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COMPUTATION COVER SHEET

Client: **IUC** Project: **White Mesa Mill** Project/ Proposal No.: Task No. **SC0349**

Title of Computations **ANALYSIS OF SLIMES DRAIN**

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No.	Sheet	Date	By	Checked by	Approval

Written by:	**M. Lithgow**	Date:	**03/16/07**	Reviewed by:	**G. Corcoran**	Date:	**03/26/07**
Client: **IUC**	Project:	**White Mesa Mill – Cell 4A**	Project/ Proposal No.:	**SC0349-01**	Task No.:	**04**	

PURPOSE AND METHOD OF ANALYSIS

The purpose of this calculation package is to demonstrate that the proposed "slimes drain system" will dewater the tailings at the site within a reasonable time.

Fluid flow rate in porous media will be evaluated using Darcy's law.

ASSUMPTIONS

- This project involves the construction of a 42 acre double lined tailings cell (Cell 4A) that is approximately 42 feet deep at its deepest point and 26 feet deep at the shallowest point with an average depth of 34 feet. The liquids level in the cell will be kept a minimum of 3 feet below the top of the berm (free-board). Therefore, the maximum depth of liquid in the cell will be 39 feet at the start of dewatering.
- The cell will be filled with -28 mesh tailings, largely consisting of medium to fine sands, silts and clays.
- The proposed slimes drain system will consists of a series of strip drains (geotextile wrapped HDPE core, 1" thick, 12" wide, with a transmissivity of 29 (gal/min/ft), which connect to a 4" diameter PVC header pipe.
- The slimes drain spacing will be 50' and will be continuous across the base of the cell (Attachment A).
- The average slimes drain lateral has a tributary area of approximately 600 ft * 50 ft = 30,000 square feet.
- A PVC pipe and gravel header will be installed to collect the liquids from the laterals and convey the liquid to the sump for removal.
- The average saturated hydraulic conductivity of the tailings is 1 x 10^{-5} cm/s (3.28 x 10^{-7} feet/sec). It is anticipated that the tailings range in size from medium to fine sand with an average saturated hydraulic conductivity of 0.1 cm/sec to a silty clay with an average saturated hydraulic conductivity of 1 x 10^{-7} cm/sec (Cedergren, 1989, Attachment B, 1/2). Thus, a conservative

hydraulic conductivity of 1 x 10^{-5} cm/sec was selected for the tailings saturated hydraulic conductivity.

- Porosity of the tailings is 0.35 and is based on an average value of the maximum and minimum porosity of a silty sand. (Holtz & Kovacs, 1981, Attachment C)
- The permeability of the tailings is isotropic.
- Darcy's law will be used to compute groundwater flow velocities.

CALCULATIONS

The geometry illustrated below was used to compute the emptying time for the proposed slimes drain system.

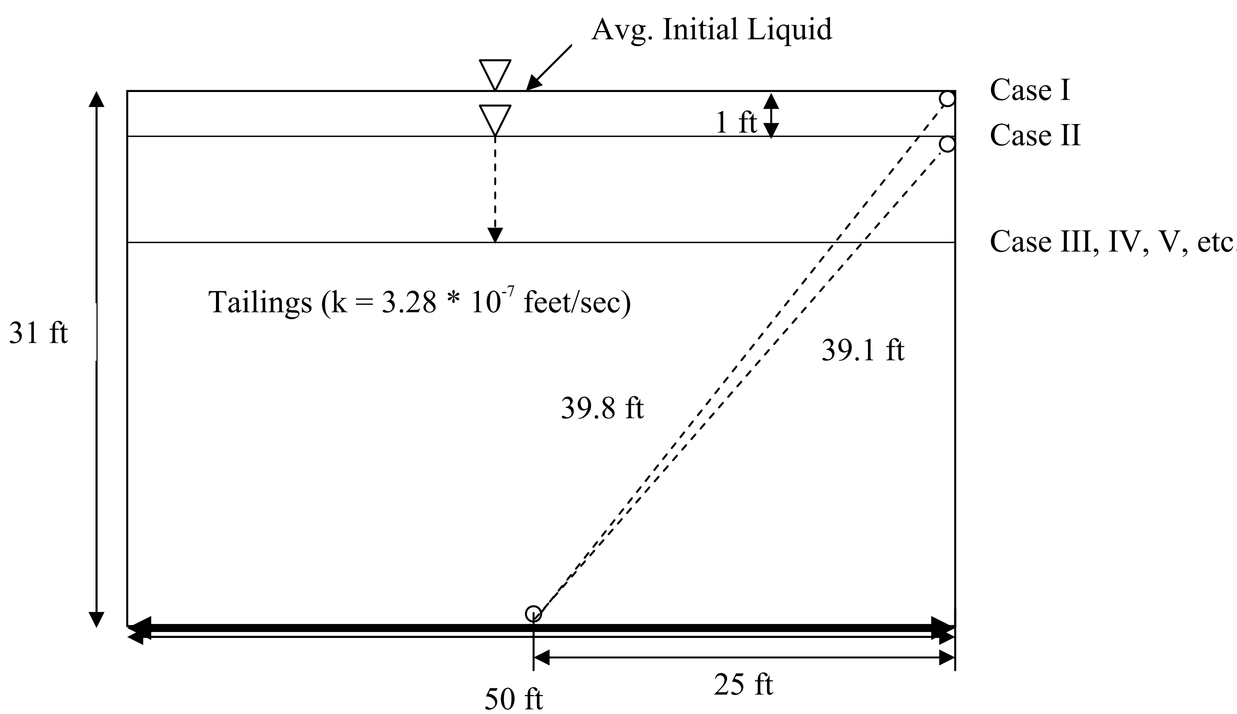

Figure 1 – Geometry for Slimes Drain Calculations

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Calculate the flow velocity along the longest flow path using Darcy's law:

$$V_S = \frac{k \times i}{n_e}$$ (Cedergren, 1989, Attachment B, 2/2)

where:

V_s = Darcy seepage velocity

k = hydraulic conductivity = $3.28 \times 10^{-7}\ \frac{ft}{\sec}$

i = gradient along flowpath = $\frac{dh}{dl} = \frac{31}{39.8} = 0.78$ (Case I)

n_e = effective porosity = 0.35

$$V_s = \frac{3.28 \times 10^{-7} \frac{ft}{\sec} \times 0.78}{0.35} = 7.31 \times 10^{-7} \frac{ft}{\sec}$$

Calculate the emptying time at this velocity:

$$\text{Time} = \frac{L}{V_s}$$

where:

V_s = Darcy seepage velocity = $7.31 \times 10^{-7} \frac{ft}{\sec}$

L = flowpath length = 39.8 ft

$$\text{Time} = \frac{39.8\, ft}{7.31 \times 10^{-7} \frac{ft}{\sec}} = 5.44 \times 10^{7} \sec$$

$$= 5.44 \times 10^{7} \sec \times \frac{1\ day}{86{,}400 \sec} \times \frac{1\ year}{365\ days} = 1.7\ years$$

Emptying time = 1.7 years at the head and hydraulic conditions for Case I only.

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This value is the calculated emptying time based on average conditions at a liquid height of 31 feet. As the liquid level drops in the cell, the flow path length will change and the hydraulic gradient will change. These changes will result in slower velocities as the cell liquid elevation decreases.

Tables 1, 2, and 3 depict the calculations for the maximum (39 feet), average (31 feet), and minimum (23 feet) cell liquid depth, respectively. The results of the average depth calculations indicate that the proposed slimes drain system will allow the tailings contained in Cell 4A to drain within approximately 4 years.

Evaluate the flow capacity of the proposed strip drains and compare this to the demand imposed on the drains by the rate of dewatering predicted above.

The total volume to be drained by any one strip composite (with an average length of 600 feet), Q_R, is:

$$Q = kiA$$

$$Q = (3.28\times10^{-7}\ \frac{ft}{\sec})(0.78)(50\,ft\ x\ 600\ \ ft)$$

$$Q = 0.0072\,\frac{ft^3}{\sec}\times\frac{60\sec}{1\min}\times 7.48\,\frac{gal}{ft^3}$$

$$Q = 3.44\ gpm$$

For this calculation we will assume that the strip drains have a flow rate of 29 gallon per minute per foot (Attachment D, GDE Multi-Flow, 2006), a width of 12" and that flow is occurring under a gradient of 0.01.

