308 --- Q200312100008

Scientific Notebooks No. 285: Modeling Studies on Seepage into Open Drifts Under Isothermal Conditions (08/18/1998 through 04/14/1999)

LABORATORY NOTEBOOK

CNWRA / SWRI

NOTEBOOK NO. 285

ISSUED TO ______

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Project No. 20-1402-861

TITLE USFIC

Book No. 285

From Page No.

This notebook records modeling studies on seepage into open drifts under isothermal conditions. (Title)

code used is MULTIFLO 1.2β

USFIC - Refer to ops Plan KTI 20-1402-861
UnSaturated Flow
Isothermal Conditions

Work done by
Debra L Hughson
PhD Earth & Environmental Science

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		Debra Hughson / DH	8/18/98

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Reference:

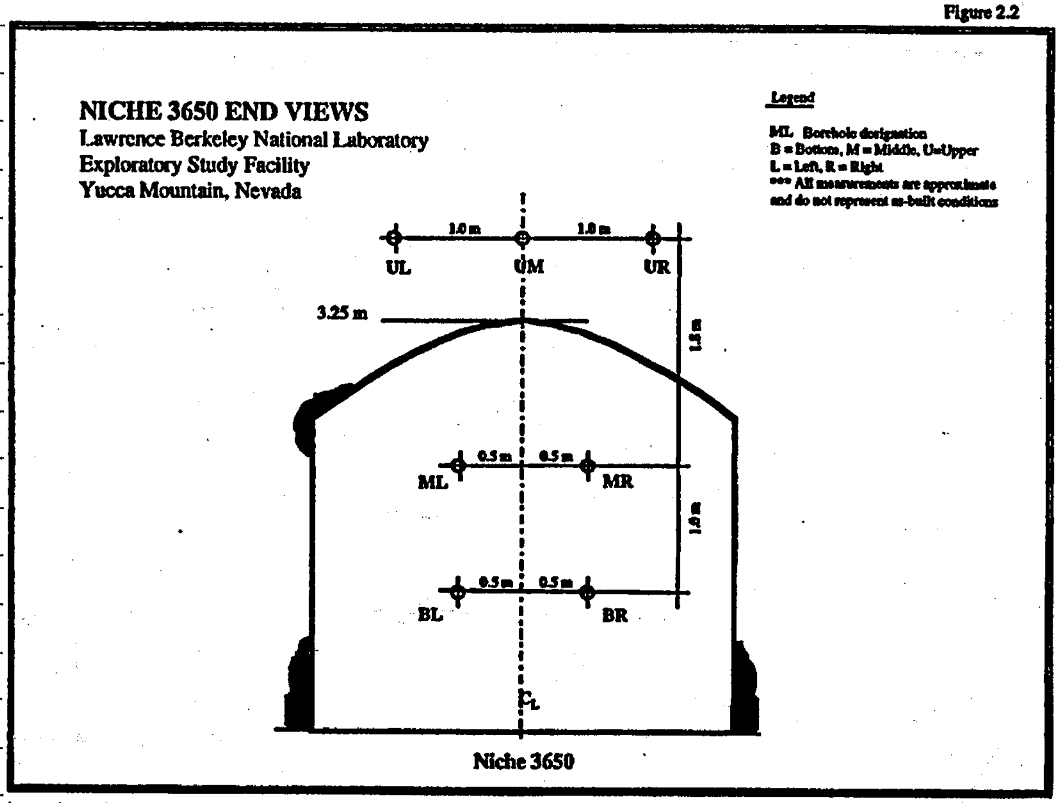
Testing and modeling of Seepage into drift, Input of Exploratory Study Facility Test Results to Unsaturated Zone models

Level 4 Milestone SP33PLM4 Jan. 1998
Earth Sciences Division, Lawrence Berkeley N.L.

Seepage tests at niche 3650
Post excavation, comparison of test & model results in Table 1.2

Are these results really as impressive as the authors claim?

Figure 2.2



SP33PLM4, January 1998

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SP33PLM4, January 1998

Table 1.2 Comparison of Niche Seepage Test Results with Drift Scale Model Results

Test	# 1	# 2	# 3	# 4	# 5
Post-Excavation Permeability (m^2)	2.0×10^{-12}	1.9×10^{-10}	1.6×10^{-12}	7.0×10^{-14}	1.1×10^{-12}
Seepage Percentage					
Test Result	22.6%	9.6%	27.2%	0%*	0%
Model Result	20.7%	5.4%**	19.6%	0%	0%
First Arrival Time (minute)					
Test Result	6.93	3.00	3.47	34.5*	NA
Model Result	5.3	3.9**	6.3	NA	NA
Duration of Dripping (minute)					
Test Result	33.83	NR	17.63	NA	NA
Model Result	12.8	2.0**	15.0	NA	NA

* liquid flow arrival was observed on the niche ceiling, no dripping.
** anisotropic permeability assumed.
NA: not applicable
NR: not recorded

1. Can I reproduce these results?
2. Hypothesis - model geometry is producing apparently good results
distance btwn source & drift ceiling = ~.65 m

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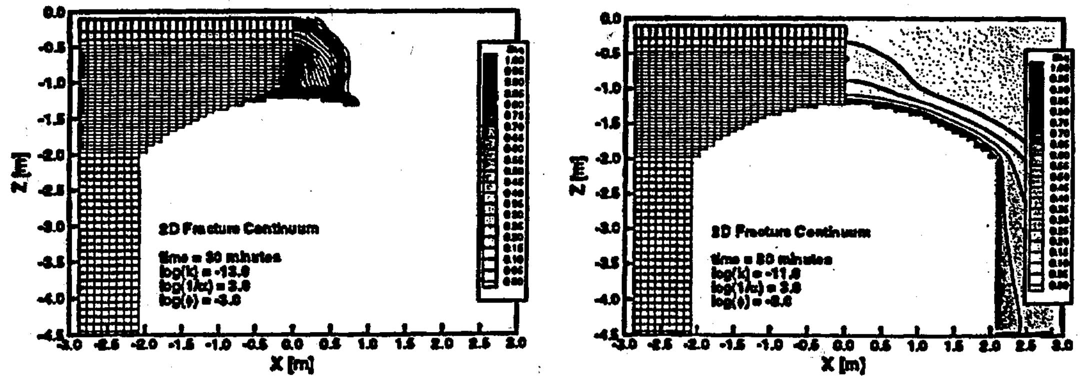
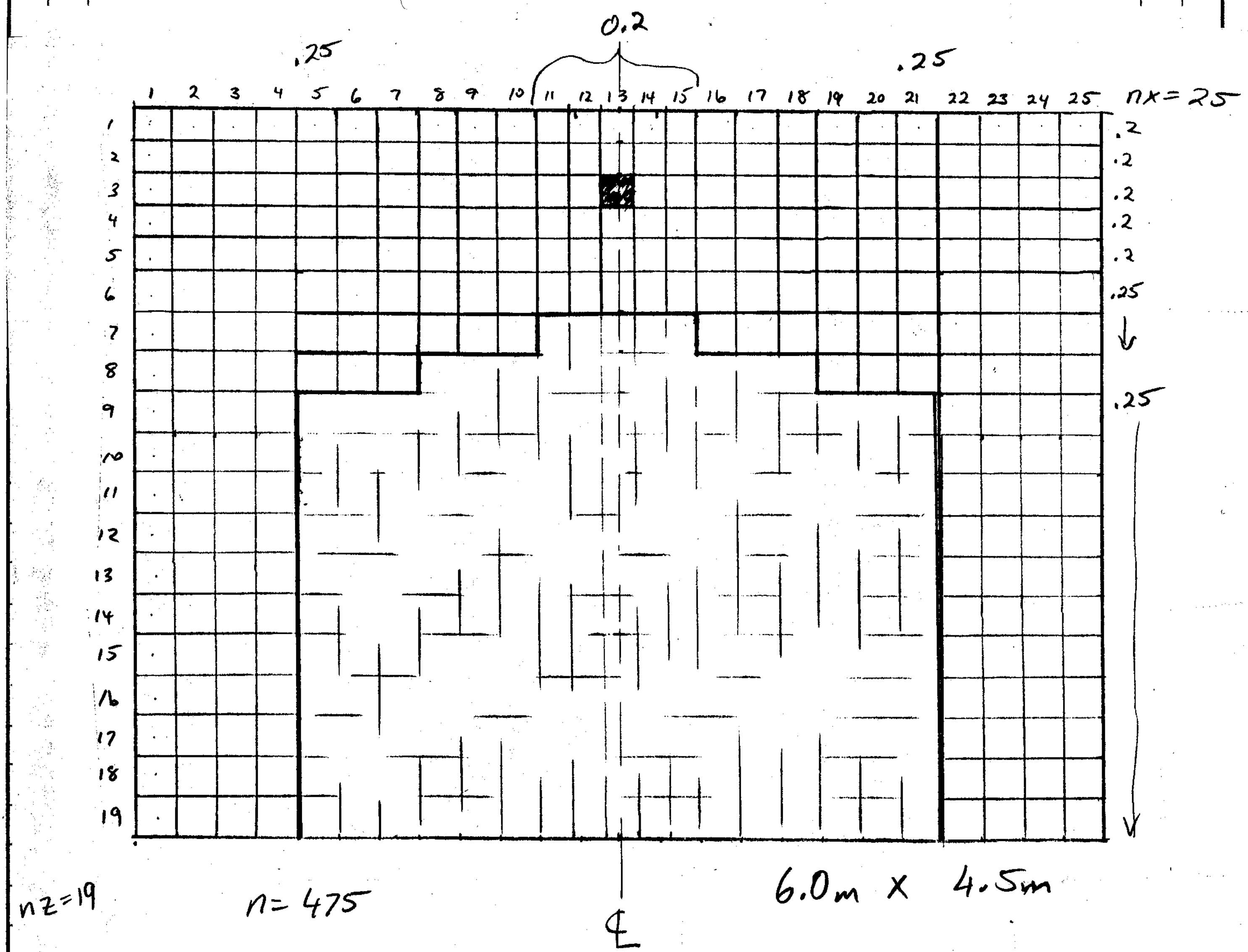


Figure 3.2 Saturation distributions after 30 minutes. Fracture permeability is perturbed by one order of magnitude from the base case parameter set [log(k)=-12.0].



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Difference in degree of discretization reflects the difference in computational resources available to LBL modelers compared to CNWRA modelers

I'm not sure how many nodes or dx dz spacing for the 2D LBL model fig 3.2

my model $nx = 25$ $nz = 19$ $n = 475$
dx and dz spacing as shown (facing page)

Single Continuum Rock properties

porosity $= 10^{-3}$ van Genuchten $1/\alpha = 10^3$ Pa
$K_s = 2 \times 10^{-2}$ m^2 $n = 2.7$

Question – how to accurately portray the open drift as one large pore

As of 3 PM & endless futile ~~atten~~ ~~atten~~ attempts ~ no success with two separate property sets. Multiflo = Multifailure

Set domain to rock properties only & work on B.C.

Absolutely no luck with this problem

this really bites

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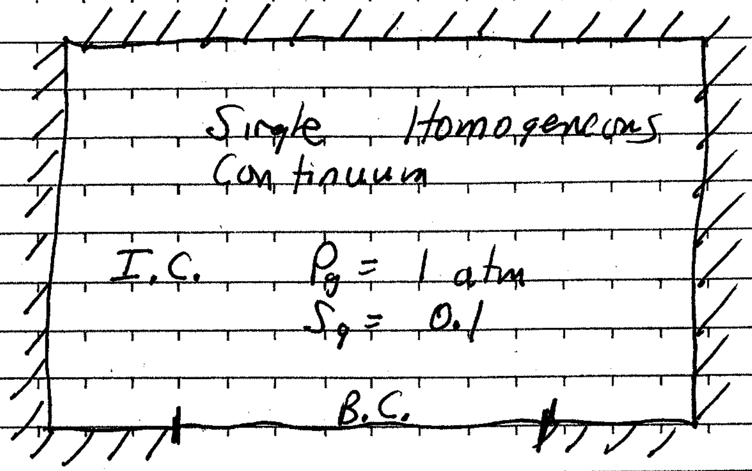

$\alpha = 10^{-3}\, P_a$
$n = 2.7$
$K = 2\times10^{-12}\, m^2$

B.C. of $P_g = 1$ atm and $S_g = 0.1$ converges in 93 time steps to steady state. This is because Final solution $\approx$ I.C.

