer contamination by comparing the results of step 1 with previous recharge estimates, and field and laboratory data.

The results of the Step 1 analyses are tabulated in Table 1 while the pertinent comparisons are discussed below. A discussion of how the various hydraulic properties were arrived at is presented in Attachment A.

TABLE 1 - STEP 1 RESULTS

	Soil Hydraulic Conductivity (cm/sec)		
	10^{-7}	10^{-8}	10^{-9}
Steady State Flow Towards Water Table (liters/day)	300	30	3
Flow Velocity Towards Water Table (feet/year)	2	0.2	0.02
Recharge Rate (inches/year, per square foot of soil)	1	0.1	0.01
Increase in Cyanide Concentration A-zone Aquifer (ug/l, ppb)*	1900	190	19

*Assumes a soil cyanide concentration of 18 ug/g. ⇒ 480,000 ppb in H_2O

In our opinion the estimated results for the unsaturated zone hydraulic conductivities of 10^{-8} to 10^{-9} centimeters per second (cm/sec) are representative for the conditions beneath the Mead Plant. This indicates that natural recharge to the aquifer should be less than 0.1 inches per year and that downward migration of cyanide should be at a rate less than 0.2 feet per year.

This conclusions is supported by the following:

1) The range of hydraulic conductivity values for various moisture contents estimated using the method of Jackson (1972). As shown on Figure 3 the hydraulic conductivity for two soil samples taken from beneath the Mead facility at existing soil moisture contents of 6% by volume is less than 10^{-9} centimeters per second.

2) Previous work completed by Crosby, et.al. (1968, 1971a, 1971b). Their studies indicated very low soil moisture conditions (similar to beneath Mead Plant) exist beneath much of the Spokane Valley. They concluded the soil moisture penetration depth beneath drainfields could be no more than 25 to 50 feet and that groundwater recharge through incident precipitation on the outwash plain is impossible or very unlikely. It was suggested that even if all the mean annual precipitation of about 17.5 inches were to fall and infiltrate at a single time then a significant increase in flow would not occur below a depth of about 50 feet.

3) A-zone aquifer cyanide concentration data for wells immediately down-gradient of the uncovered pot-lining do not show significant increases as compared with wells up-gradient. Well ES-9 (up-gradient, Figure 1) typically ranges in concentration from 60 to slightly over 100 ppb total cyanide while down-gradient well HC-2A (located on Figure 1) now shows a total cyanide concentration of less than 100 ppb. A mass balance analysis to evaluate the probable range in total cyanide concentrations that could be expected to be found in A-zone aquifer water, indicates that at hydraulic conductivities greater than 10^{-8} cm/sec increases in cyanide concentrations should be observable. We estimate these increases would be on the order of greater than 100 ppb total cyanide even if a soil cyanide concentration of 1.0 microgram per gram (ug/g) is considered (in Table 1 a soil cyanide concentration of 18 ug/g was used).

4) We do not believe that past estimates of recharge (3 to 6 inches per year) using the Thornthwaite method (Robinson and Noble, 1978; Todd, 1975) are realistic. This method is limited, especially in deep aquifer situations, because it does not incorporate deep soil moisture conditions. It should also be noted that the Thornthwaite method may over estimate recharge by 100 percent or more as compared to other methods which use similar data (Dunne and Leopold, 1978).

The above discussion presents a summary of a relatively complex analysis. We would be glad to answer any questions you may have or furnish you with any additional details of the analysis you may require.

Sincerely,

HART-CROWSER & ASSOCIATES, INC.