Design Flow rate of strip drains:

$$q = \Theta i$$

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where:

q = flowrate per unit width

$$i = \frac{dh}{dl} = 0.01$$

Θ = transmissivity = 29 gpm/ft

To account for detrimental effects on the geonet such as chemical clogging, biological clogging, installation defects, and creep, partial factors of safety were used to reduce the strip drain transmissivity. Using recommended partial factor of safety values from Koerner (1999) (Attachment E, 2/4), the reduced transmissivity is calculated as follows:

$$\Theta_{allow} = \Theta_{ult}\left[\frac{1}{FS_{IN} \times FS_{CR} \times FS_{CC} \times FS_{BC}}\right]$$

where:

$\square_{allow}$ = allowable flow

$\square_{ultimate}$ = calculated value of flow

FS_{IN} = factor of safety for installation, 1.5 (CQA performed during installation)

FS_{CR} = factor of safety for creep, 2.0

FS_{CC} = factor of safety for chemical clogging, 2.0

FS_{BC} = factor of safety for biological clogging, 1.0 (low pH precludes biological activity)

The factors of safety are used to calculate the allowable transmissivity:

$$\Theta_{allow} = 29\,\frac{gpm}{ft}\left[\frac{1}{1.5 \times 2.0 \times 2.0 \times 1.0}\right] = 4.83\,\frac{gpm}{ft}$$

Using this transmissivity value, the average factor of safety for flow in the strip composite is estimated to be as follows:

$$FS = \frac{Q_D}{Q_R} = \frac{4.83\ gpm}{3.44\ gpm} = 1.4 \quad \text{(Acceptable)}$$

The average allowable flow rate is larger than the average maximum flow rate, even with the built-in partial factors of safety. Furthermore, as indicated on Tables 1, 2, and 3, the calculated flow rate within the strip drain decreases with time, which further increases the factor of safety.

Calculate the minimum required AOS and permittivity for filtration geotextile component of strip drain

The geotextile serves as a filter between the strip composite core and the tailings material. The geotextile minimizes fine particles of the tailings material from migrating into the strip composite, yet allows water to penetrate. Migration of fine particles would have the adverse effect of decreasing the transmissivity of the strip composite layer.

To be conservative in these calculations, the tailings material soil is assumed to consist of more than 20 percent clay.

The retention requirements for geotextiles can be evaluated using the chart entitled "Soil Retention Criteria for Steady-State Flow Conditions" developed by Luettich et al., (1991) (Attachment F, 1/3). This chart uses soil properties to evaluate the required apparent opening size (AOS or O_{95}) of the geotextile. Using the Soil Retention Chart, the AOS of the filter fabrics shall be:

$O_{95} < 0.21$ mm, which corresponds to sieve No. 70.

The permeability of the filter fabric must be evaluated to allow flow through the filter fabric. The following equation can be used to evaluate the minimum allowable geotextile permeability:

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$k_g > i_s\, k_s$ (Luettich et al. (1991), Att. F, 2/3)

where: k_g = permeability of geotextile (cm/s)
i_s = hydraulic gradient (dimensionless)
k_s = permeability of the tailings material (cm/s)

Hydraulic Gradient, i: Attachment F, page 3/3 from Luettich et al. (1991) lists typical hydraulic gradients for various geotextile drainage applications. In this attachment, a hydraulic gradient of 10 for liquid impoundment applications is recommended.

Soil Permeability, k_s: A permeability of 1.0 x 10^{-5} cm/s was assumed for the tailings material, as previously defined.

Therefore,

$k_g >$ $i_s\, k_s = (10)(1x10^{-5}$ cm/s)
$k_g >$ 1.0 x 10^{-4} cm/s

Koerner (1999) suggests applying partial factors of safety to the ultimate flow capacity of the geotextile to account for clogging of the geotextile. Using recommendations given in Table 2.12 on p. 150 of Koerner (1999) (Attachment E, 1/4), the following partial safety values were applied:

soil clogging and blinding:	10 (5 – 10)
creep reduction of voids:	2.0 (1.5 – 2.0)
intrusion into voids:	1.2 (1.0 – 1.2)
chemical clogging:	1.5 (1.2 – 1.5)
biological clogging (low pH precludes biological activity):	1.0 (2 – 10)

Therefore,
$k_g >$ (1.0 x 10^{-4})(10)(2)(1.2)(1.5)(1)
$k_g >$ 0.0036 cm/s

The thickness of a typical nonwoven needled punched 4 oz/yd^2 (135 g/m^2) geotextile is approximately 40 mils (0.10 cm), see Attachment G. Dividing the permeability by the thickness of the geotextile results in a required minimum permittivity of 0.036 sec^{-1}. The geotextile used in this project has a permittivity of 2.0 sec^{-1}, which is greater than the required permittivity.

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Check Pipe Flow Rate

Based on calculations from previous sections, the maximum daily flow rate to the sump is estimated to be 158 gpm (0.35 cfs) (Table 2). The capacity of the pipe is calculated based on Manning's equation for gravity flow as follows:

$$Q = \frac{1.486}{n} R_h^{2/3} S^{1/2} A = 0.35\ cfs$$

Where

n = 0.010 (Koerner (1999), Attachment E, 4/4)
S = Slope of liner (ft/ft) = 1.0 %
R_h = hydraulic radius, ft
Q = flow rate, cubic feet per second, cfs
A = flow area, sf

Assuming 4-inch pipe:

$A = \pi D^2/4$ = 12.6 sq. inches = 0.088 sf
R_h = Area ($\pi D^2/4$)/Wetted Perimeter (π D)
= D/4 = 1 in = 0.083 ft

$$Q = \frac{1.486}{0.010} 0.083^{2/3} 0.01^{1/2} 0.088\ sf = 0.28\ cfs = 112\ gpm$$

Since 112 gpm is less than the maximum required 158 gpm, this calculation shows that the 4-inch diameter slimes drain pipe is the limiting factor for dewatering the tailings in the early phase of dewatering (high flow rates). However, it does not mean that the pipe will be unable to handle this flow, but rather the pipe will require additional time to drain. The additional time needed is computed in the following section.

Effect of Maximum Pipe Capacity on Drainage Time

The maximum capacity of the pipe is 112 gpm, as computed above. Assuming the cell's total lateral length of strip drain is 27,550 feet, the flow rate, per foot of strip drain is calculated to be:

$$\text{Flow Rate} = \frac{112\ gallon}{\min} * \frac{60 \min}{1\ hr} * \frac{24\ hr}{1\ day} * \frac{1\ ft^3}{7.48\ gallon} * \frac{1}{27{,}550\ \ feet} = 0.78 \frac{ft^3}{day}$$

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The time needed to de-water first layer is:

$$Time = \frac{Volume}{Drain\ \ length\ \times\ flow\,rate} = \frac{(50x1x1x0.35)\ ft^3}{1\ ft \times 0.78\ \dfrac{ft^3}{day}} = 22.43\,day$$

The difference between the maximum daily flow rate drainage time and the maximum daily flow the pipe is able to deliver for the first foot is:

22.43 day – 15.86 day (first row of Table 2) = 6.57 days.

Therefore, the first layer will require an additional 6.57 days to drain. The calculation is repeated until the pipe's allowable flow capacity of 112 gpm is equal to the maximum flow rate from the cell (Table 2). The additional drainage time needed for each layer is added to the original drainage time of 3.7 years. The results of this analysis are shown in Table 4.

The total additional drainage time occurs over the first 15 layers and adds 63 days (0.17 years) to the computed drainage time. Including the effects of the maximum pipe capacity, the cell will take an estimated 3.9 years to drain.

Effect of Precipitation on Drainage Time

To account for the effect of precipitation added to the tailings pond, a maximum yearly precipitation event of 13.4 inches per year, as cited in the design report for the Cell 4A, is used in a further analysis. This value is very conservative as a large percentage of the precipitation will evaporate. Using a pond area of 42 acres and conservatively assuming that the maximum annual rainfall event occurs for four consecutive years and no evaporation occurs, the amount of precipitation added to the tailings pond is calculated as:

$$13.4\,\frac{inches}{year} \times \frac{1\ foot}{12\,inches} \times 42\ acres \times \frac{43{,}560\ ft^2}{1\,acre} \times 4\ year \times \frac{7.48\,gallon}{1\,ft^3} = 61{,}125{,}483\ gallons$$

The average flow rate during Cell 4A dewatering, as calculated from Table 2 is equal to 87 gpm (125,280 gallon/day).