Use program defaults for Autostep and limit and change $S_g = .2$ on the boundary then $dt \rightarrow 10^{-22}$ and gets stuck there.

Change Autostep dpmxe to 1E+2 and limit dpmx to 3e+2 then $dt \rightarrow 10^{-13}$ and stays there.

TO get a solution with multiflo, you need to use the solution as the initial condition

Aug 19, 1998

How to get multiflo to solve simple 1-D flow problems. Attempt w/ above & previous page (pg. 4) geometry with prescribed pressure top and bottom boundaries, homogeneous single continuum ~~media~~ medium

DH 8/19/98 DH 8/19/98

* Believe I have found the problem in ~~multiflo~~ input van Genuchten Parameters.
multiflo wants m & I input n

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From Page No. Aug 19, 1998

van Genuchten as I'm used to seeing it

$\psi = P_g - P_l \qquad S = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left(1 + |\alpha\psi|^n\right)^{-m} \qquad m = 1 - 1/n$

$K_r = \sqrt{S}\left(1 - \left(1 - S^{1/m}\right)^m\right)^2$

van Genuchten for metra

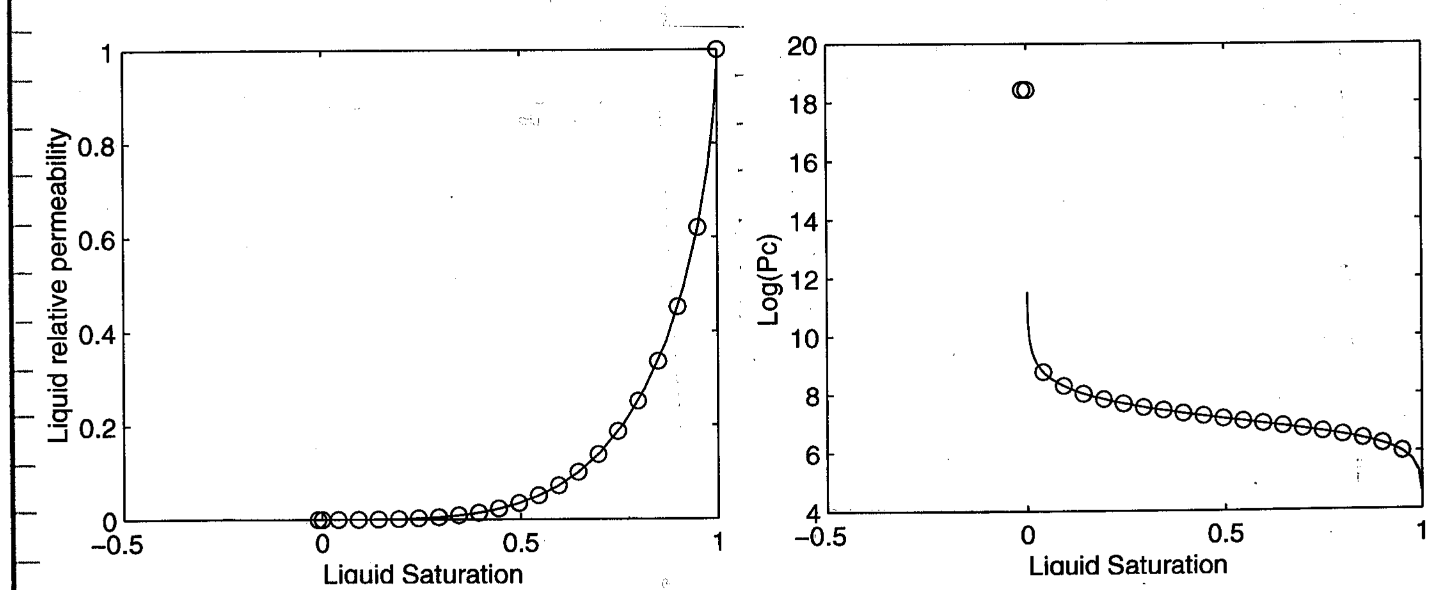
$P_c = P_g - P_l \qquad S_l^{eff} = \frac{S_l - S_l^r}{S_l^0 - S_l^r} = \left(1 + |\alpha P_c|^m\right)^{-\lambda} \qquad \lambda = 1 - 1/m$

Note the n − m confusion

$K_{rl} = \sqrt{S_l^{eff}}\left(1 - \left(1 - (S_l^{eff})^{1/\lambda}\right)^\lambda\right)^2$

And for the output tables plots S_l vs P_c and K_r where $S_l = S_l^{eff}(S_l^0 - S_l^r) + S_l^r$

For my single continuum properties $\alpha = 10^{-3}\, P_a^{-1}$
SWIRM $= S_l^r = .01$ RPM $= \lambda = 1 - 1/2.7 = .63$
Solid line is the function and circles are multiflo tables



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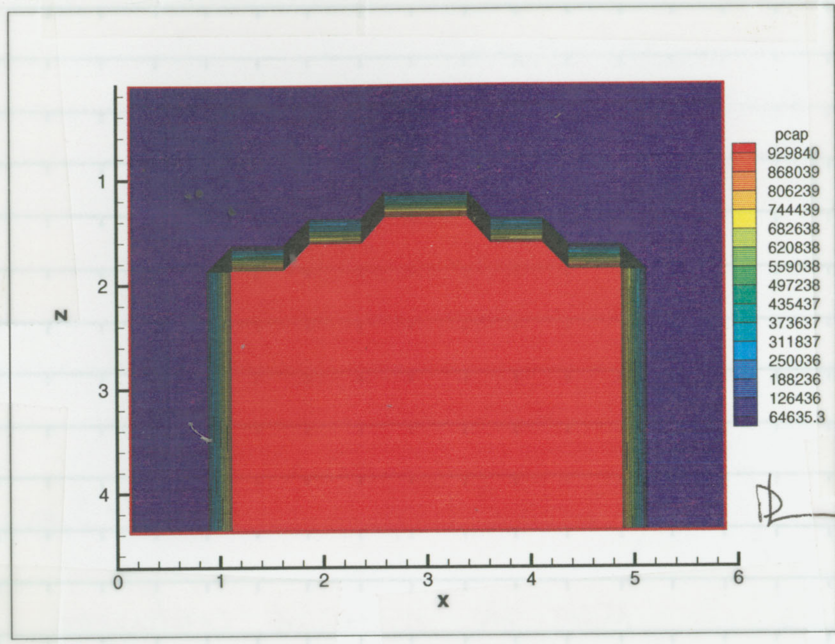

this is the most extreme variation in media properties I was able to attain with this geometry.

Rock

$S_r = .01$

$\lambda = .63$

$\alpha = 1e\text{-}3 \; Pa^{-1}$

$\phi = .001$

$k = 2e\text{-}12 \; m^2$

Drift

$S_r = .001$

$\lambda = .95$

$\alpha = 9e\text{-}6 \; Pa^{-1}$

$\phi = 1.0$

$K = 6e\text{-}4 \; m^2$

I arrived at this state by starting with a homogeneous domain with rock properties then changing bit by bit the properties representing the drift using the solution for each minor change as initial condition for the next minor change. This is the place where this scheme ceased to work. Obviously I have to find another way to model this.

Save this input file as

~dhughson/multiflo/inputbak/multi.7

On right - new grid - left side of top of alcove. Same rock properties as above - Drift $S_r = 1e\text{-}6$ $\lambda = .7$ $\alpha = 1.0 \; Pa^{-1}$ $\phi = 1$ $K_s = 2e\text{-}2 \; m^2$. Top BC liquid vel 1mm/year bottom BC $P_g = atm$ $T = 20C$ $S_g = .95$

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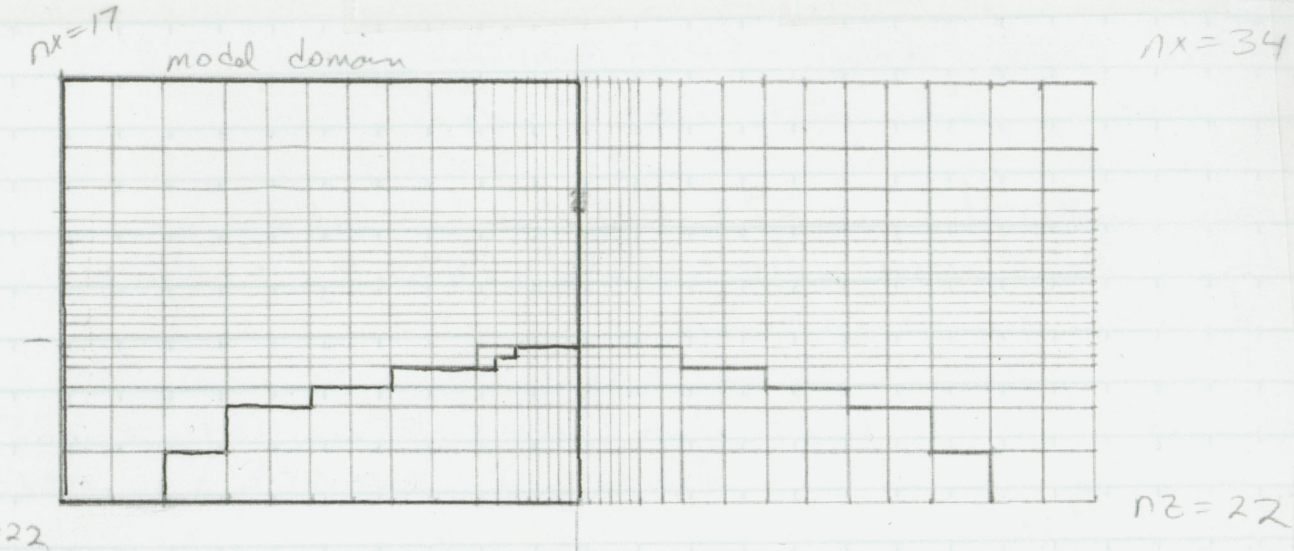


dx	dz
.25	.3
.25	.2
.3	.1
6x.2	15x.05
2x.1	2x.1
6x.05	.2
	.25

symmetrical around center line

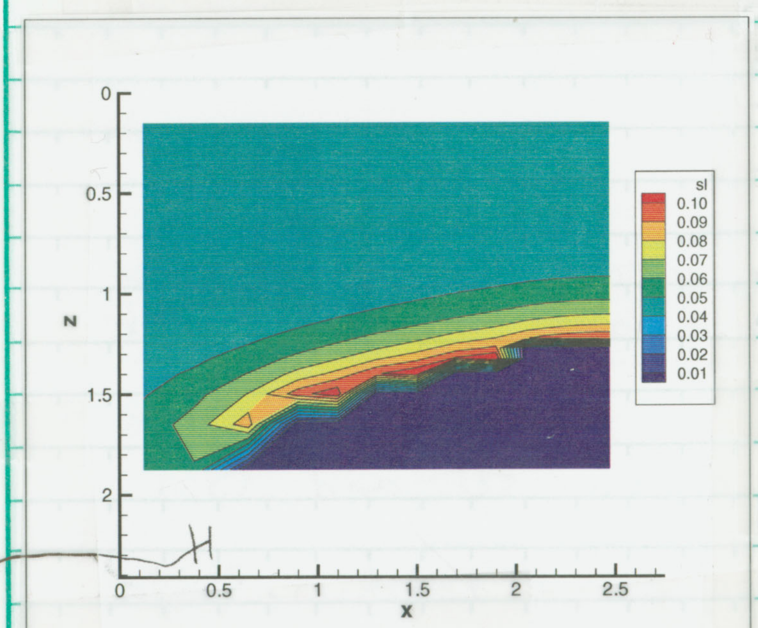
dy ~ .2

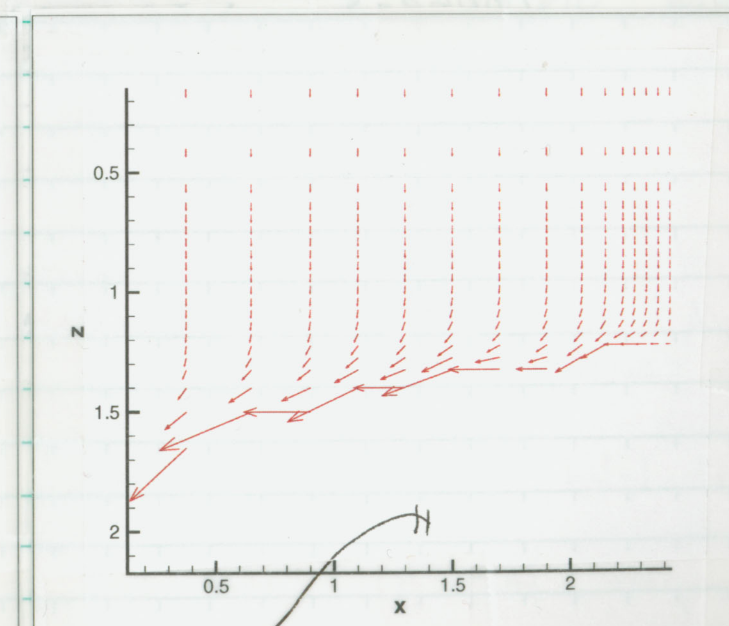
source term at

17 3

dx = .05

dz = .1





file ~dhughson/multiflo/input bak/multi.13

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From Page No.___ Sept 4, 1998