Matthew G. Dalton

MATTHEW G. DALTON
Senior Project Hydrogeologist

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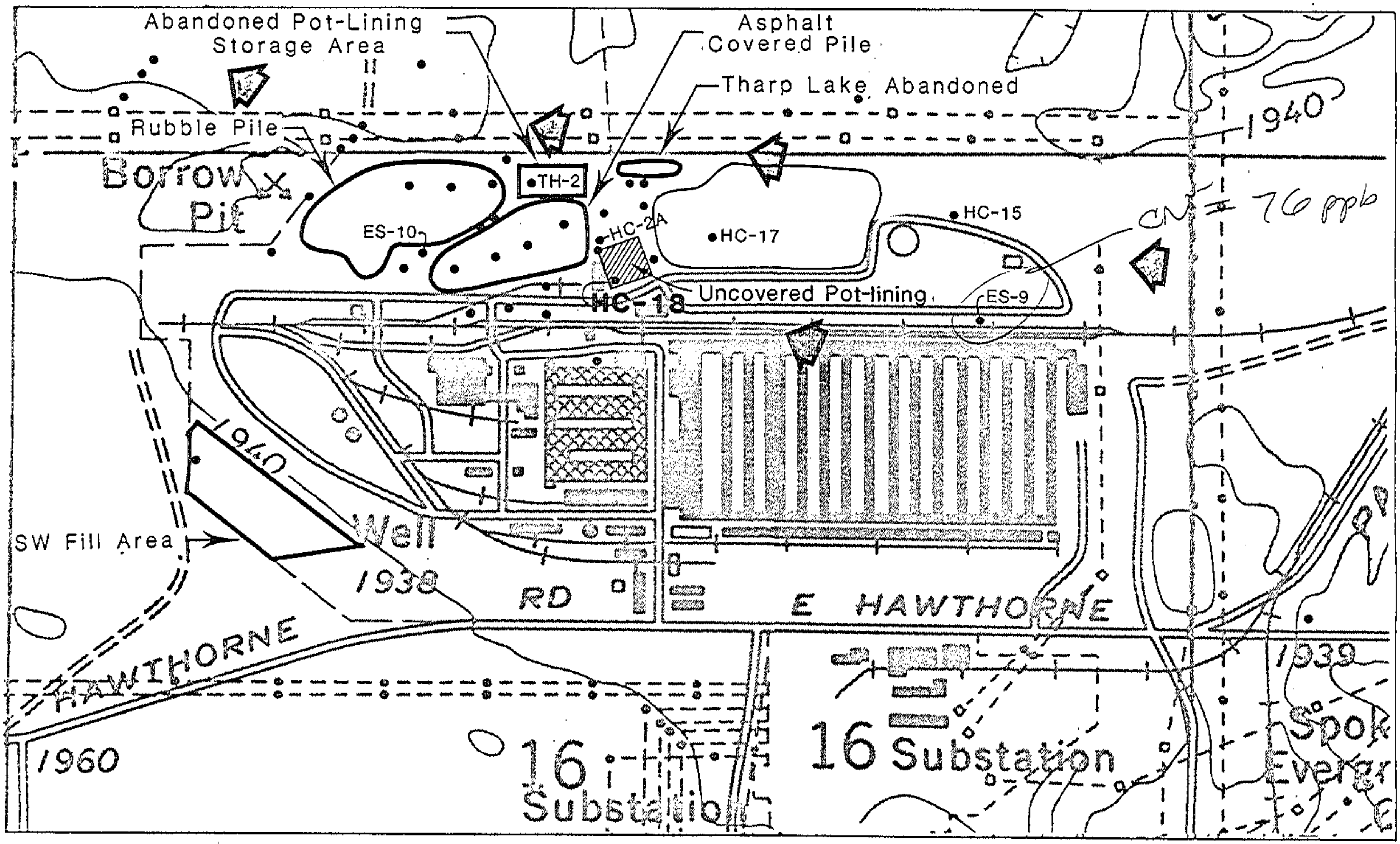
Enclosures: Figures 1 through 3
Attachments A and B

Well and Uncovered Pot-lining Location Map



Dartford and Mead Quadrangles

Showing Generalized Ground Water Flow Direction

Scale 1" = 624'