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The time required to drain the additional volume of precipitation in the tailing is computed using the following equation:

$$Time = \frac{Volume}{FlowRate} = \frac{61{,}125{,}483\ gal}{125{,}280\,\frac{gal}{day}} = 488\ days = 1.3\,years$$

The additional time that the pond will require to empty due to precipitation is approximately 1.3 years.

Therefore, the estimated time to dewater Cell 4A will be 3.7 years (baseline) + 0.2 years (pipe limitations) + 1.3 years (conservative precipitation) = 5.2 years.

REFERENCES

Cedergren, H.R., “Seepage, Drainage, and Flow Nets,” 3rd Ed., John Wiley & Sons, Inc., 1989
(Attachment B)

Kovacs, W. and Holtz, R.D., “An Introduction to Geotechnical Engineering,” Prentice Hall, 1981.
(*Attachment C)*

GDE Control Products, Inc. November 2006. Accessed 13 March 2007 <http://www.gdecontrol.com/Multi-Flow5.html>
(Attachment D)

Koerner, R. M., “Designing With Geosynthetics,” 4th Ed., Prentice Hall, 1999.
(*Attachment E)*

Luettich, S.M., Giroud, J.P., and Bachus, R.C., (1991), “Geotextile Filter Design Manual, report prepared for Nicolon Corporation, Norcross, GA.
(Attachment F)

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Amoco Fabrics and Fibers Company, (1991), "*Amoco Waste Related Geotextiles.*" *(Attachment G)*

Table 1
Maximum Depth
Cell 4A Slimes Drain Performance Evaluation
White Mesa Mill
Blanding, Utah

Permeability (cm/sec)	Permeability (ft/min)	Drainage length (ft.)	Thickness (ft.)	Seepage Velocity (ft/min.)	Volume of Liquid (CF)	Time to dewater (min/ft)	Time to dewater (days)	Maximum Flow Rate (CF/day) per foot of lateral	Approximate Total Cell Lateral Length (ft)	Maximum Flow Rate from Cell (gpm)
1.00E-05	1.97E-05	46.3	39	4.74E-05	21,000	21,113	14.66	1.19	27,550	170.8
1.00E-05	1.97E-05	45.5	38	4.70E-05	21,000	21,295	14.79	1.18	27,550	169.4
1.00E-05	1.97E-05	44.7	37	4.65E-05	21,000	21,486	14.92	1.17	27,550	167.8
1.00E-05	1.97E-05	43.8	36	4.62E-05	21,000	21,638	15.03	1.16	27,550	166.7
1.00E-05	1.97E-05	43.0	35	4.58E-05	21,000	21,850	15.17	1.15	27,550	165.1
1.00E-05	1.97E-05	42.2	34	4.53E-05	21,000	22,074	15.33	1.14	27,550	163.4
1.00E-05	1.97E-05	41.4	33	4.48E-05	21,000	22,312	15.49	1.13	27,550	161.6
1.00E-05	1.97E-05	40.6	32	4.43E-05	21,000	22,564	15.67	1.12	27,550	159.8
1.00E-05	1.97E-05	39.8	31	4.38E-05	21,000	22,833	15.86	1.10	27,550	157.9
1.00E-05	1.97E-05	39.1	30	4.31E-05	21,000	23,179	16.10	1.09	27,550	155.6
1.00E-05	1.97E-05	38.3	29	4.26E-05	21,000	23,488	16.31	1.07	27,550	153.5
1.00E-05	1.97E-05	37.5	28	4.20E-05	21,000	23,819	16.54	1.06	27,550	151.4
1.00E-05	1.97E-05	36.8	27	4.13E-05	21,000	24,240	16.83	1.04	27,550	148.8
1.00E-05	1.97E-05	36.1	26	4.05E-05	21,000	24,693	17.15	1.02	27,550	146.0
1.00E-05	1.97E-05	35.4	25	3.97E-05	21,000	25,183	17.49	1.00	27,550	143.2
1.00E-05	1.97E-05	34.7	24	3.89E-05	21,000	25,713	17.86	0.98	27,550	140.2
1.00E-05	1.97E-05	34.0	23	3.80E-05	21,000	26,290	18.26	0.96	27,550	137.2
1.00E-05	1.97E-05	33.3	22	3.71E-05	21,000	26,919	18.69	0.94	27,550	134.0
1.00E-05	1.97E-05	32.6	21	3.62E-05	21,000	27,608	19.17	0.91	27,550	130.6
1.00E-05	1.97E-05	32.0	20	3.51E-05	21,000	28,455	19.76	0.89	27,550	126.7
1.00E-05	1.97E-05	31.4	19	3.40E-05	21,000	29,391	20.41	0.86	27,550	122.7
1.00E-05	1.97E-05	30.8	18	3.29E-05	21,000	30,431	21.13	0.83	27,550	118.5
1.00E-05	1.97E-05	30.2	17	3.17E-05	21,000	31,594	21.94	0.80	27,550	114.1
1.00E-05	1.97E-05	29.7	16	3.03E-05	21,000	33,013	22.93	0.76	27,550	109.2
1.00E-05	1.97E-05	29.2	15	2.89E-05	21,000	34,621	24.04	0.73	27,550	104.2
1.00E-05	1.97E-05	28.7	14	2.74E-05	21,000	36,458	25.32	0.69	27,550	98.9
1.00E-05	1.97E-05	28.2	13	2.59E-05	21,000	38,579	26.79	0.65	27,550	93.5
1.00E-05	1.97E-05	27.7	12	2.44E-05	21,000	41,053	28.51	0.61	27,550	87.8
1.00E-05	1.97E-05	27.3	11	2.27E-05	21,000	44,138	30.65	0.57	27,550	81.7
1.00E-05	1.97E-05	26.9	10	2.09E-05	21,000	47,840	33.22	0.53	27,550	75.4
1.00E-05	1.97E-05	26.6	9	1.90E-05	21,000	52,563	36.50	0.48	27,550	68.6
1.00E-05	1.97E-05	26.2	8	1.72E-05	21,000	58,244	40.45	0.43	27,550	61.9
1.00E-05	1.97E-05	26.0	7	1.51E-05	21,000	66,057	45.87	0.38	27,550	54.6
1.00E-05	1.97E-05	25.7	6	1.31E-05	21,000	76,177	52.90	0.33	27,550	47.3
1.00E-05	1.97E-05	25.5	5	1.10E-05	21,000	90,701	62.99	0.28	27,550	39.8
1.00E-05	1.97E-05	25.3	4	8.89E-06	21,000	112,487	78.12	0.22	27,550	32.1
1.00E-05	1.97E-05	25.2	3	6.69E-06	21,000	149,390	103.74	0.17	27,550	24.1
1.00E-05	1.97E-05	25.1	2	4.48E-06	21,000	223,196	155.00	0.11	27,550	16.2
1.00E-05	1.97E-05	25.0	1	2.25E-06	21,000	444,614	308.76	0.06	27,550	8.1
							1,470.35	days		
							4.03	**years**		

Soil Porosity	0.35	
Soil Permeability	1.00E-05	cm/sec
Length of Drain (max.)	1200	ft
Distance Between Drains	50	ft
Thickness of Unit	1	ft
Maximum Depth	39	ft