Injection rates from SP33PLM4 Jan 1998 page 23 and Table 2.1

~~In~~ For interval 4.27 - 4.57 m 2.02 g/s
for 8.45 min for total 1023.8 g - 15.1 g
= 1008.7 g injected

Block 17 3 $dz = .1\,m$ $dx = .05\,m$ $dy = .25\,m$
porosity = .001

$$\frac{(1.01\,g/s)\left(\frac{kg}{1000\,g}\right)}{(.1m)(.05m)(.25m)(.001)} = 808\ kg/m^3/s$$

From multi-out source sink summary

time [s]	Qm kgms/s	cumm kgms/s
1	1.008e-3	9.254e-5
2	1.006e-3	5.889e-5
3	1.004e-3	5.247e-5
10	9.904e-4	3.054e-4
30	9.505e-4	2.897e-4

first second injection fairly close. Why the decrease with time? Cummulative mass numbers make no sense.

Calculated 1st arrival time between 50 and 55 s

Compare this to Table 1.2 pg 3 #1 at 5.3 min

What am I doing different?

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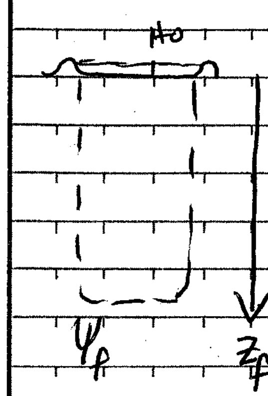
From Page No.___ Sept 4 1998

Set top BC flux to 0.0, rerun steady state with source, 1st arrival is between 55 and 60 s

Cut flux rate in half, arrival about 100 s

Sept 8, 1998 Comparison with Green-Ampt infiltration



$$Kt = \theta_\Delta z_f - \theta_\Delta (H_o + \Psi_f) \ln\left[1 + \frac{z_f}{H_o + \Psi_f}\right]$$

$$1/\alpha = 1000\,Pa = 1000\,\frac{kg\,m/s^2}{m^2} \qquad \Psi_f = \frac{(1/\alpha)}{\rho g}$$

$$\Psi_f = \frac{1000\,\frac{kg\,m/s^2}{m^2}}{1000\,kg/m^3 \ 9.8\,m/s^2} = .102\ m$$

$$K = \frac{k\rho g}{\mu} = \frac{2\times10^{-12}\,m^2\ 1000\,kg/m^3\ 9.8\,m/s^2}{1.119\times10^{-3}\ \frac{kg}{m\cdot s}} = 1.75\times10^{-5}\ m/s$$

$\theta_\Delta = \theta_f - \theta_i$ maximum is porosity $\phi = .001$

$H_o = 0$ $z_f = .65\,m$

$t = 25.5\,s$

Called JS Wang 10 AM Sept 8, 1998 @ 510-486-6753 for information to resolve discrepancies between model arrival times

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Expand in y-direction for 3 slices of .3m
Source at .3m section i = 17 j = 2 k = 3

~~Travel~~ Arrival time between 2 and 3 minutes

Expand in y-direction for 5 slices of 0.3m
Source at i=17 j=3 k=3

Arrival time ~~close~~ btwn 3 & 4 min — close to 4

Expand in y to 7 slices of .3m

excede limit for nconn nconmx = 7000

Sept 9, 1998 Apparently 2D vs 3D is the culprit in the difference btwn the model results here and those in Table 1.2
But I have to wait for Painter to return to recompile metra for larger problems.

In the meantime, under this project number, I'm looking at inverse modeling parameter sets & assumptions involved.

Sept 16, 1998

Found the Appendix to Chap 6 at ftp site
hydra.lbnl.gov in pub/properties

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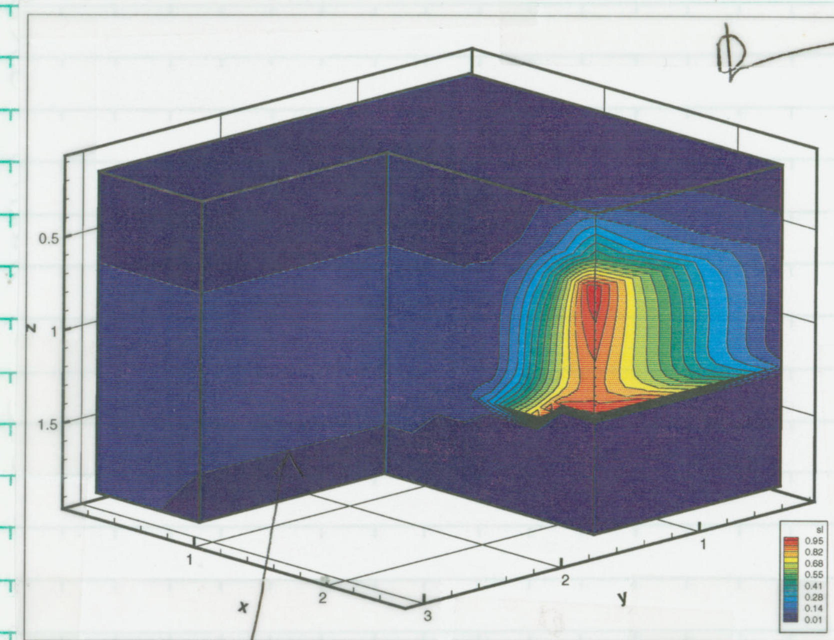
Sept 16, 1998

7 blocks in the y-direction [.6 .5 .4 .3 .4 .5 .6] dy
where injection of 1L is in block .3m

No dripping even at 10 minutes

Input file ~dhughson/multiflo/inputbak/multi.14



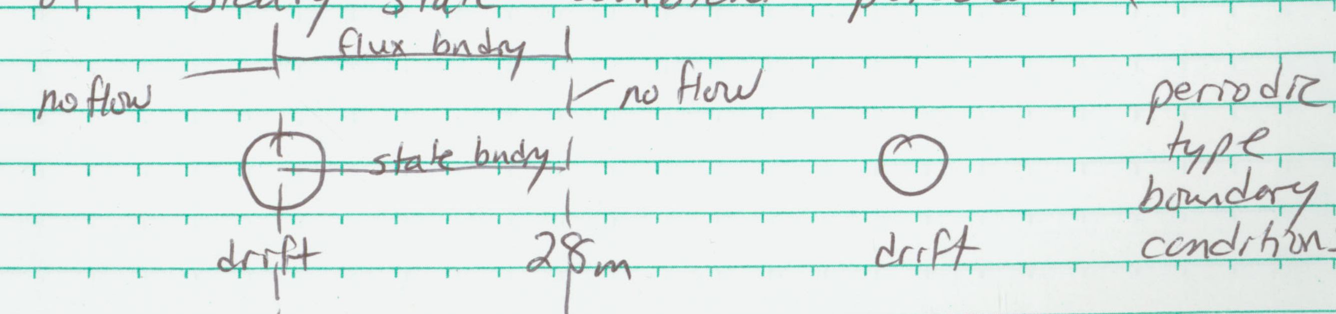
Liquid saturation at 6 minutes after start of injection

Drift ceiling is seen as line ~~at~~ between dark and less dark blue

drift ceiling

Sept 22, 1998

Change model domain ~~to~~ & geometry to model seepage into drifts as a function of steady state ambient percolation



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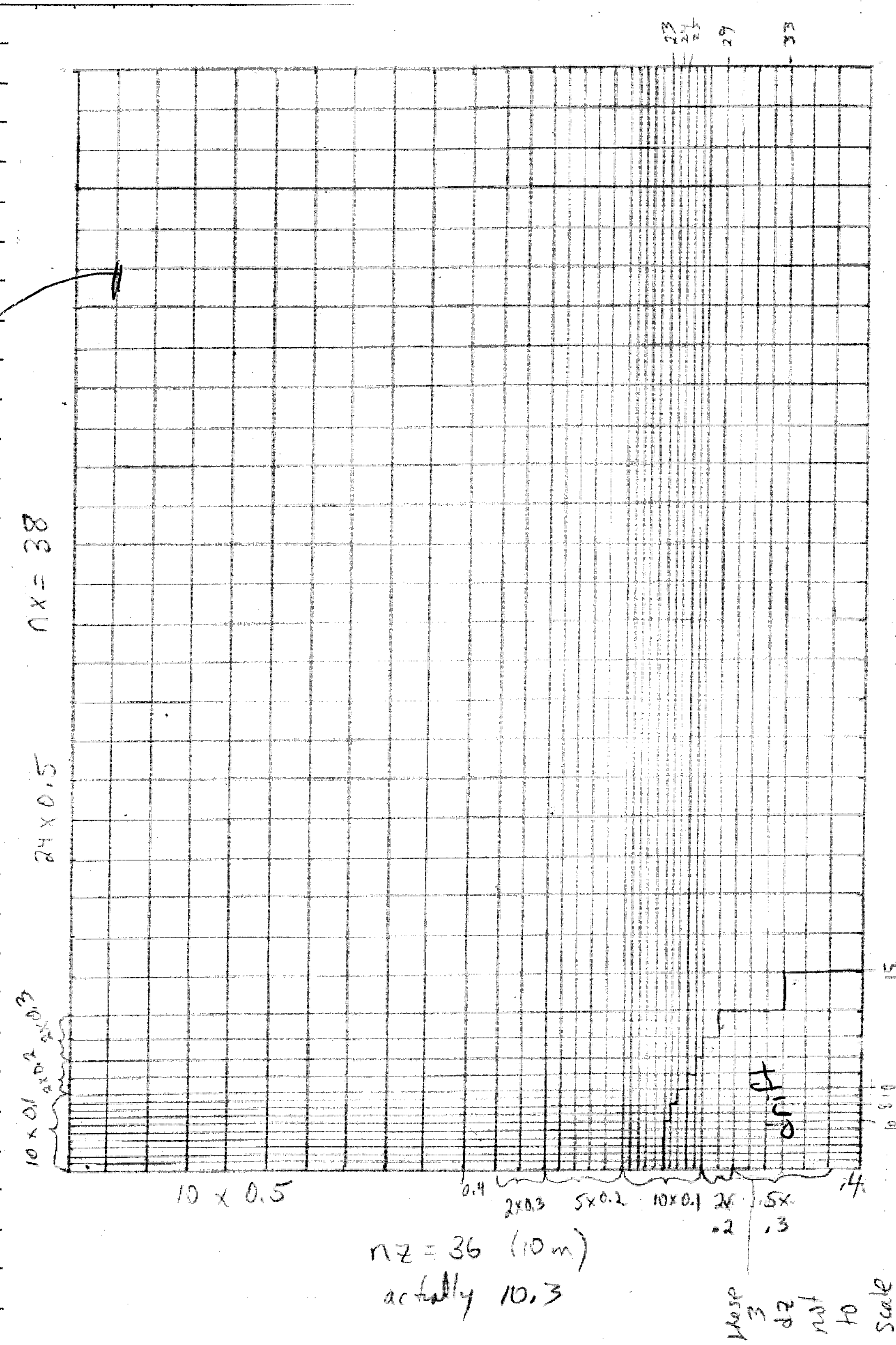

Note where I messed up the scale by making 5x0.2 + 2x0.3 instead of 2x0.2 + 5x0.3 in the drawing (writing is correct)

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Table 3-16 Reference hydrologic properties for steady-state isothermal seepage calculations

Fracture permeability K_f	6.54 x 10^{-7} m^2
Fracture porosity ϕ_f	2.43 x 10^{-4}
Fracture residual saturation S_{rf}	0.04
Fracture van Genuchten α_f	6.86x10^{-4} Pa^{-1}
Fracture van Genuchten $n_f = 1/(1-m_f)$	1.481
Matrix permeability K_m	1.0 x 10^{-13} m^2
Matrix porosity ϕ_m	0.110
Matrix residual saturation S_{rm}	0.08
Matrix van Genuchten α_m	7.54 x 10^{-7} Pa^{-1}
Matrix van Genuchten $n_m = 1/(1-m_m)$	1.473

these parameters used with the ECM for the 2-D homogeneous case

Near-Field/Altered-Zone Models Report
UCRL-ID-129179

3.6.5.4 Results for Steady-State Isothermal Models

A model with uniform hydrologic properties has symmetry along the direction of the drift so that a 2-D model can be used. Various runs were made with 2-D models with different uniform property values. Also run were 2-D and 3-D heterogeneous models, including isotropic and anisotropic heterogeneities. Note that 2-D heterogeneous models can be viewed as approximations to 3-D heterogeneous models with large-scale statistical correlation in the direction of the third axis.