Generalized Ground Water Flow Direction

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Figure 1

Boring Log and Construction Data for Well HC-18

Geologic Log

Depth In Feet

Ground Surface Elevation in Feet

Depth (ft)	Description
0	Potlining
~6	Damp, dark brown, silty, fine to coarse SAND.
~10	Damp, brown, slightly silty to clean, fine to coarse SAND, ammonia odor.
~38	Damp, brown, silty, fine SAND to fine, sandy SILT, ammonia odor.
~45	Damp, brown, fine to medium SAND, ammonia odor.
~60	Damp, brown, clayey SILT.
~64	Damp, brown, fine to coarse SAND.
~73	Damp, brown, slightly silty, fine to coarse SAND.
~78	Damp, brown, fine to coarse SAND, slight ammonia odor.
~85	Damp, brown, fine to medium SAND, slight ammonia odor.
~127	Damp, brown, fine SAND with trace of gravel.
~133	Damp, brown, fine to coarse SAND.
~140	Damp, brown, fine to medium SAND.
~145	Damp, brown, slightly silty, fine SAND.
~149	Damp, brown, very silty, fine SAND to very fine sandy SILT.
~153	Damp to wet, brown, silty, fine to medium SAND.

Bottom of Boring at 157 Feet.
Completed 10/29/82.

Well Design

No Observation Well Installed

Qualitative Chemical Concentrations at Sampled Depths

W.C. %	CN^-, µg/g	F, %	
19	171	4	
9	761	0.150	1000
6	309	0.200	2000
6	635	0.012	120
5	688	0.005	50
4	50	<.001	10
4	180	0.001	10
3	137	0.001	10
10	191	0.037	370
3	63	0.013	130
3	65	0.005	50
3	139	0.003	30
6	140	0.073	730
4	164	0.049	490
4	144	0.010	100
4	173	0.006	60
18	186	0.235	2,350
3	5	0.015	
3	9	0.008	
3	8	0.050	
2	6	0.020	
3	11	0.014	
6	14	0.008	
4	8	0.006	
3	9	0.006	
3	14	0.009	
5	25	0.009	
5	11	0.006	
4	32	0.009	
3	35	0.006	
3	34	0.006	
3	38	0.004	
4	55	<0.001	
4	54	<0.001	
4	3	<0.001	
2	2	<0.001	
3	4	<0.001	
4	1	<0.001	
18	3	<0.001	
29	1	0.002	
12	2	0.001	

NOTES: 1. Soil descriptions are interpretive and actual changes may be gradual.
2. Water Level is for date indicated and may vary with time of year.
ATD:At Time of Drilling

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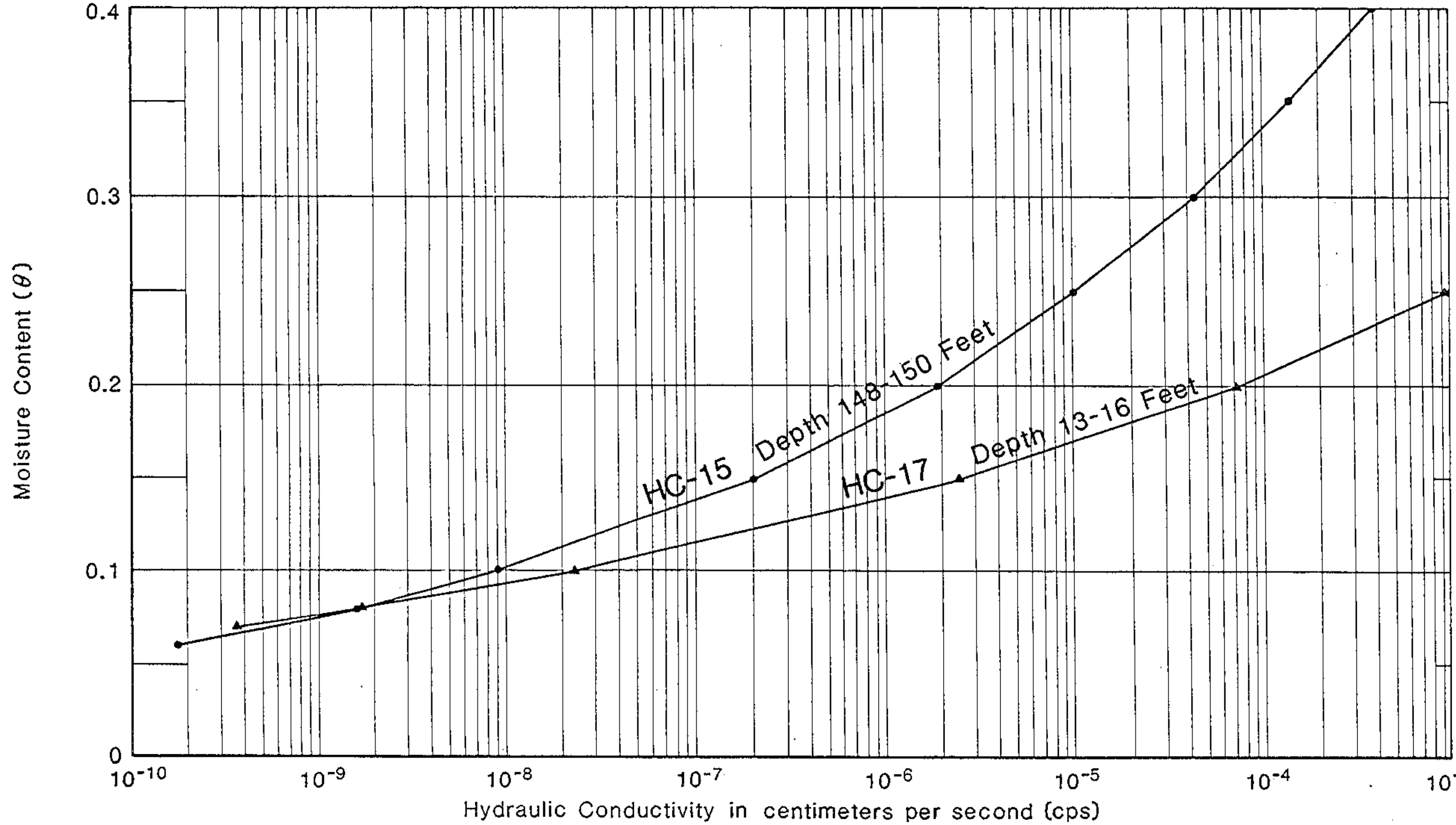
Figure 2