Table 2
White Mesa Mill
Cell 4A Slimes Drain
Average Liquid Depth

Permeability (cm/sec)	Permeability (ft/min)	Drainage length (ft.)	Thickness (VF)	Seepage Velocity (ft/min.)	Volume of Liquid (CF/VF)	Time to dewater (min/VF)	Time to dewater (days/VF)	Flow Rate (CF/day) per LF of lateral	Approximate Total Cell Lateral Length (LF)	Maximum Flow Rate from Cell (gpm)
1.00E-05	1.97E-05	39.8	31	4.38E-05	21,000	22,833	15.86	1.10	27,550	157.9
1.00E-05	1.97E-05	39.1	30	4.31E-05	21,000	23,179	16.10	1.09	27,550	155.6
1.00E-05	1.97E-05	38.3	29	4.26E-05	21,000	23,488	16.31	1.07	27,550	153.5
1.00E-05	1.97E-05	37.5	28	4.20E-05	21,000	23,819	16.54	1.06	27,550	151.4
1.00E-05	1.97E-05	36.8	27	4.13E-05	21,000	24,240	16.83	1.04	27,550	148.8
1.00E-05	1.97E-05	36.1	26	4.05E-05	21,000	24,693	17.15	1.02	27,550	146.0
1.00E-05	1.97E-05	35.4	25	3.97E-05	21,000	25,183	17.49	1.00	27,550	143.2
1.00E-05	1.97E-05	34.7	24	3.89E-05	21,000	25,713	17.86	0.98	27,550	140.2
1.00E-05	1.97E-05	34.0	23	3.80E-05	21,000	26,290	18.26	0.96	27,550	137.2
1.00E-05	1.97E-05	33.3	22	3.71E-05	21,000	26,919	18.69	0.94	27,550	134.0
1.00E-05	1.97E-05	32.6	21	3.62E-05	21,000	27,608	19.17	0.91	27,550	130.6
1.00E-05	1.97E-05	32.0	20	3.51E-05	21,000	28,455	19.76	0.89	27,550	126.7
1.00E-05	1.97E-05	31.4	19	3.40E-05	21,000	29,391	20.41	0.86	27,550	122.7
1.00E-05	1.97E-05	30.8	18	3.29E-05	21,000	30,431	21.13	0.83	27,550	118.5
1.00E-05	1.97E-05	30.2	17	3.17E-05	21,000	31,594	21.94	0.80	27,550	114.1
1.00E-05	1.97E-05	29.7	16	3.03E-05	21,000	33,013	22.93	0.76	27,550	109.2
1.00E-05	1.97E-05	29.2	15	2.89E-05	21,000	34,621	24.04	0.73	27,550	104.2
1.00E-05	1.97E-05	28.7	14	2.74E-05	21,000	36,458	25.32	0.69	27,550	98.9
1.00E-05	1.97E-05	28.2	13	2.59E-05	21,000	38,579	26.79	0.65	27,550	93.5
1.00E-05	1.97E-05	27.7	12	2.44E-05	21,000	41,053	28.51	0.61	27,550	87.8
1.00E-05	1.97E-05	27.3	11	2.27E-05	21,000	44,138	30.65	0.57	27,550	81.7
1.00E-05	1.97E-05	26.9	10	2.09E-05	21,000	47,840	33.22	0.53	27,550	75.4
1.00E-05	1.97E-05	26.6	9	1.90E-05	21,000	52,563	36.50	0.48	27,550	68.6
1.00E-05	1.97E-05	26.2	8	1.72E-05	21,000	58,244	40.45	0.43	27,550	61.9
1.00E-05	1.97E-05	26.0	7	1.51E-05	21,000	66,057	45.87	0.38	27,550	54.6
1.00E-05	1.97E-05	25.7	6	1.31E-05	21,000	76,177	52.90	0.33	27,550	47.3
1.00E-05	1.97E-05	25.5	5	1.10E-05	21,000	90,701	62.99	0.28	27,550	39.8
1.00E-05	1.97E-05	25.3	4	8.89E-06	21,000	112,487	78.12	0.22	27,550	32.1
1.00E-05	1.97E-05	25.2	3	6.69E-06	21,000	149,390	103.74	0.17	27,550	24.1
1.00E-05	1.97E-05	25.1	2	4.48E-06	21,000	223,196	155.00	0.11	27,550	16.2
1.00E-05	1.97E-05	25.0	1	2.25E-06	21,000	444,614	308.76	0.06	27,550	8.1
							1,349.28	days		
							3.70	**years**		

Soil Porosity	0.35	
Soil Permeability	1.00E-05	cm/sec
Length of Drain (max.)	1200	ft
Distance Between Drains	50	ft
Thickness of Unit	1	ft
Maximum Depth	31	ft

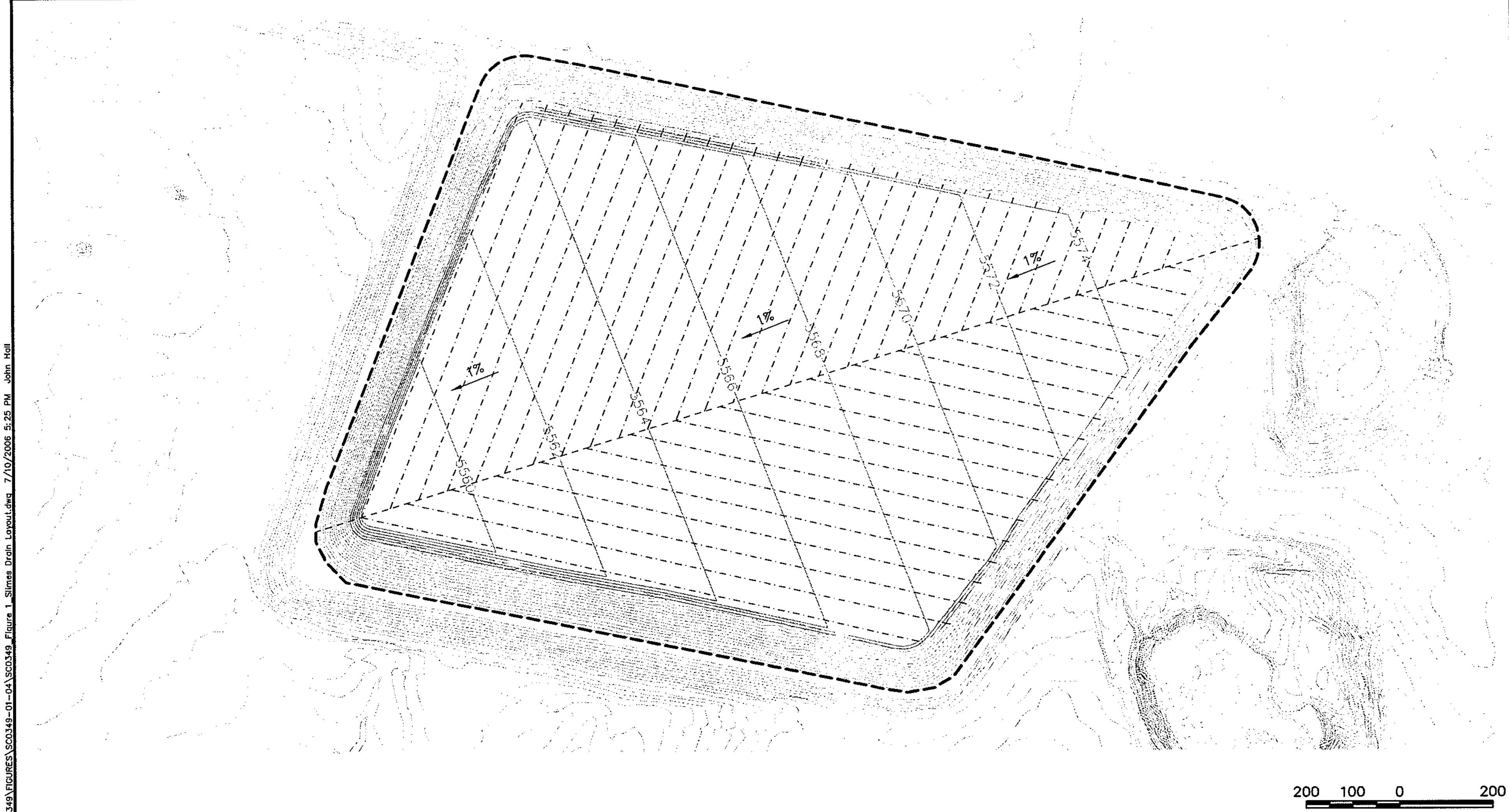
Table 3
White Mesa Mill
Cell 4A Slimes Drain
Minimum Liquid Depth