Figure 3-24 shows the seepage flux vs. average percolation flux on a semilog scale. The seepage flux is in units of flow per unit area of the footprint of the drift (i.e., the horizontal plane passing through the drift centerline). Case A shown on the plot is for a 2-D homogeneous model with the reference properties (Table 3-16).

Figure 3-24 Seepage flux into drift vs. average percolation flux into top of model

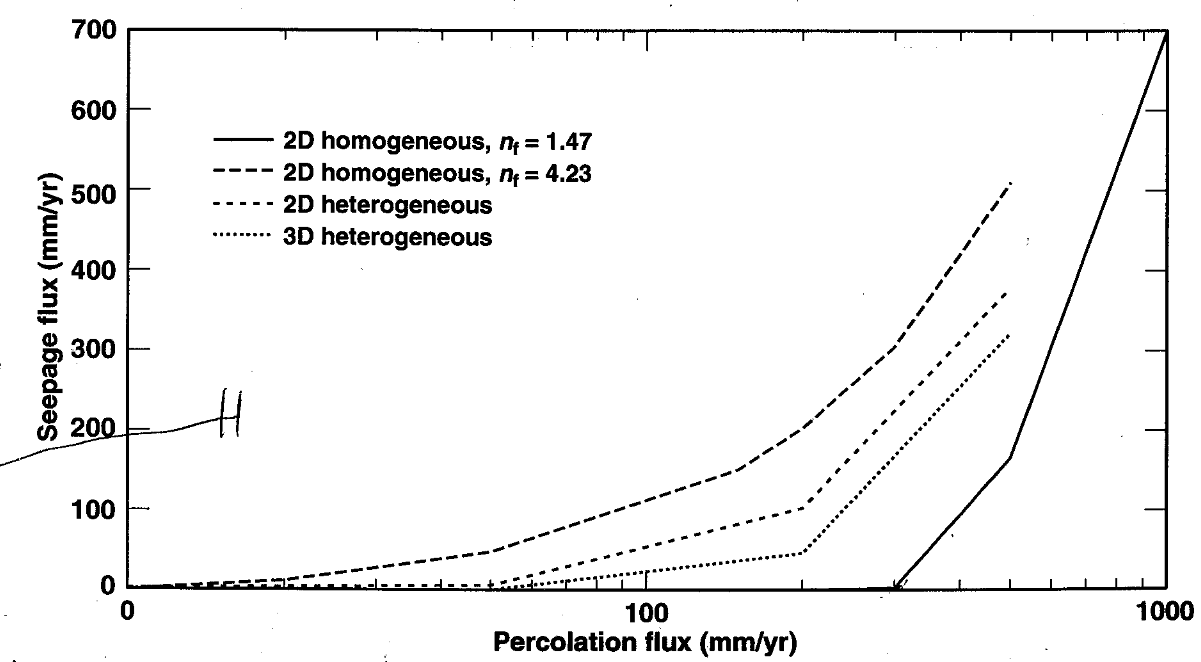

Figure 3-24. Seepage flux into drift vs. average percolation flux into top of model

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TOP BC TYPE 5
Flux = 9×10^{-3} Kg/m²/s $P = 1.014 \times 10^{5}$ Pa $S_g = 0.1$
T = 20C

Bottom BC i = 1 ... 15 TYPE 1
$P = 1.014 \times 10^{5}$ Pa   T = 20C $S_g = 0.5$

i = 16 ... 38
$P = 1.014 \times 10^{5}$ Pa   T = 20C $S_g = 0.1$

this is the flux at which seepage first enters the drift

~~So~~ DH 9/22/98 9×10^{-3} $\frac{Kg}{m^2/s}$ $\frac{1000 m^3}{Kg}$ $\frac{60s}{min}$ $\frac{60min}{hr}$ $\frac{24hr}{d}$ $\frac{365.25d}{yr}$ $\frac{1000mm}{m}$

284018 mm/yr   About 3 orders of magnitude too large

$\alpha_f = 6.86 \times 10^{-4}$ /Pa $\alpha_m = 7.54 \times 10^{-7}$ /Pa } ECM

α drift = 1.0 /Pa   } SCM

Seepage at one block in drift x = 1.55m y = 7.95m
is 1.03×10^{5} mm/yr

Look for cause of too large flux in the parameters modeling the drift as a capillary barrier

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Change drift α from 1.0 to 1×10^{-3} Pa^{-1}
Everything else remaining the same

Seepage break through btw 6.5×10^{-3} to 6.9×10^{-3} Kg/m²/s
or 205124 to 217747 mm/yr

For drift α 1×10^{-5} Pa^{-1}
No seepage at 8.9×10^{-4} Kg/m²/s TOP BC Flux
& can't get past runtime error at 9×10^{-4} Kg/m²/s

this is probably because seepage is ready to occur

9×10^{-4} Kg/m²/s = 28401 mm/yr

1 order magnitude in seepage break thru perc flux for 5 order magnitude change in α

Fig 3-24 pg 15 DH 9/23/98 ~~they~~ their model shows seepage at 200 mm/yr. Mine at least 28400 mm/yr

Difference
1) model geometry   their model constricts flow & forces water into the drift with no-flow boundaries close to the drift.

2) drift simulation – mine is an effective capillary barrier. their K is high for blocks & $P_c = P_g - P_e = 0$ so $P_g = P_e$

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From Page No. ___ Sept 23, 1998

Regarding #2 on previous page.

Using TABular for retention/relative K allows specification of $P_c = 0$ for all saturation

Using the option runtime errors don't allow me to get past 6.3×10^{-3} kg/m²/s & $S_l \sim 1$ right above the drift. Assume seepage occurs (source of runtime error)

~ 198813 mm/yr Bottom boundary dominates P_c & S_l near drift. this & LLNL no-flow boundaries point towards model geom.

My lower BC is possible a primary culprit

Sept 28, the last in this sequence of runs ~~archived~~ DH 9/28/98 ~~is~~ input file archived as

~dhughson/multiflo/inputbak/multi.15

Change of model domain to TSPA-VA geometry. this should show the effect of boundary conditions.

2D slice only. Can be easily expanded to 3D when reasonable results are obtained

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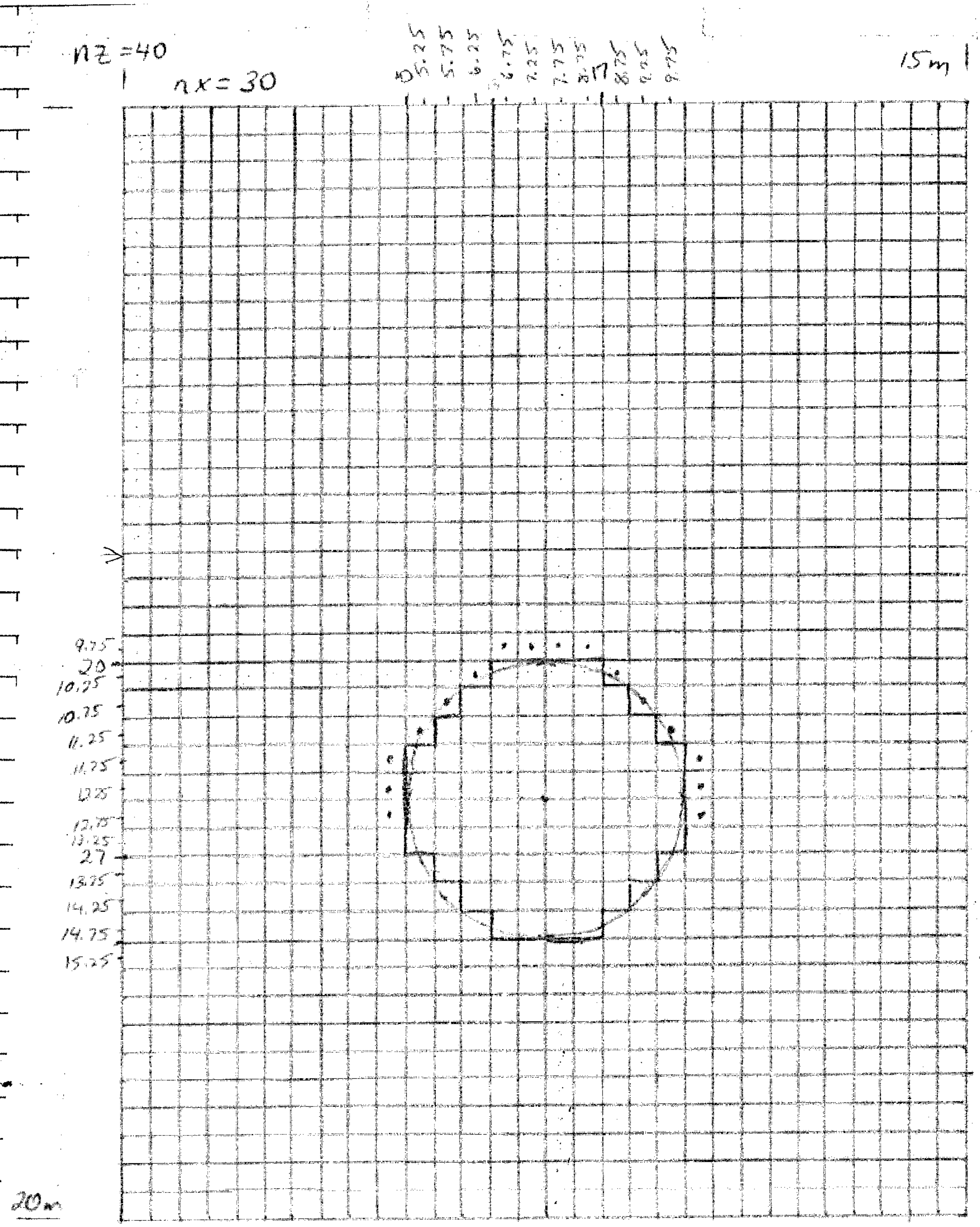

Scale 1" = 3m

Block size is $(0.5m)^3$

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Attempt a direct comparison with previous geometry (pg 14) by using ECM parameters in Table 3-16

The drift is SCM with $S_r = .01$ $m = 0.7$
$\alpha = 0.9 / Pa$ $K_s = 1.e-4$ m^2

Started with $\alpha = 1\ Pa^{-1}$ and could not get past FPE at itype 5 BC flux of $4.e-3$ $kg/m^2/s$.

Changed α to $\alpha = 0.9\ Pa^{-1}$ and seepage occurred

$4.e-3 \frac{kg}{m^2/s} \cdot \frac{m^3}{1000 kg} \cdot \frac{1000 mm}{m} \cdot \frac{60 s}{min} \cdot \frac{60 min}{hr} \cdot \frac{24 hr}{day} \cdot \frac{365.25 day}{yr}$

= 126230 mm/yr So this is the effect of

changing domain, drop from 284018 mm/yr
archive = ~dhughson/multiflo/inputbak/multi.16

Sept 30, 1998 List of comments about multiflo

1) Free drainage boundary
2) what about leap years
3) mass balance in Gem

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Same ECM properties but with Mohan's tabular ~~tabular~~ DH 9/30/98 type curve which sets P_c in the ~~drift~~ to zero for all saturation

No seepage at $3e-3$ $\frac{kg}{m^2/s}$ but endless

run timex errors at $4e-3$ $kg/m^2/s$ as I presume, water tries to enter the drift.