Hydraulic Conductivity vs Moisture Content for Selected Samples



1. Curves were constructed using the method of Jackson (1972) where $K_\theta = K_S(\theta/\phi)^{2b+2}$ (For discussion of method, see text)
2. Saturated Hydraulic Conductivity ($\theta = 0.4$) were determined in the laboratory to be: HC-15 $K_S = 3.8 \times 10^{-4}$ cps HC-17 $K_S = 2.2 \times 10^{-1}$ cps
3. Average soil moisture content below HC-18 is $\theta = 0.06$

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Figure 3

ATTACHMENT A

Summary of Analyses

The following is a discussion of the approach and methods used to evaluate the properties of soil beneath the Mead Plant. The purpose of these evaluations is to assess the potential for uncovered pot-lining to contaminate groundwater. The results are presented in the accompanying letter.

Steady State Flow Towards Aquifer

Steady state flow towards the aquifer was estimated using Darcy's Law:

$$Q_{uz} = K(\theta)i\ A \quad \text{where} \qquad (1)$$

Q_{uz} = unsaturated zone flow towards aquifer

$K(\theta)$= Hydraulic conductivity (assumed)

i = Hydraulic gradient (assumed to be 1.0)

A = Area (200 by 200 feet)

Flow Velocity Towards Water Table

The flow velocity was evaluated using a form of Darcy's Law:

$$\nu = \frac{K\theta i}{\theta} \quad \text{where} \qquad (2)$$

ν = Flow velocity

$K(\theta)$= Hydraulic conductivity

i = Hydraulic gradient (assumed to be 1.0)

θ = Volumetric water content (estimated to be 0.06 based upon moisture content determinations of soil samples taken from HC-18 and other borings)

Recharge Rate

The recharge rate was estimated by dividing the flow volume moving towards the water table by 40,000 square feet (200 feet x 200 feet) and accounting for differing units.

Increase in Cyanide Concentration, A-Zone Aquifer

This estimate was made using a mass balance analysis. The important factors in the analysis are:

- o A-zone aquifer flow volumes beneath the uncovered pot-lining (Q A-zone = 20,875 gallons per day)

- o Unsaturated flow volume moving towards the water table (listed in Table 1).

- o Cyanide concentration of soil pore water migrating towards the water table (cpw = 480,000 ppb total CN).