Permeability (cm/sec)	Permeability (ft/min)	Drainage length (ft.)	Thickness (ft.)	Seepage Velocity (ft/min.)	Volume of Liquid (CF)	Time to dewater (min/ft)	Time to dewater (days)	Maximum Flow Rate (CF/day) per foot of lateral	Approximate Total Cell Lateral Length (ft)	Maximum Flow Rate from Cell (gpm)
1.00E-05	1.97E-05	34.0	23	3.80E-05	21,000	26,290	18.26	0.96	27,550	137.2
1.00E-05	1.97E-05	33.3	22	3.71E-05	21,000	26,919	18.69	0.94	27,550	134.0
1.00E-05	1.97E-05	32.6	21	3.62E-05	21,000	27,608	19.17	0.91	27,550	130.6
1.00E-05	1.97E-05	32.0	20	3.51E-05	21,000	28,455	19.76	0.89	27,550	126.7
1.00E-05	1.97E-05	31.4	19	3.40E-05	21,000	29,391	20.41	0.86	27,550	122.7
1.00E-05	1.97E-05	30.8	18	3.29E-05	21,000	30,431	21.13	0.83	27,550	118.5
1.00E-05	1.97E-05	30.2	17	3.17E-05	21,000	31,594	21.94	0.80	27,550	114.1
1.00E-05	1.97E-05	29.7	16	3.03E-05	21,000	33,013	22.93	0.76	27,550	109.2
1.00E-05	1.97E-05	29.2	15	2.89E-05	21,000	34,621	24.04	0.73	27,550	104.2
1.00E-05	1.97E-05	28.7	14	2.74E-05	21,000	36,458	25.32	0.69	27,550	98.9
1.00E-05	1.97E-05	28.2	13	2.59E-05	21,000	38,579	26.79	0.65	27,550	93.5
1.00E-05	1.97E-05	27.7	12	2.44E-05	21,000	41,053	28.51	0.61	27,550	87.8
1.00E-05	1.97E-05	27.3	11	2.27E-05	21,000	44,138	30.65	0.57	27,550	81.7
1.00E-05	1.97E-05	26.9	10	2.09E-05	21,000	47,840	33.22	0.53	27,550	75.4
1.00E-05	1.97E-05	26.6	9	1.90E-05	21,000	52,563	36.50	0.48	27,550	68.6
1.00E-05	1.97E-05	26.2	8	1.72E-05	21,000	58,244	40.45	0.43	27,550	61.9
1.00E-05	1.97E-05	26.0	7	1.51E-05	21,000	66,057	45.87	0.38	27,550	54.6
1.00E-05	1.97E-05	25.7	6	1.31E-05	21,000	76,177	52.90	0.33	27,550	47.3
1.00E-05	1.97E-05	25.5	5	1.10E-05	21,000	90,701	62.99	0.28	27,550	39.8
1.00E-05	1.97E-05	25.3	4	8.89E-06	21,000	112,487	78.12	0.22	27,550	32.1
1.00E-05	1.97E-05	25.2	3	6.69E-06	21,000	149,390	103.74	0.17	27,550	24.1
1.00E-05	1.97E-05	25.1	2	4.48E-06	21,000	223,196	155.00	0.11	27,550	16.2
1.00E-05	1.97E-05	25.0	1	2.25E-06	21,000	444,614	308.76	0.06	27,550	8.1
							1,215.15	days		
							3.33	**years**		

Soil Porosity	0.35	
Soil Permeability	1.00E-05	cm/sec
Length of Drain (max.)	1200	ft
Distance Between Drains	50	ft
Thickness of Unit	1	ft
Maximum Depth	23	ft

White Mesa Mill
Cell 4A Slimes Drain
Additional Drainage Time Calculation
Table 4

Thickness (VF)	Time to dewater (days/VF)	Flow Rate (CF/day) per LF of lateral	Approximate Total Cell Lateral Length (LF)	Maximum Flow Rate from Cell (gpm)	Additional Time Needed to Dewater (days)
31	15.86	1.10	27,550	157.9	6.57
30	16.10	1.09	27,550	155.6	6.33
29	16.31	1.07	27,550	153.5	6.12
28	16.54	1.06	27,550	151.4	5.89
27	16.83	1.04	27,550	148.8	5.60
26	17.15	1.02	27,550	146.0	5.28
25	17.49	1.00	27,550	143.2	4.94
24	17.86	0.98	27,550	140.2	4.57
23	18.26	0.96	27,550	137.2	4.17
22	18.69	0.94	27,550	134.0	3.74
21	19.17	0.91	27,550	130.6	3.26
20	19.76	0.89	27,550	126.7	2.67
19	20.41	0.86	27,550	122.7	2.02
18	21.13	0.83	27,550	118.5	1.30
17	21.94	0.80	27,550	114.1	0.49
16	22.93	0.76	27,550	109.2	
				Sum	**62.95**



GEOSYNTEC CONSULTANTS

SLIMES DRAIN LAYOUT
CELL 4A
BLANDING, UTAH

FIGURE NO.	1
PROJECT NO.	SC0349
DATE:	MARCH 2007

P:\PRJ\SDCadd\CADD\SC0349\FIGURES\SC0349-01-04\SC0349_Figure 1_Slimes Drain Layout.dwg 7/10/2006 5:25 PM John Hall

ATTACHMENT A, 1/1

ered that when well-graded mixtures of sand and gravel contained as little as 5% of fines (sizes smaller than a No. 200 sieve) high compactive efforts reduced the effective porosities nearly to zero and the permeabilities to less than 0.01% of those at moderate densities. These tests explain one of the reasons that blends of sand and gravel often used for drains are virtually useless as drainage aggregates if they contain more than insignificant amounts of fines.

In the preceding paragraphs variations in the permeability of remolded materials caused by variable compaction were discussed. Any factor that densifies soils reduces permeability. Studies of the rate of consolidation of clay and peat foundations are sometimes made by using initial coefficients of permeability of compressible formations. While the consolidation process is going on in foundations their permeabilities are becoming less. Generally, decreases in the permeabilities of clay foundations are rather moderate, but they can be large in highly compressible organic silts and clays and in peats. Modified calculation methods utilizing the changing permeability are needed in the analysis of highly compressible foundations. Some typical variations in permeability caused by consolidation are given in Fig. 2.10, a plot of consolidation pressure versus permeability.

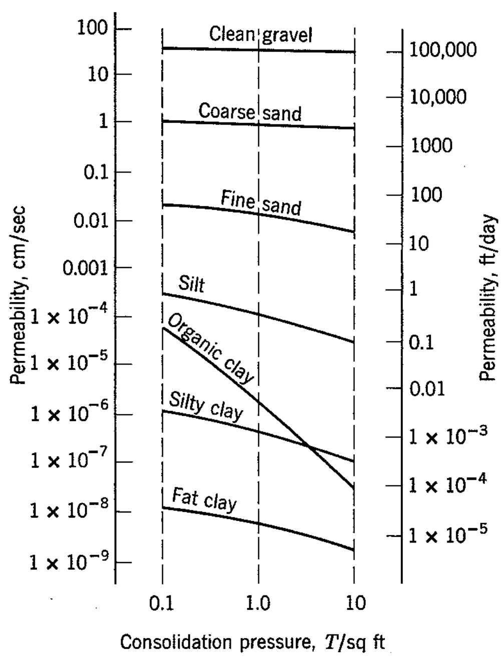


FIG. 2.10 Permeability versus consolidation pressure.

"Seepage, Drainage, and Flow Nets" 3rd Edition, Cedergren, H.R. 1989

Attachment B

1/2

$$k = \frac{Q}{iAt} \tag{2.2}$$

Darcy's *discharge velocity* multiplied by the entire cross-sectional area, including voids e and solids 1, gives the seepage quantity Q under a given hydraulic gradient $i = \Delta h/\Delta l$ or h/L. It is an imaginary velocity that does not exist anywhere. The average *seepage velocity* v_s of a mass of water progressing through the pore spaces of a soil is equal to the discharge velocity $(v_d = ki)$ multiplied by $(1 + e)/e$ or the discharge velocity divided by the effective porosity n_e; hence permeability is related to seepage velocity by the expression

$$k = \frac{v_s n_e}{i} \tag{2.3}$$

For any seepage condition in the laboratory or in the field in which the *seepage quantity,* the area perpendicular to the direction of flow, and the hydraulic gradient are known the coefficient of permeability can be calculated. Likewise, for any situation where the *seepage velocity* is known at a point at which the hydraulic gradient and soil porosity also are known, permeability can be calculated.

Experimentally determined coefficients of permeability can be combined with prescribed hydraulic gradients and discharge areas in solving practical problems involving seepage quantities and velocities. When a coefficient of permeability has been properly determined, it furnishes a very important factor in the analysis of seepage and in the design of drainage features for engineering works.