$4e-3$ $kg/m^2/s$ is the same as I got with the $\alpha = 0.9/Pa$, about 126230 mm/year.

SCM, fracture continuum properties

$\phi = 1.24 \times 10^{-4}$ $\alpha = 0.97 \times 10^{-3} / Pa$ $m = 0.633$

$K_s = 10^{-13}$ m^2, Tabular $P_c = 0$ for drift
$K_s = 1.e-4$ m^2 for drift

Top bc flux of $3.07e-8 \frac{kg}{m^2/s} = 0.968$ mm/yr

seepage into drifts between 0.807 and 0.95 mm/yr

Almost all of percolation at this low rate goes straight into the drift.

use drift parameters $S_r = 0.01$ $m = 0.633$
$\alpha = 0.9 / Pa$ $K_s = 1.e-4$ m^2

.968 mm/yr percolation

rates into drift from 0.808 to 0.95 mm/yr

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change α from 0.9 to 100,

seepage between 0.808 and 0.95 mm/yr

Oct 2, 1998

Given all of these conflicting results, I thought it would be a worthwhile exercise to compare multiflo ~~file~~ DH 10/2/98 with the Ross capillary diversion formula. the original reference is

Ross, B. the diversion capacity of capillary barriers, Water Resources Research 27, 2157, 1991

Of course nothing is ever as straight forward as it first appears. this formula is derived using the Gardner form of unsat hydraulic conductivity

While it's probably possible to put in the Gardner form using the TABuler option, there also needs to be a relation between saturation and capillary pressure. After messing around with this for some time it just seemed easier to use the van gen form and the generalized form of the Ross formula. This reference is

Webb, S.W. Generalization of Ross' tilted capillary barrier diversion formula for different two-phase characteristic curves, Water Resourc. Research 33(8), 1855-1859, 1997

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Witnessed & Understood by me, Date | Invented by | Recorded by DH | Date 10/2/98

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Besides the saturation function for Gardner, the boundary condition on the downdip end is problematic. I used 1 1 1 8 with RIGHT and this did not make much sense looking at the results. So I tried using a no-flow boundary and making the ~~vo~~ DH 10/5/98 volume of the end column of blocks 1×10^{20} m^3 each

Oct 5, 1998 each layer is 0.5 m thick

For the example in Webb, the soil properties are

	fine upper	coarse lower
porosity ϕ	0.39	0.42
hydraulic conductivity m/s	2.1×10^{-4}	0.1
θ_r	0.154	0.012
θ_s	0.99	0.99
n	5.74	2.19
m	0.826	0.543
α_{vg} m^{-1}	3.9	490

Convert to multiflo units using $\rho_w = 1000 \frac{kg}{m^3}$
$\mu_w = 1.119 \times 10^{-3} \frac{kg}{m \cdot s}$

	fine upper	coarse lower
porosity	0.39	0.42
k m^2	2.398×10^{-11}	1.142×10^{-8}
S_r	0.184	0.012
m	0.826	0.543
α P_a^{-1}	3.98×10^{-4}	0.05

Infiltration q = 0.48 cm/d

$$\frac{0.48\,cm}{d} \cdot \frac{m}{100\,cm} \cdot \frac{1000\,kg}{m^3} \cdot \frac{d}{24\,hr} \cdot \frac{hr}{60\,min} \cdot \frac{min}{60\,s} = 5.556 \times 10^{-5}\ kg/m^2/s$$

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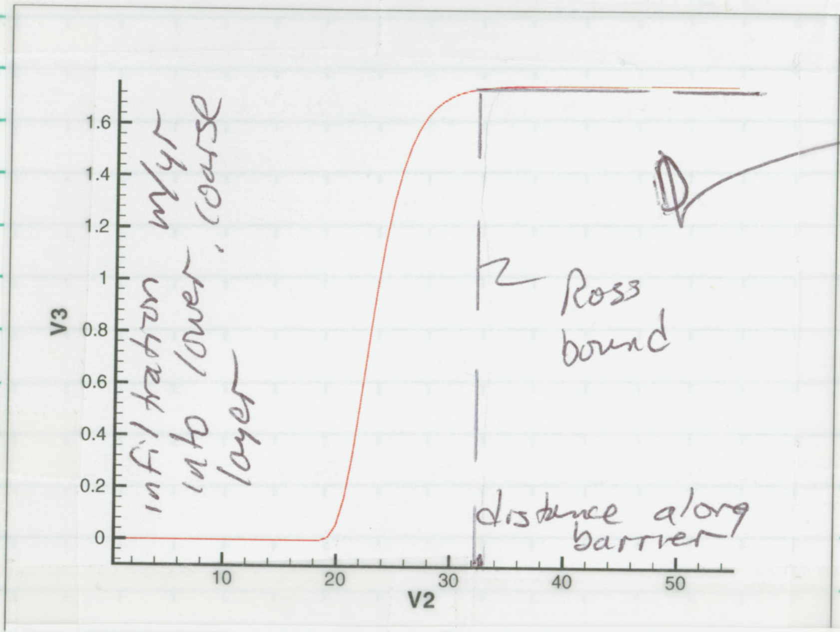
Coarse & fine layer are each 0.5 m thick & dip at 2.86°

Ross formula $Q_{max} = K_s \tan\phi \int K_r \, d\psi$ where the upper and lower bounds are $\frac{q}{K_s}$ for upper & lower layer such that

$$K_r(\psi) = \frac{q}{K_s}$$



comparison to TOUGH2 results in Webb 1997 Figure 5

Early part of curve at x = 20 m is very similar but TOUGH2 doesn't reach a maximum until almost x ≈ 50 m

One difference could be discretization

Save

~dhughson/multiflo/inputbak/multi.17

```
In[369]:= a = 3.98 10^-4;

In[370]:= m = .826;

In[371]:= n = 1/(1-m);

In[372]:= P = P;

In[373]:= S = (1 + Abs[a*h]^n)^(-m);

In[374]:= kr = Sqrt[S] * (1 - (1 - S^(1/m))^m)^2;

In[375]:= ks = 2.1 10^-4;

In[376]:= f = NIntegrate[kr, {h, 283.4, 4399}]

Out[376]= 1692.35

In[377]:= Q = ks * Tan[2.86 * Pi / 180] * f * 1/1000 * 1/9.8

Out[377]= 1.81171 × 10^-6

In[378]:= Q/(5.556 10^-8)

Out[378]= 32.6082
```

Ross Generalized bound

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I may have made a mistake in the residual liquid saturation. DH 10/6/98 ~~by~~ But anyway, changing S_r from 0.184 to 0.154 makes absolutely no difference in the breakthrough curve shown on the facing page.

OK, the Ross capillary diversion formula benchmark went fairly well. It appears the code is working right. One difference in LLNL and my model is the bottom boundary. They use a "free-drainage" BC, while I've been using a first type BC.

Check this. Eliminate boundary along the bottom and put instead a row of blocks with volume each 1×10^{20} m^3. Results are identical. I didn't really think the bottom BC made any difference

Mohan suggested I change the fracture pore volume increase by a factor of 2. Change porosity from 1.24e-4 to 2.48e-4. No change in results. Still .807 to .95 mm/yr into drift

Controlling factor is fracture α parameter change α from 0.97e-3 to 0.97e-4 Pa^{-1} and there is no seepage

Obviously an important parameter about which there is no data

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Reference for the first set of models ~~Ɓ~~ niche 3650 & seepage model on page 15 is the Near-Field/Altered-zone Models Report

Reference for the fracture continuum starting on page 19 is

Total System Performance Assessment (TSPA-VA) Analyses Technical Basis Document Unsaturated zone hydrology model Aug 14, 1998 by TRW Environmental Safety Systems

pg 2-88 "there is a need to include heterogeneities"

pg 2-92 "Heterogeneity is considered only for the fracture permeabilities"

There is no data on van Genuchten parameters for fracture continuum. From Bodvarsson 1997

Assume fracture permeability = air permeability

$K = \bar{f}\,\frac{b^3}{12}$ cubic law where $\bar{f}$ = mean fracture frequency

Assume simplified form of Young-Laplace eq. (Altman, 1996)

$\alpha = \frac{b\rho g}{2\tau\cos\theta}$ $\rho = 998\ \frac{kg}{m^3}$ @ 20°C

$\tau = 0.072\ N/m$ θ = contact angle (assumed = 0)

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Or alternatively $S_{we} = \frac{1}{2}\left[1 \pm \mathrm{erf}\left|\frac{\log\bar{b} - \beta}{\sigma\sqrt{2}}\right|\right]$

$\beta = \sigma^2 \ln 10 + y_0$ $y_0 = \log \bar{b}$

$P_c = \frac{2\tau\cos\theta}{\bar{b}\rho g}$ then curve fit

From TSPA-VA mean of $K = 10^{-13}\ m^2$

$\bar{f} = 1.88/m$

$b = \left(\frac{10^{-13}\ 12}{1.88}\right)^{1/3} = 8.61\times10^{-5}\ m$

$\alpha = \frac{(8.61\times10^{-5}\ m)\left(998\ \frac{kg}{m^3}\right)\left(9.8\ \frac{m}{s}\right)}{2\ (.072\ kg/s^2)} = 5.85/m$

$= 5.98\times10^{-4}\ /Pa$

as compared to α used $= 0.97\times10^{-3}\ /Pa$

Reasoning used to hold α uniform at $9.7\times10^{-4}\ /Pa$ is inconsistent since it is very unlikely that $\bar{f}$ will vary over 4 orders of magnitude. Also seepage into drifts likely to be much more sensitive to α than K

α should vary with K according to the distribution of $\bar{f}$

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Project No. 20-1402-861
Book No. 285 TITLE USFIC

From Page No.____ Oct 7, 1998

With $K_s = 10^{-13}\,m^2$ & varying α, rest of van Genuchten parameters constant, seepage first occurs into the drift with $\alpha = 5.1e-4/Pa$ at percolation 2 mm/year.

Suppose this calibrates my model to Livermore or TSPA-VA, then ~~each~~ calculate seepage fraction based on total volumetric flux

Note * this model is very sensitive to the fracture van gen α parameter

Top area $= 15\,m \times 0.5\,m = 7.5\,m^2$
$q = 6.34 \times 10^{-8}$ kg/m²/s

$$\left(6.34\times10^{-8}\,\frac{kg}{m^2/s}\right)\left(7.5\,m^2\right)\frac{m^3}{998\,kg}\;\frac{60\,s}{\cancel{min}}\;\frac{60\,min}{hr}\;\frac{24\,hr}{day}\;\frac{365.25\,d}{year}$$

DH 10/7/98

$= 1.503571 \times 10^{-2}$ m³/year $= 2.005$ mm/year

$K_s = 10^{-13}\,m^2$ $\alpha = 5.1e-4\,/Pa$ $m = .633$ $S_r = .01$

DH 10/7/98

~~infiltration~~
~~6.34×10^{-8} kg/m²/s 1.504×10^{-2} m³/yr~~

not how I want to do it DH

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Infiltration kg/m²/s	m³/yr	mm/yr	Cummulative Seepage m³/yr	fraction
6.34×10^{-8}	1.5036×10^{-2}	2.005	1.13156×10^{-5}	7.526×10^{-4}
1.58×10^{-7}	3.7471×10^{-2}	4.996	6.83046×10^{-3}	1.8229×10^{-1}
3.17×10^{-7}	7.518×10^{-2}	10.024	1.90463×10^{-2}	2.5335×10^{-1}
6.34×10^{-7}	1.5036×10^{-1}	20.048	4.35952×10^{-2}	2.8994×10^{-1}
1.27×10^{-6}	3.0119×10^{-1}	40.158	9.32109×10^{-2}	3.0948×10^{-1}
2.54×10^{-6}	6.0238×10^{-1}	80.317	0.192865	3.2017×10^{-1}
4.75×10^{-6}	1.1265	150.199	~~0.33~~ 0.366989	3.2578×10^{-1}

Looking at volumn fraction seepage per volumn infiltration should approach 0.33 as $q_{in} \to \infty$ simply based on model geometry. Drift intercepts 1/3 of the total width. Seepage is not uniform along the ~~ce~~ ceiling of the drift so I'll just take the average