A-zone aquifer flow volumes were estimated using a form of Darcy's Law:

$$Q_{A\text{-zone}} = Ti\ W$$ where

$Q_{A\text{-zone}}$ = A-zone aquifer flow volumes

T = A-zone aquifer transmissivity (estimated to be 41,750 gallons per day per foot from pumping tests of ES-9 and ES-10)

i = hydraulic gradient (estimated to be 0.0025 from water level measurements made in monitoring wells)

W = Width (assumed to be 200 feet)

The total cyanide concentration of soil pore water was estimated using:

$$C_{pw} = \frac{Scn}{V}$$ where

C_{pw} = Cyanide concentration of soil pore water

Scn = Soil cyanide concentration (18 microgram per gram of soil)

V = Volume of water (0.0375 milliliters per gram) of soil at a soil moisture of 0.06 and a soil density of 1.6 grams per cubic centimeter).

Using these values we calculate a soil pore water total cyanide concentration of about 480,000 micrograms per liter.

The increase in A-zone cyanide concentration for a given hydraulic conductivity was determined from the following equation:

$$\Delta C_{A\text{-zone}} = \frac{(Q_{uz})\ (C_{pw})}{Q_{A\text{-zone}}}$$ where

$\Delta C_{A\text{-zone}}$ = Increase in A-zone cyanide concentration

Q_{uz} = Unsaturated zone flow volume towards water table

C_{pw} = Cyanide concentration of soil pore water

$Q_{A\text{-zone}}$ = A-zone aquifer flows

Unsaturated Zone Hydraulic Conductivity

The unsaturated zone hydraulic conductivity was evaluated using the method of Jackson (1972). In this method the conductivity can be estimated using the equation:

$$K\theta = Ks \left(\frac{\theta}{\phi}\right)^{2b + 2}$$ where

$K\theta$ = hydraulic conductivity at a given moisture content θ

Ks = saturated hydraulic conductivity

θ = Volumetric moisture content

ϕ = Porosity

b = Constant obtained by laboratory determination of soil moisture retention curves

Soil moisture retention curves and saturated hydraulic conductivity were determined for two soil samples, (a third is still in preparation) taken from borings completed on the Mead Plant site. The moisture retention curves were constructed from data obtained using a porous plate extractor by initally saturating the samples, applying suctions ranging from 0.2 to 13 bars and for a given suction determining a resultant moisture content. The saturated hydraulic conductivities were determined using a conventional laboratory permeameter.

The samples were compacted to a density of 1.60 grams per cubic centimeter which we consider representative of the natural site soils. We estimate at this density the soils have an approximate porosity of 0.40. Pertinent data used in our calculations are listed below. The hydraulic conductivities for various moisture contents are presented as curves in Figure 3.

Boring Number	Depth	Ks	b
HC-15	148-150	3.8×10^{-4} cm/sec	2.85
HC-17	13 - 16	2.2×10^{-1} cm/sec	4.80

ATTACHMENT B

REFERENCES

Crosby, J.W., D.L., Johnstone, C.H. Drake and R.L. Fenton, 1968, Migration of Pollutants in a Glacial Outwash Environment: Water Resources Research v.4 No. 5 pp. 1095-1114.

Crosby, J.W., D.L. Johnstone and R.L. Fenton, 1971A, Migration of Pollutants in a Glacial Outwash Environment 2: Water Resources Res. v. 7 No. 1 pp. 204-208.

Crosby, J.W., D.L. Johnstone and R.L. Fenton, 1971B, Migration of Pollutants in a Glacial Outwash Environment 3: Water Resources Research v. 7 n. 3 pp. 713-720.

Jackson, R.D., 1972, On the Calculation of Hydraulic Conductivity: Soil Sci Soc Am. Proc., 36, pp. 380-382.

Robinson & Noble, 1979, Status Report of Aquifer Contamination at Kaiser Aluminum and Chemical Corporation, Mead Works, through May 1, 1979.

Todd, D.K., 1975, The Effect of Applied Surface Waters on Ground Water Quality in the Spokane Valley prepared for Water Resources Study Metropolitan Spokane Region, Dept. of the Army, Corpos of Engineers and Kennedy-Tudor Consulting Engineers.