The coefficient of permeability as used in this book and in soil mechanics in general should be distinguished from the physicists' coefficient of permeability K, which is a more general term than the engineers' coefficient and has units of centimeters squared rather than a velocity; it varies with the porosity of the soil but is independent of the viscosity and density of the fluid. The transmissibility factor T represents the capability of an aquifer to discharge water and is the product of permeability k and aquifer thickness t.

The engineers' coefficient, which is used in practical problems of seepage through masses of earth and other porous media, applies only to the flow of water and is a simplification introduced purely from the standpoint of convenience. It has units of a velocity and is expressed in centimeters per second, feet per minute, feet per day, or feet per year, depending on the habits and personal preferences of individuals using the coefficient. In standard soil mechanics terminology k is expressed in centimeters per second.

Although coefficient of permeability is often considered to be a constant for a given soil or rock, it can vary widely for a given material, depending on a number of factors. Its absolute values depend, first of all, on the properties of water, of which viscosity is the most important. For individual materials

Attachment B, 2/2

Cedergren, "Seepage, Drainage, and Flow Nets", 3rd Ed. 1989

TABLE 4-2 Typical Index Properties for Granular Soils*

	Particle Size and Gradation				Voids			
	Approx. Size Range (mm)		Approx. D_{10} (mm)	Approx. Range C_u	Void Ratio		Porosity (%)	
	D_{max}	D_{min}			e_{max} (loose)	e_{min} (dense)	n_{max} (loose)	n_{min} (dense)
1. Uniform materials:								
(a) Equal spheres	—	—	—	1.0	0.92	0.35	48	26
(b) Standard Ottawa sand	0.84	0.59	0.67	1.1	0.80	0.50	44	33
(c) Clean, uniform sand (fine or medium)	—	—	—	1.2 to 2.0	1.0	0.40	50	29
(d) Uniform, inorganic silt	0.05	0.005	0.012	1.2 to 2.0	1.1	0.40	52	29
2. Well-graded materials:								
(a) Silty sand	2.0	0.005	0.02	5 to 10	0.90	0.30	47	23
(b) Clean, fine to coarse sand	2.0	0.05	0.09	4 to 6	0.95	0.20	49	17
(c) Micaceous sand	—	—	—	—	1.2	0.40	55	29
(d) Silty sand and gravel	100	0.005	0.02	15 to 300	0.85	0.14	46	12

← average n, = 35

*Modified after B. K. Hough (1969), *Basic Soils Engineering*, © 1969 by the Ronald Press, Co. Reprinted by permission of John Wiley & Sons, Inc.

TABLE 4-2 Continued

	Density (Mg/m³)†						
	Dry Density, ρ_d			Wet Density, ρ		Submerged Density, ρ'	
	Min. (loose)	100% Mod. Proctor	Max. (dense)	Min. (loose)	Max. (dense)	Min. (loose)	Max. (dense)
1. Uniform materials:							
(a) Equal spheres (theoretical values)	—	—	—	—	—	—	—
(b) Standard Ottawa sand	1.49	—	1.78	1.51	2.12	0.93	1.12
(c) Clean, uniform sand (fine or medium)	1.35	1.86	1.92	1.37	2.20	0.85	1.18
(d) Uniform, inorganic silt	1.29	—	1.92	1.31	2.20	0.83	1.18
2. Well-graded materials:							
(a) Silty sand	1.41	1.98	2.06	1.43	2.30	0.88	1.28
(b) Clean, fine to course sand	1.38	2.14	2.23	1.40	2.39	0.86	1.40
(c) Micaceous sand	1.23	—	1.95	1.24	2.23	0.77	1.23
(d) Silty sand and gravel	1.44	—	2.36	1.46	2.51	0.91	1.49

†Tabulation is based on $\rho_s = 2.65$ Mg/m³. Multiply by 62.4 to obtain lbf/ft³.

Attachment C, 1/1

Kovacs, Holtz "An Introduction to Geotechnical Engineering," 1981.

GDE Control Products, Inc.

Multi-FLO!

Technical Properties

Drainage Core

Property	Test Method	Value
Thickness, inches	ASTM D-1777	1.0
Flow Rate, gpm/ft*	ASTM D-4716	29
~~Compressive Strength~~	~~ASTM D-1621~~	~~6000~~

Geotextile Filter

Property	Test Method	Value
Weight, oz/sq yd2	ASTM D-3776	4.0
Tensile Strength, lb.	ASTM D-4632	100
Elongation, %	ASTM D-4632	50
Puncture, lb.	ASTM D-4833	50
Mullen Burst, psi	ASTM D-3786	200
Trapezoidal Tear, lb.	ASTM D-4533	42
Coeffecient of Perm,cm/sec	ASTM D-4491	0.1
Flow Rate, gpm/ft2	ASTM D-4491	100
Permittivity, 1/sec	ASTM D-4491	1.8
A.O.S Max US Std Sieve	ASTM D 4751	70
UV Stability, 500 hrs., %	ASTM D-4355	70
Seam Strength, lb./ft	ASTM D-4595	100
Fungus	ASTM G-21	No Growth

* Horizontal Installation , gradient = 0.01, compressive force = 10 psi for 1(

All values given represent minimum average roll values

GDE Control Products, Inc. Laguna Hills, CA. 949-305-7117

GDE, Multi-Flow
<http: www.gdccontrol.com/Multi-Flow5.html> Attachment D 1/1

TABLE 2.12 RECOMMENDED REDUCTION FACTOR VALUES FOR USE IN EQ. (2.25a)

	Range of Reduction Factors				
Application	Soil Clogging and Blinding*	Creep Reduction of Voids	Intrusion into Voids	Chemical Clogging†	Biological Clogging
Retaining wall filters	2.0 to 4.0	1.5 to 2.0	1.0 to 1.2	1.0 to 1.2	1.0 to 1.3
Underdrain filters	5.0 to 10	1.0 to 1.5	1.0 to 1.2	1.2 to 1.5	2.0 to 4.0
Erosion-control filters	2.0 to 10	1.0 to 1.5	1.0 to 1.2	1.0 to 1.2	2.0 to 4.0
Landfill filters	5.0 to 10	1.5 to 2.0	1.0 to 1.2	1.2 to 1.5	5 to 10‡
Gravity drainage	2.0 to 4.0	2.0 to 3.0	1.0 to 1.2	1.2 to 1.5	1.2 to 1.5
Pressure drainage	2.0 to 3.0	2.0 to 3.0	1.0 to 1.2	1.1 to 1.3	1.1 to 1.3

*If stone riprap or concrete blocks cover the surface of the geotextile, use either the upper values or include an additional reduction factor.

†Values can be higher particularly for high alkalinity groundwater.

‡Values can be higher for turbidity and/or for microorganism contents greater than 5000 mg/l.

$$q_{\text{allow}} = q_{\text{ult}}\left(\frac{1}{\Pi \text{RF}}\right) \tag{2.25b}$$

where

q_{allow} = allowable flow rate,
q_{ult} = ultimate flow rate,
RF_{SCB} = reduction factor for soil clogging and blinding,
RF_{CR} = reduction factor for creep reduction of void space,
RF_{IN} = reduction factor for adjacent materials intruding into geotextile's void space,
RF_{CC} = reduction factor for chemical clogging,
RF_{BC} = reduction factor for biological clogging, and
ΠRF = value of cumulative reduction factors.

As with Eqs. (2.24) for strength reduction, this flow-reduction equation could also have included additional site-specific terms, such as blocking of a portion of the geotextile's surface by riprap or concrete blocks.

2.5 DESIGNING FOR SEPARATION

Application areas for geotextiles used for the separation function were given in Section 1.3.3. There are many specific applications, and it could be said, in a general sense, that geotextiles always serve a separation function. If they do not also serve this function, any other function, including the primary one, will not be served properly. This should not give the impression that the geotextile function of separation always plays a secondary role. Many situations call for separation only, and in such cases the geotextiles serve a significant and worthwhile function.

Attachment E 1/4

4.1.6 Allowable Flow Rate

As described previously, the very essence of the design-by-function concept is the establishment of an adequate factor of safety. For geonets, where flow rate is the primary function, this takes the following form.

$$\mathrm{FS} = \frac{q_{\text{allow}}}{q_{\text{reqd}}} \tag{4.3}$$

where

FS = factor of safety (to handle unknown loading conditions or uncertainties in the design method, etc.),
q_{allow} = allowable flow rate as obtained from laboratory testing, and
q_{reqd} = required flow rate as obtained from design of the actual system.