10 blocks with footprint $(0.5\,m)^2 = 0.25\,m^2$

area $= 2.5\,m^2$

$$0.366989\,\frac{m^3}{yr}\;\frac{1}{2.5\,m^2}\;\frac{1000\,mm}{m} = 146.8\,mm/yr$$

fraction $= 0.977$

file used to produce this data archived as

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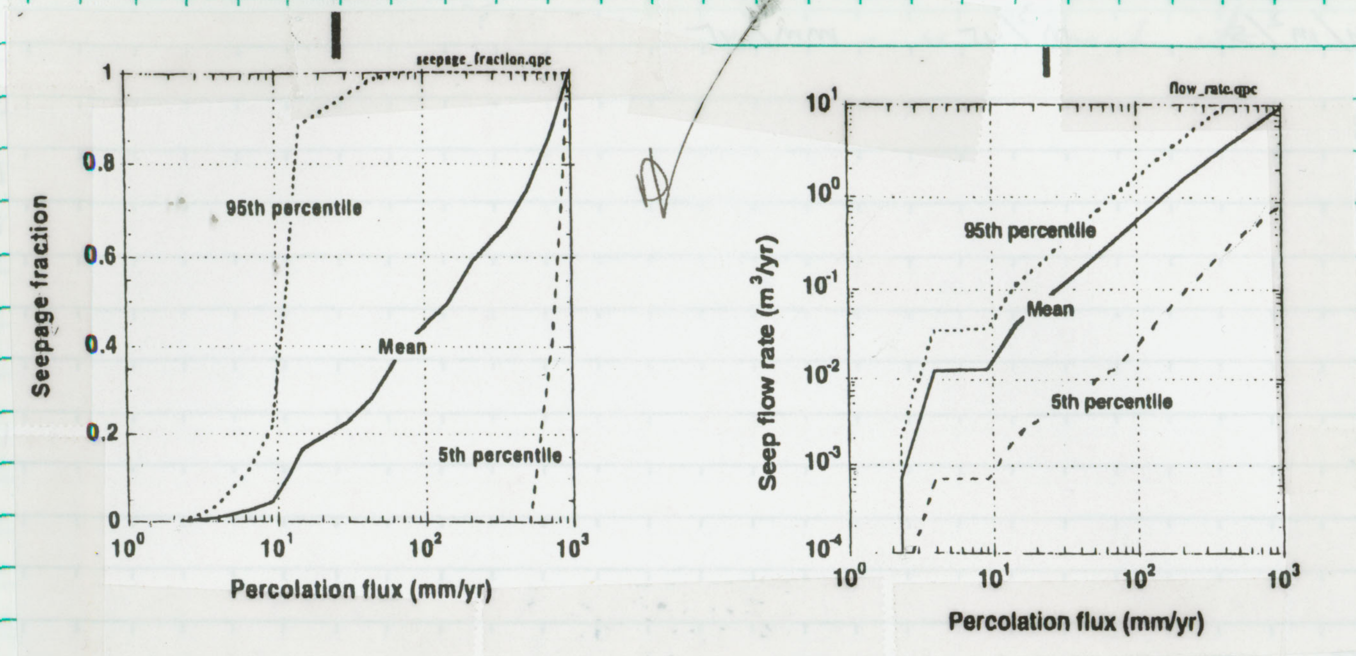
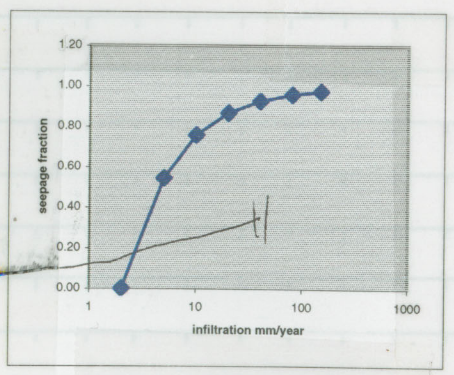
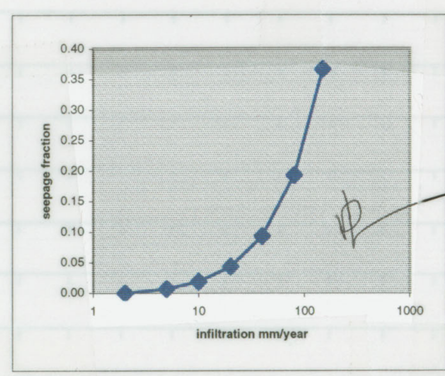
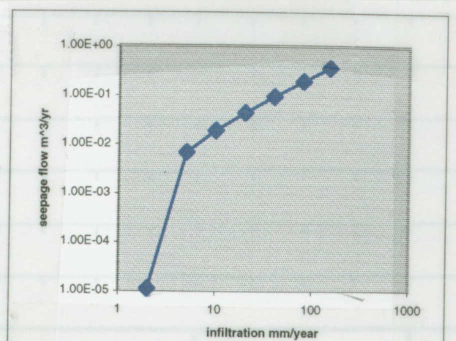


these figures are from an overhead labeled TSPA-VA Base Case Seepage and the identifier is TRBANDRW.PPT, 125, NWTRB/6-24-98







This y-axis is volumetric seepage into drift m^3/year

← same plot with log-y axis

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Seepage flow rate (m^3/year) vs. percolation flux (mm/yr) compare much more closely (same data) than does seepage fraction vs. percolation flux suggesting that we are defining seepage fraction differently

A related set of overheads is

A process model for seepage into drifts at Yucca Mountain, presented to DOE/NRC Technical exchange on TSPA-VA by Jens Birkholzer

In addition to Remaining Uncertainties and Issues on the last slide of this set I would add

- at a fracture spacing of 1.88/m how viable is the continuum approach with block size on the order of 0.5 m ?
- A key parameter is fracture α yet there are no data, only another conceptual model relating this to air permeability. How well are fractures represented by van Genuchten model ?

According to the above referenced presentation by Birkholzer, if I increase K_s an order of magnitude from 10^{-13} to 10^{-12} m^2 holding α the same I should get less seepage

Ks/m²/s	m³/year		
6.34e-8	0	6.34e-6	0.436578
1.58e-7	0	7.92e-6	0.559609
3.17e-7	0		
6.34e-7	2.26603e-4		
1.27e-6	4.49434e-2		
2.54e-6	0.142319		
4.75e-6	0.313115		

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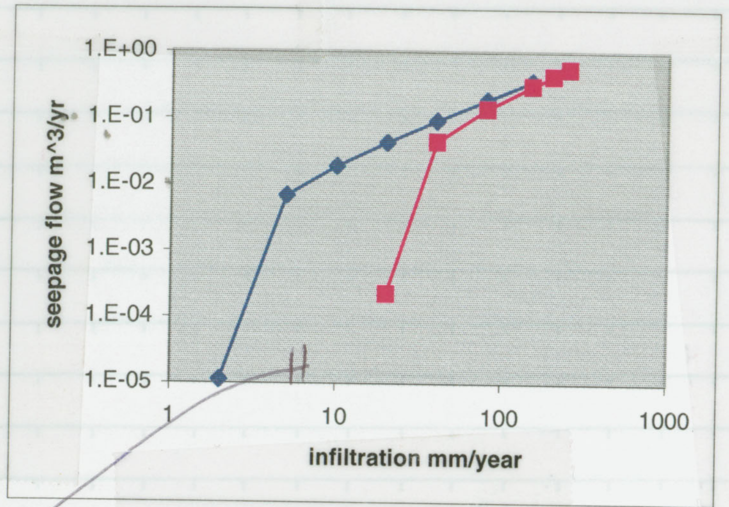


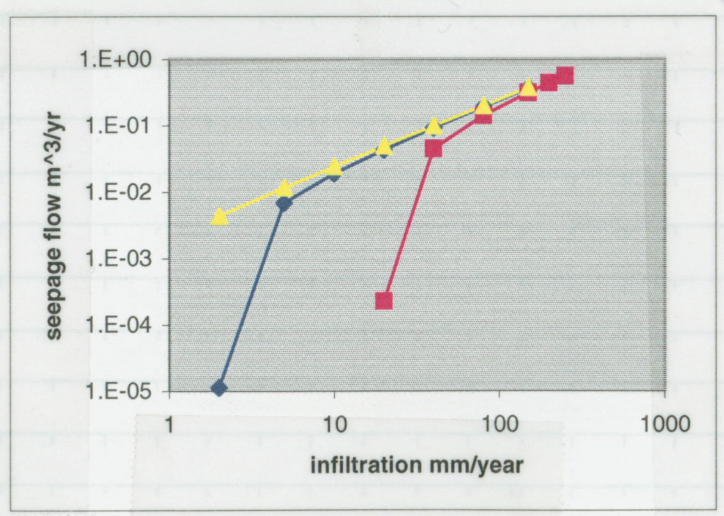
Red line is from holding α constant at 5.1e-4 / Pa and changing K_s from 10^{-13} to 10^{-12} m^2

DH 11/6/98

~~DSH~~ Notice how changing one parameter by 1 order of magnitude causes the curve to fall outside of the 5th percentile on the TSPA-VA plot (pg 30). Yet this parameter varies at least over 3 orders of magnitude. This doesn't lend much confidence to the supposed confidence intervals for TSPA-VA

Keep α constant = 5.1e-4/Pa & change K_s to 10^{-14} m^2

Infiltration kg/m²/s	seepage m³/year
6.34e-8	4.36578e-3
1.58e-7	1.17611 e-2
3.17e-7	2.42663e-2
6.34e-7	4.92936e-2
1.27e-6	9.96360e-2
2.54e-6	0.200353
4.75e-6	0.375857



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Preliminary attempt to develop an alternative conceptual model for seepage into drifts.

* Does not rely on a fracture continuum approach.
* Takes into account prominent discrete fractures
* Incorporates geologic information where available
* Results in estimates of fraction of packages dripped on
* Results in estimates of seepage spacing

References:

Philip, J.R. J.H Knight, R.T. Waechter, Unsaturated seepage and subterranean holes: Conspectus, and exclusion problem for circular cylindrical cavities WRR 25(1) p 16-28, 1989

Philip, J.R. Asymptotic solutions of the seepage exclusion problem for elliptic-cylindrical, spheroidal, and strip- and disc- shaped cavities, WRR 25(7), p 1531-1540, 1989

Philip, J.R. The seepage exclusion problem for sloping cylindrical cavities, WRR 25(6) p 1447-1448, 1989

derivation of basic idea as follows

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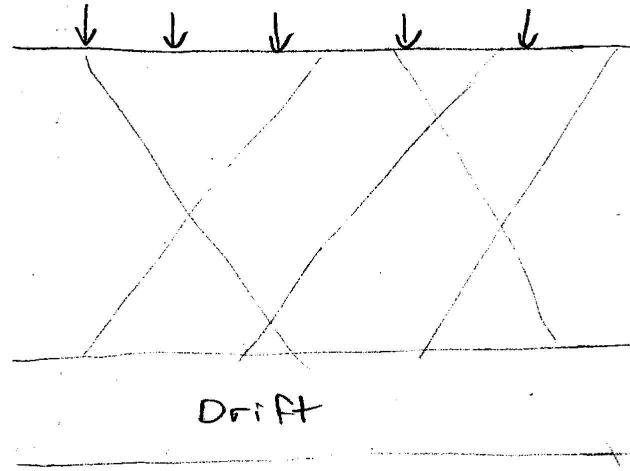
Fracture Continuum in the Dual Continuum model Approach provides } Boundary condition on vertical seepage flux

q_{inf} = uniform & constant



Discrete Fracture Model

Ignore matrix flux

Ignore fracture intersections

seepage = f(q_{inf}, fracture distribution, fracture properties)

Assume: Flow in each fracture can be described by a 2D form of Richard's Eq. (steady state)

For a fracture parallel to gravity:

$$\nabla\cdot\left(K\nabla(\psi - z)\right) = 0$$

Isotropic

$$\nabla\cdot\left(K\left(\frac{\partial\psi}{\partial x} + \frac{\partial\psi}{\partial z} - 1\right)\right) = 0 \qquad \frac{\partial}{\partial x}\left(K\frac{\partial\psi}{\partial x}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial\psi}{\partial z}\right) - \frac{\partial K}{\partial z} = 0$$

$$\nabla\cdot(K\nabla\psi) = \frac{\partial K}{\partial z}$$

Kirchoff transformation:

$$\Theta = \int_{-\infty}^{\psi} K(\psi)\,d\psi$$

using the Gardner model $K(\psi) = K_s e^{\alpha\psi}$

Leibnitz Rule:

$$\frac{d}{dx}\int_{a(x)}^{b(x)} f(x,y)\,dy = \int_{a(x)}^{b(x)} \frac{\partial f(x,y)}{\partial x}\,dy + f(b,y)\frac{\partial b}{\partial x} - f(a,y)\frac{da}{dy}$$