Alternatively, we could work from transmissivity to obtain the equivalent relationship.

$$\mathrm{FS} = \frac{\theta_{\text{allow}}}{\theta_{\text{reqd}}} \tag{4.4}$$

where θ is the transmissivity, under definitions as above. As discussed previously, however, it is preferable to design with flow rate rather than with transmissivity because of nonlaminar flow conditions in geonets.

Concerning the allowable flow rate or transmissivity value, which comes from hydraulic testing of the type described in Section 4.1.3, we must assess the realism of the test setup in contrast to the actual field system. If the test setup does not model site-specific conditions adequately, then adjustments to the laboratory value must be made. This is usually the case. Thus the laboratory-generated value is an ultimate value that must be reduced before use in design; that is,

$$q_{\text{allow}} < q_{\text{ult}}$$

One way of doing this is to ascribe reduction factors on each of the items not adequately assessed in the laboratory test. For example,

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{\mathrm{RF}_{IN} \times \mathrm{RF}_{CR} \times \mathrm{RF}_{CC} \times \mathrm{RF}_{BC}}\right] \tag{4.5}$$

or if all of the reduction factors are considered together.

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{\Pi \mathrm{RF}}\right] \tag{4.6}$$

where

q_{ult} = flow rate determined using ASTM D4716 or ISO/DIS 12958 for short-term tests between solid platens using water as the transported liquid under laboratory test temperatures,

ATTACHMENT E, 2/4

ction concept is the es-
flow rate is the primary

(4.3)

ditions or uncertainties

testing, and
e actual system.

e equivalent relationship.

(4.4)

liscussed previously, how-
transmissivity because of

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setup does not model site-
atory value must be made.
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ach of the items not ade-

(4.5)

(4.6)

ISO/DIS 12958 for short-
as the transported liquid

q_{allow} = allowable flow rate to be used in Eq. (4.3) for final design purposes,
RF_{IN} = reduction factor for elastic deformation, or intrusion, of the adjacent geosynthetics into the geonet's core space,
RF_{CR} = reduction factor for creep deformation of the geonet and/or adjacent geosynthetics into the geonet's core space,
RF_{CC} = reduction factor for chemical clogging and/or precipitation of chemicals in the geonet's core space,
RF_{BC} = reduction factor for biological clogging in the geonet's core space, and
ΠRF = product of all reduction factors for the site-specific conditions.

Some guidelines for the various reduction factors to be used in different situations are given in Table 4.2. Please note that some of these values are based on relatively sparse information. Other reduction factors, such as installation damage, temperature effects, and liquid turbidity, could also be included. If needed, they can be included on a site-specific basis. On the other hand, if the actual laboratory test procedure has included the particular item, it would appear in the above formulation as a value of unity. Examples 4.2 and 4.3 illustrate the use of geonets and serve to point out that high reduction factors are warranted in critical situations.

Example 4.2

What is the allowable geonet flow rate to be used in the design of a capillary break beneath a roadway to prevent frost heave? Assume that laboratory testing was done at the proper design load and hydraulic gradient and that this testing yielded a short-term between-rigid-plates value of 2.5×10^{-4} m²/s.

Solution: Since better information is not known, average values from Table 4.2 are used in Eq. (4.5).

TABLE 4.2 RECOMMENDED PRELIMINARY REDUCTION FACTOR VALUES FOR EQ. (4.5) FOR DETERMINING ALLOWABLE FLOW RATE OR TRANSMISSIVITY OF GEONETS

Application Area	RF_{IN}	RF_{CR}*	RF_{CC}	RF_{BC}
Sport fields	1.0 to 1.2	1.0 to 1.5	1.0 to 1.2	1.1 to 1.3
Capillary breaks	1.1 to 1.3	1.0 to 1.2	1.1 to 1.5	1.1 to 1.3
Roof and plaza decks	1.2 to 1.4	1.0 to 1.2	1.0 to 1.2	1.1 to 1.3
Retaining walls, seeping rock, and soil slopes	1.3 to 1.5	1.2 to 1.4	1.1 to 1.5	1.0 to 1.5
Drainage blankets	1.3 to 1.5	1.2 to 1.4	1.0 to 1.2	1.0 to 1.2
Surface water drains for landfill covers	1.3 to 1.5	1.1 to 1.4	1.0 to 1.2	1.2 to 1.5
Secondary leachate collection (landfills)	1.5 to 2.0	1.4 to 2.0	1.5 to 2.0	1.5 to 2.0
Primary leachate collection (landfills)	1.5 to 2.0	1.4 to 2.0	1.5 to 2.0	1.5 to 2.0

*These values are sensitive to the density of the resin used in the geonet's manufacture. The higher the density, the lower the reduction factor. Creep of the covering geotextile(s) is a product-specific issue.

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The above formula can be readily converted to flow rate, Q, by multiplying the velocity by the cross-sectional area A of the pipe.

For pipelines that are either flowing full or flowing partially full, the *Manning equation* is generally used.

$$V = \frac{1}{n} R_H^{0.66} S^{0.5} \tag{7.10}$$

where

V = velocity of flow (m/s),
R_H = hydraulic radius (m),
S = slope or gradient of pipeline (m/m), and
n = coefficient of roughness (see Table 7.7) (dimensionless).

Note that plastic pipe of the type discussed in this chapter, with a *smooth interior,* has a Manning coefficient from 0.009 to 0.010. Plastic pipe with a *profiled or corrugated interior* has a Manning coefficient ranging from 0.018 to 0.025.

Eqs. (7.9) and (7.10) are generally used in the form of charts or nomographs to determine pipe sizes, flow velocity or discharge flow rates (see Figures 7.6 and 7.7). For each chart we include an example from Hwang [7], illustrated on the respective nomographs by heavy lines. Note that both nomographs are for pipes flowing full.

Example 7.1

A 100 m long pipe with D = 200 mm and C = 120 carries a discharge of 30 l/s. Determine the head loss in the pipe. (See the Hazen-Williams chart in Figure 7.6.)

Solution: Applying the conditions given to the solution chart in Figure 7.6, the energy gradient is obtained.

$$S = 0.0058 \text{ m/m}$$

TABLE 7.7 VALUES OF MANNING ROUGHNESS COEFFICIENT, *N,* FOR REPRESENTATIVE SURFACES

Type of Pipe Surface	Representative n value
* Lucite, glass, or plastic*	0.010
Wood or finished concrete	0.013
Unfinished concrete, well-laid brickwork, concrete or cast iron pipe	0.015
Riveted or spiral steel pipe	0.017
Smooth, uniform earth channel	0.022
Corrugated flumes, typical canals, river free from large stones and heavy weeds	0.025
Canals and rivers with many stones and weeds	0.035

*The table does not distinguish between different types of plastic, or between smooth wall, profiled wall, or pipes with perforations.

Source: After Fox and McDonald [9].