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$$\frac{\partial\Theta}{\partial x} = \frac{\partial}{\partial x}\int_{-\infty}^{\psi} e^{\alpha\psi}\,d\psi = \int_{-\infty}^{\psi} 0\,d\psi + e^{\alpha\psi}\frac{\partial\psi}{\partial x} - 0 = K\frac{\partial\psi}{\partial x}$$

$$\frac{\partial^2\Theta}{\partial x^2} = \frac{\partial}{\partial x}\left(K\frac{\partial\psi}{\partial x}\right) \quad \text{likewise} \quad \frac{\partial^2\Theta}{\partial z^2} = \frac{\partial}{\partial z}\left(K\frac{\partial\psi}{\partial z}\right)$$

so $\nabla\cdot(K\nabla\psi) = \frac{\partial K}{\partial z}$ becomes $\nabla^2\Theta = \frac{\partial K}{\partial z}$

$$\frac{\partial K}{\partial z} = \frac{\partial(e^{\alpha\psi})}{\partial z} \qquad \Theta = \int_{-\infty}^{\psi} e^{\alpha\psi}\,d\psi = \frac{e^{\alpha\psi}}{\alpha}\Big|_{-\infty}^{\psi} = \frac{e^{\alpha\psi}}{\alpha}$$

$\alpha\Theta = e^{\alpha\psi}$ α = constant so $\frac{\partial K}{\partial z} = \alpha\frac{\partial\Theta}{\partial z}$

$$\nabla^2\Theta = \alpha\frac{\partial\Theta}{\partial z}$$

Far from the drift seepage is uniform $K_0 = q_{inf}$

so $\lim_{x^2+y^2\to\infty}\Theta = \Theta_0$

normalize $\theta = \frac{\Theta}{\Theta_0}$ $\zeta = \frac{x}{l}$ $\eta = \frac{z}{l}$

$$\frac{\partial}{\partial x}\left(\frac{\partial\theta}{\partial x}\right) + \frac{\partial}{\partial z}\left(\frac{\partial\theta}{\partial z}\right) = \alpha\frac{\partial\theta}{\partial z}$$

$$\frac{\partial}{\partial(l\zeta)}\left(\frac{\partial\theta}{\partial(l\zeta)}\right) + \frac{\partial}{\partial(l\eta)}\left(\frac{\partial\theta}{\partial(l\eta)}\right) = \alpha\frac{\partial\theta}{\partial(l\eta)}$$

$\nabla^2\theta = \alpha l\frac{\partial\theta}{\partial\eta}$ where ∇ is on the transformed coordinates

let $s = \frac{\alpha l}{2}$ then $\nabla^2\theta = 2s\frac{\partial\theta}{\partial\eta}$

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Let $H = (\vartheta - 1)e^{-s\eta} = \vartheta e^{-s\eta} - e^{-s\eta}$

$$\frac{\partial H}{\partial \zeta} = \frac{\partial \vartheta}{\partial \zeta} e^{-s\eta} \qquad \frac{\partial^2 H}{\partial \zeta^2} = \frac{\partial^2 \vartheta}{\partial \zeta^2} e^{-s\eta}$$

$$\frac{\partial H}{\partial \eta} = \frac{\partial \vartheta}{\partial \eta} e^{-s\eta} - \vartheta s e^{-s\eta} + s e^{-s\eta}$$

$$\frac{\partial^2 H}{\partial \eta^2} = \frac{\partial^2 \vartheta}{\partial \eta^2} e^{-s\eta} - \frac{\partial \vartheta}{\partial \eta} s e^{-s\eta} - \frac{\partial \vartheta}{\partial \eta} s e^{-s\eta} + \vartheta s^2 e^{-s\eta} - s^2 e^{-s\eta}$$

substitute in $\frac{\partial^2 \vartheta}{\partial \zeta^2} + \frac{\partial^2 \vartheta}{\partial \eta^2} = 2s \frac{\partial \vartheta}{\partial \eta}$

$$\frac{\partial^2 \vartheta}{\partial \zeta^2} = \frac{\partial^2 H}{\partial \zeta^2} e^{s\eta} \qquad \frac{\partial \vartheta}{\partial \eta} = \frac{\partial H}{\partial \eta} e^{s\eta} + \vartheta s + s$$

$$\frac{\partial^2 \vartheta}{\partial \eta^2} = \frac{\partial^2 H}{\partial \eta^2} e^{s\eta} + 2\frac{\partial \vartheta}{\partial \eta} s - \vartheta s^2 + s^2$$

$$\frac{\partial^2 H}{\partial \zeta^2} e^{s\eta} + \frac{\partial^2 H}{\partial \eta^2} e^{s\eta} + 2\frac{\partial \vartheta}{\partial \eta} s - \vartheta s^2 + s^2 = 2s\left(\frac{\partial H}{\partial \eta} e^{s\eta} + \vartheta s + s\right)$$

$$= 2s \frac{\partial H}{\partial \eta} e^{s\eta} + 2\vartheta s^2 + 2s^2$$

$$\frac{\partial^2 H}{\partial \zeta^2} + \frac{\partial^2 H}{\partial \eta^2} = 2s\frac{\partial H}{\partial \eta} - 2s\frac{\partial \vartheta}{\partial \eta} e^{-s\eta} + 3s^2 \vartheta e^{-s\eta} + s^2 e^{-s\eta}$$

$$= 2s\frac{\partial H}{\partial \eta} - 2s e^{-s\eta}\left(\frac{\partial H}{\partial \eta} e^{s\eta} + \vartheta s + s\right) + 3s^2\vartheta e^{-s\eta} + s^2 e^{-s\eta}$$

$$= 2s\frac{\partial H}{\partial \eta} - 2s\frac{\partial H}{\partial \eta} - 2s^2\vartheta e^{-s\eta} - 2s^2 e^{-s\eta} + 3s^2\vartheta e^{-s\eta} + s^2 e^{-s\eta}$$

$$= s^2 \vartheta e^{-s\eta} - s^2 e^{-s\eta}$$

$$= s^2 e^{-s\eta}(\vartheta - 1) = s^2 H$$

then $\nabla^2 H = s^2 H$ Helmholtz Eq.

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For a circle of radius ℓ centered at $(x=0, y=0)$

$$H = 4\left\{\sum_{j=1}^{\infty} \frac{j I_j(s)}{K_j(s)} K_0(sr) + \sum_{n=1}^{\infty} (-1)^n K_n(sr) \cos n\phi \left[\frac{n I_n(s)}{K_n(s)} + 2\sum_{j=n+1}^{\infty} \frac{j I_j(s)}{K_j(s)}\right]\right\}$$

for radial coordinates $x = r\sin\phi$ $z = r\cos\phi$

then

$$\vartheta = 1 + 4e^{sr\cos\phi}\left\{\sum_{j=1}^{\infty} \frac{j I_j(s)}{K_j(s)} K_0(sr) + \sum_{n=1}^{\infty} (-1)^n K_n(sr)\cos n\phi \left[\frac{n I_n(s)}{K_n(s)} + 2\sum_{j=n+1}^{\infty} \frac{j I_j(s)}{K_j(s)}\right]\right\}$$

Critical seepage

$$q_* = \frac{K_s}{\vartheta_{max}(s)}$$

$$\vartheta_{max} = 1 + 4e^{-s}\left\{\frac{s}{2}\left(I_0(s) + I_1(s)\right) + \sum_{n=1}^{\infty} \frac{n I_n(s)}{K_n(s)} \sum_{j=-(n-1)}^{n-1} K_j(s)\right\}$$

For an ellipse with apical ~~radius~~ of curvature ℓ and long axis vertical

$$\vartheta_{max} \cong 2s + 3 - \frac{3}{s} + \frac{21}{s^2} - \cdots$$

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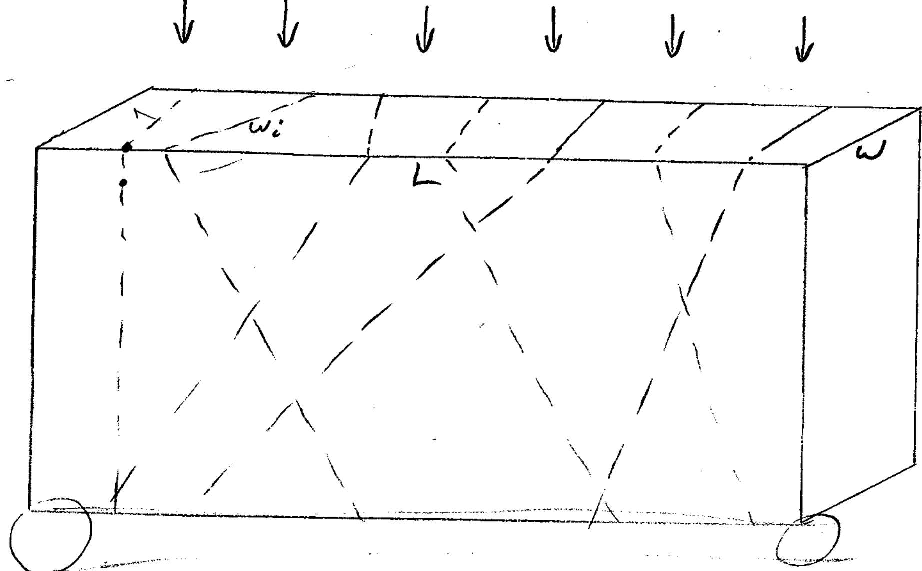


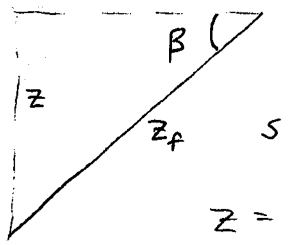
q_{inf} = uniform & constant

n fractures each with aperture b_i so that

$$(q_{inf})Lw = Q = \sum_{i=1}^{n} w_i b_i q_i$$

DH Nov 9 1998

In 1D for fracture dipping at angle β



$$\sin\beta = \frac{z}{z_f}$$

$$z = z_f \sin\beta$$

$$\frac{\partial}{\partial z}\left(K\frac{\partial\psi}{\partial z}\right) = \frac{\partial K}{\partial z}$$

$$\frac{\partial}{\partial(z_f\sin\beta)}\left(K\frac{\partial\psi}{\partial(z_f\sin\beta)}\right) = \frac{\partial K}{\partial(z_f\sin\beta)}$$

$$\frac{\partial}{\partial z_f}\left(K\frac{\partial\psi}{\partial z_f}\right) = \sin\beta\,\frac{\partial K}{\partial z_f}$$

$$q_i = -K\frac{\partial(\psi - z)}{\partial z} = -K\left(\frac{\partial\psi}{\partial z} - 1\right)$$

$$q_i = -K\frac{\partial(\psi - z_f\sin\beta)}{\partial(z_f\sin\beta)} = -K\left(\frac{\partial\psi}{\sin\beta\,\partial z_f} - 1\right) = \frac{-K}{\sin\beta}\left(\frac{\partial\psi}{\partial z_f} - \sin\beta\right)$$

$$q_i = K_i$$

$$(q_{inf})Lw = \sum_{i=1}^{n} w_i b_i K_i \qquad K_i = K_{S_i} e^{\alpha_i \psi}$$

w_i = length of trace of fracture intersection with horizontal

K_{S_i} = Saturated K of fracture i

α_i = fracture α related to b_i

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Review of Seepage into drifts from Chapter 2 of the TSPA-VA

Pg 2-60 – "there are no direct measurements of fracture aperture" – So Why Not?

2-101 – seepage depends sensitively on fracture α and K

2-102 – "long-term alteration will induce additional fracturing close to drift wall".

the point is that the fractures have to be a network for capillary diversion to be effective. But what's the basis for this statement and how does that jive with the postulated silica precipitation from the thermal pulse?

2-102 – "better estimates of discrete features"

But fractures are by their very nature "discrete features" and the continuum is only a conceptual model. One that is not well-substantiated.