Koerner, R.M., "Designing with Geosynthetics," 4th Ed., 1999.
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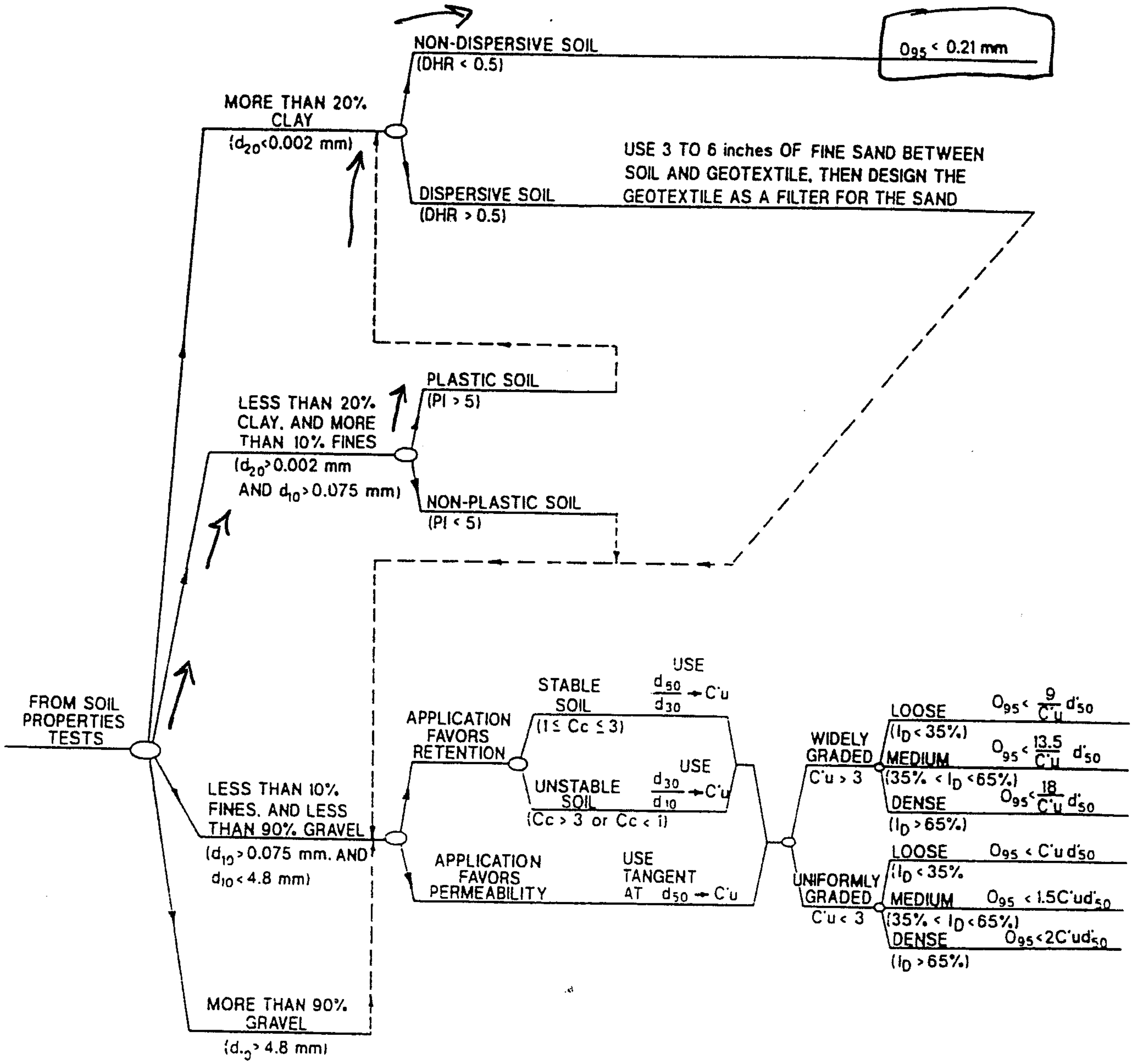
CHART 1
SOIL RETENTION CRITERIA
FOR STEADY-STATE FLOW CONDITIONS



NOTES:

d_x is the particle size of which x percent is smaller

$C'u = \sqrt{\frac{d'_{100}}{d'_0}}$ where: d'_{100} and d'_0 are the extremities of a straight line drawn through the particle-size distribution, as directed above; and d'_{50} is the midpoint of this line.

$Cc = \frac{(d_{30})^2}{d_{60} \times d_{10}}$

I_D is the relative denisty of the soil

PI is the plasticity index of the soil

DHR is the double-hydrometer ratio of the soil

Portions of this flow chart modified from Giroud (1988)

Source: Luettich, S.M., Giroud, J.P., and Bachus, R.C. (1991). "Geotextile Filter Design Manual". Report prepared for Nicolon Corporation, Norcross, Georgia.

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4.2 Define the Hydraulic Gradient for the Application (i_s)

The hydraulic gradient will vary depending on the application of the filter. Anticipated hydraulic gradients for various applications may be estimated using Figure 3.

4.3 Determine the Minimum Allowable Geotextile Permeability (k_g)

After determining the soil hydraulic conductivity and the hydraulic gradient, the following equation can be used to determine the minimum allowable geotextile permeability [Giroud, 1988]:

$$k_g > i_s\, k_s$$

The hydraulic conductivity (permeability) of the geotextile can be calculated from the permittivity test method ASTM D 4491; this value can often be obtained from the manufacturer's literature as well. The geotextile permeability is defined as the product of the permittivity, ψ, and the geotextile thickness, t_g:

$$k_g > \varphi\, t_g$$

STEP 5. DETERMINE ANTI-CLOGGING REQUIREMENTS

To minimize the risk of clogging, the following criteria should be met:

- Use the largest opening size (O_{95}) that satisfies the retention criteria.
- For nonwoven geotextiles, use the largest porosity available, but not less than 30 percent.
- For woven geotextiles, use the largest percent open area available, but not less than 4 percent.

Source: Luettich, S.M., Giroud, J.P., and Bachus, R.C. (1991). "Geotextile Filter Design Manual". Report prepared for Nicolon Corporation, Norcross, Georgia.

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Table 4-5

Typical Hydraulic Gradients[a]

DRAINAGE APPLICATION	TYPICAL HYDRAULIC GRADIENT
Standard Dewatering Trench	1.0
Vertical Wall Drain	1.5
Pavement Edge Drain	1[b]
Landfill LCDRS	1.5
Landfill LCRS	1.5
Landfill SWCRS	1.5
Inland Channel Protection	1[b]
Shoreline Protection	10[b]
Dams	10[b]
Liquid Impoundments	10[b]

NOTES: [a] Table developed after Giroud [1988].

[b] Critical applications may require designing with higher gradients than those given.

Attachment F
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AMOCO WASTE RELATED GEOTEXTILES

MINIMUM PHYSICAL PROPERTIES
(Minimum Average Roll Values)

Property	Test Method	Units	4504	4506	4508	4510	4512	4516
Unit Weight	ASTM D-3776	Oz./yd.^{2}	4.0 *	6.0	8.0	10.0	12.0	16.0
Grab Tensile	ASTM D-4632	lbs.	95	150	200	235	275	350
Grab Elongation	ASTM D-4632	%	50	50	50	50	50	50
Mullen Burst	ASTM D-3787	psi	225	350	450	550	650	750
Puncture	ASTM D-4833	lbs.	55	90	130	165	185	220
Trapezoid Tear	ASTM D-4533	lbs.	35	65	80	95	115	130
Apparent Opening Size	ASTM D-4751	US Sieve Number	70	70	100	100	100	100
Permittivity	ASTM D-4491	gal/min/ft^2 sec^{-1}	100 2.0	90 1.7	80 1.5	70 1.1	60 0.9	50 0.7
Permeability	ASTM D-4491	cm/sec	.2	.2	.2	.2	.2	.2
Thickness	ASTM D-1777	mils	40 *	65	90	110	130	175
U.V. Resistance	ASTM D-4355[1]	%[2]	70	70	70	70	70	70

1. Fabric conditioned per ASTM-D-4355 2. Percent of minimum grab tensile after conditioning.

TYPICAL PHYSICAL PROPERTIES

Property	Test Method	Units	4504	4506	4508	4510	4512	4516
Grab Tensile	ASTM D-4632	lbs.	130/115	225/200	275/270	315/310	410/370	510/470
Grab Elongation	ASTM D-4632	%	75	65	65	65	65	65
Mullen Burst	ASTM D-3786	psi	285	410	575	650	825	920
Puncture	ASTM D-4833	lbs.	75	120	170	190	210	270
Trapezoid Tear	ASTM D-4533	lbs.	60/50	100/80	140/120	160/140	185/155	220/180
Apparent Opening Size	ASTM D-4751	US Sieve Number	70/120	70/140	100/200	100+	100+	100+
Permittivity	ASTM D-4491	gal/min/ft^2 sec^{-1}	150 3.1	110 2.0	100 1.8	80 1.5	70 1.3	60 1.0
Permeability	ASTM D-4491	cm/sec	.35	.31	.27	.26	.25	.23
Thickness	ASTM D-1777	mils	50	75	115	130	150	195

PACKAGING

Dimensions		4504	4506	4508	4510	4512	4516
Roll Width	ft.	15	15	15	15	15	15
Roll Length	ft.	1200	900	600	600	450	300
Gross Weight	lbs.	500	550	500	600	550	500
Area	sq. yds.	2000	1500	1000	1000	750	500

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Amoco Fabrics & Fibers Company, 1991. "Amoco Waste Related Geotextiles" G 1/1