2-126 "process model consisted of a 3D heterogeneous fracture-continuum" If heterogeneity is so important, how can you represent it with a single realization?

2-128 "Seepage fraction, or fraction of waste packages contacted by seepage water"

this appears to be a definition of sorts

From Page No. Nov 11, 1998

What happens between pages 2-128 and 2-129

pg 2-91 "the experimental information discussed above is insufficient to determine the correlation structure of the heterogeneous field"

But if you think that the air permeability data are such that you can condition the heterogeneous fields on this data, then why can't you use the same data to calculate a simple variogram to estimate the correlation?

2-92 "Heterogeneity is considered only for the fracture permeabilities", "the other fracture and matrix properties are assumed to be uniformly distributed"

But seepage is sensitive to both α and k. So how can you justify considering α constant and k random? The rationale in the following paragraph does not support the assumption of uniform α

2-100 "This indicates the need for a stochastic approach..."

So why don't you actually do one instead of repeating that you need to over and over again?

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2-100 "for the second case using $\alpha = 2\times10^{-4}$ Pa^{-1} instead of the original value of $\alpha = 9.73\times10^{-4}$ Pa^{-1}"

Given the highly uncertain recharge used to derive this parameter, the total lack of data, and the natural heterogeneity, don't you think the variability ~~of~~ might be larger than this? [initials] 11/11/98

2-106 "Spacing of seepage locations is dependent on the correlation lengths"

See my comment 2-91

2-113 "project personnel derive appropriate distributions of seepage fraction..."

HOW?

2-114 "f_s is just the fraction of drift segments that have some seepage"

2-132

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From Page No. ___ Nov 12, 1998

Resulting from the VA review,

Need to find out in a systymatic way the importance of the van Genuchten α parameter to seepage into drifts.

* ~~Is~~ Does spatial heterogeneity of α in addition to spatial heterogeneity of K increase seepage?

Attempt a 5 m segment of the 2-D grid on page 19.

Needs 30 x 40 x 10 nodes = 12,000

OK - it works for the homogeneous case

Notes from Chap 2 TSPA-VA TBD pg 2-112 (rev 0)

range of α 3.3e-4, 9.7e-4, 3.3e-3 Pa^{-1}

$\sigma_\alpha = 0.5$ $\sigma_\alpha^2 = 0.25$

range of K 10^{-14} 10^{-13}, 10^{-12} m^2

Chap 2 TSPA-VA TBD pg 2-91

spherical corr 2m for $K < 10^{-12.5}$ m^2

corr 4m vertical & NS and

corr 1.4 m EW for $K > 10^{-12.5}$

using SGSIM and histogram in fig 2-54

5/4 7135209484

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From Page No. ___ Nov 13, 1998

Generate random K field, set for correlations

$\lambda_x = 2m$ $\lambda_y = 2m$ $\lambda_z = 4m$, generated field used for simulation has geometric mean = 1.779e-13 m^2 $\sigma_f^2 = 0.245$

min = 3.81e-15 m^2 max = 6.87e-12 m^2

α = constant 9.7e-4 Pa^{-1} m = 0.633

ϕ = constant = 1.24e-4

Nov 16, 1998

Infiltration Rate (mm/year)	cummseep (m^3/y)	Avg seep (mm/yr)
2 mm/yr = 6.~~38~~ 4 e-8 kg/m²/s (DH 11/16/98)	4.188e-2	1.67

* All blocks in drift ceiling were dripping

10 mm/yr = 3.16e-7 kg/m²/s	0.2038	8.15

↑ random K field saved as 3drank.1
seed # is 123456789

new field seed = ~~71635 7912~~ 272638459 (DH 11/16/98) 3drank.2

log10 mean = -12.1329 geomean = 7.36452e-13 $\sigma_f^2 = 0.147$

min = 2.67e-14 max = 1.51e-11 m^2

2 mm/y = 6.34e-8 kg/m²/s 4.839e-2 m^3/yr 1.935 mm/yr

Random field saved as 3drank.2 for later reference

all cases S_r = .01

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From Page No. ___ Nov 16, 1998

Homogeneous – 2D since 3rd dimension can be obtained by multiplying by the thickness

$\alpha = 9.7e\text{-}4\ Pa^{-1}$ $K = 1.779e\text{-}13\ m^2$ *

Infiltration	Cummulative (m^3/yr) *10 to compare w/ 3/D case	Average seepage mm/yr
2mm/yr = 6.3~~8~~4e-8 $kg/m^2/s$ ✓ DH 11/17/98	~~4.777e-3~~ 4.7456e-3 DH 11/17/98	~~1.91~~ 1.898

Homogeneous $\alpha = 9.7e\text{-}4\ Pa^{-1}$
geomean $K = 7.365e\text{-}13\ m^2$

2mm/yr = 6.34e-8 $kg/m^2/s$ 4.124e-3 m^3/yr 1.65 mm/yr

In the first case, 3drank.1, heterogeneous K resulted in less average seepage than the homogeneous case using geometric mean $K = 1.779e\text{-}13\ m^2$

In the second case, 3drank.2, heterogeneous K resulted more average seepage than in the homogeneous case using geometric mean $K = 7.365e\text{-}13\ m^2$

In both cases, however, with $\alpha = 9.7e\text{-}4\ Pa^{-1}$ most of the 2mm/year infiltration (1.65–1.94) mm/yr went into the drifts. Probably should look at sensitivity of seepage to α with constant K

* From pages 2-90 and 2-91 rev 0 Chap 2 TSPA-VA TBS
The K value here is the geomean of 3drank.1 prev. page, TSPA-VA geomean $K = 10^{-13}\ m^2$

To Page No. ___

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From Page No. ___ Nov 17, 1998

Sensitivity of seepage to van Genuchten α at constant $K = 10^{-13}\ m^2$ *

$\alpha = 9.7e\text{-}4\ Pa^{-1}$

Infiltration Rate	Cummulative Seepage m^3/y	Average seepage mm/yr
6.34e-8 $kg/m^2/s$ = 2mm/yr	4.847e-3 m^3/y	1.938 mm/yr
3.16e-7 $kg/m^2/s$ = 10 mm/y	2.479e-2 m^3/y	9.91 mm/yr
3.16e-8 $kg/m^2/s$ = 1 mm/yr	2.351e-3 m^3/y	0.940 mm/yr

$\alpha = 3.3e\text{-}4\ Pa^{-1}$

3.16e-8 $kg/m^2/s$ = 1 mm/yr	0	0
6.34e-8 $kg/m^2/s$ = 2 mm/y	0	0
3.16e-7 $kg/m^2/s$ = 10 mm/yr	0 DH 11/17/98	0
6.33e-7 $kg/m^2/s$ = 20 mm/yr	0	0
1.58e-6 $kg/m^2/s$ = 50 mm/yr	5.7216e-2 m^3/yr	22.88 mm/yr
3.16e-6 $kg/m^2/s$ = 100 mm/y	~~8.179e~~ 0.1789 m^3/y	71.538 mm/y
1.11e-6 $kg/m^2/s$ = 35 mm/y	2.164e-2 m^3/y	8.655 mm/y
8.86e-7 $kg/m^2/s$ = 28 mm/y	5.932×10^{-3} m^3/y	2.372

DH 11/17/98
$\alpha = \cancel{3.3e\text{-}4}\ 3.3e\text{-}3\ Pa^{-1}$

3.16e-8 $kg/m^2/s$ = 1mm/y	2.505e-3 m^3/y	1.0018 mm/y
6.34e-8 $kg/m^2/s$ = 2mm/y	5.026e-3 m^3/y	2.01 mm/y
3.16e-7 $kg/m^2/s$ = 10mm/y	2.505e-2 m^3/y	10.015

Graph on next page

* Page 2-112 rev 0 Chap 2 TSPA-VA TBD

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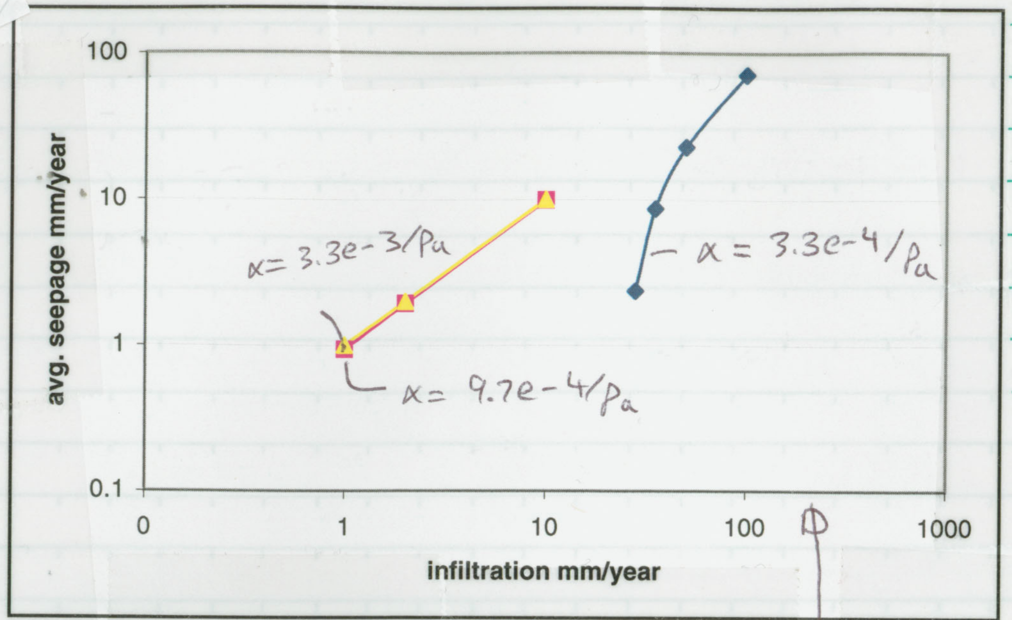

K = constant 10^{-13} m^2 Compare to bottom graph pg 32

DH 11/17/98

Given $K = 10^{-13}$ m^2 there seems to be an α such that all ~~seepage~~ infiltration seeps. This α is somewhere around ~~3e8~~ 9.7e-4 /Pa or less. From page 32 where α = constant = 5.1e-4, if $K < 10^{-13}$ m^2 like close to 10^{-14} m^2, then basically all infiltration seeps. So in order to have any significant capillary exclusion

$\alpha < 9.7e-4$ $K > 10^{-13}$ m^2

Time to check this model geometry against the Philip Solution.

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From Page No.

Ref: Philip, J.R., and J.H. Knight & Waechter, R.T. WRR 25(1) p 16-28 1989

Analytical solution

$$\theta_{max} = 1 + 4e^{-s}\left\{\frac{s}{2}\left(I_0(s) + I_1(s)\right) + \sum_{n=1}^{\infty}\frac{n\,I_n(s)}{K_n(s)}\sum_{j=-(n-1)}^{n-1}K_j(s)\right\}$$

Gardner Model $K = K_s e^{\alpha\psi}$ $-\infty < \psi \le 0$

$s = \frac{\alpha l}{2}$ l = radius of cylinder

First check to see that I have the analytical solution correct.

phillip1.nb

```
In[5]:= s = 8.
Out[5]= 8.
In[6]:= ds = 30;
In[7]:= tm = Sum[n*BesselI[n, s] / BesselK[n, s] *BesselK[m, s], {n, 1, ds}, {m, -(n-1), n-1}]
Out[7]= 9225.13
In[8]:= q = 1+4*Exp[-s] * (s / 2 * (BesselI[0, s] + BesselI[1, s]) + tm)
Out[8]= 17.8199
```

In ~~Fabl~~ Table 2 of Philip et al 1989 this number is 17.820 OK

DH 11/18/98

Ref: Russo, D. and M. Bouton, WRR 28(7) p 1911 1992

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From Page No.

First soil in Tables 1 and 2 of Russo and Bouton (1992)

<u>Gardner Russo Parameters</u>   <u>Van Genuchten Parameters</u>

$K_s = 0.04239$ cm/min 0.04348 cm/min $= K_s$

$\alpha = 0.15544$ /cm 0.05791 /cm $= \alpha$

$1.82323 = n$

$$0.04239 \frac{cm}{min} \frac{min}{60s} \frac{m}{100cm} 1.119\times10^{-3} \frac{kg}{m \cdot s} \frac{m^3}{998Kg} \frac{s^2}{9.8m} = 8.083\times10^{-13}\ m^2$$

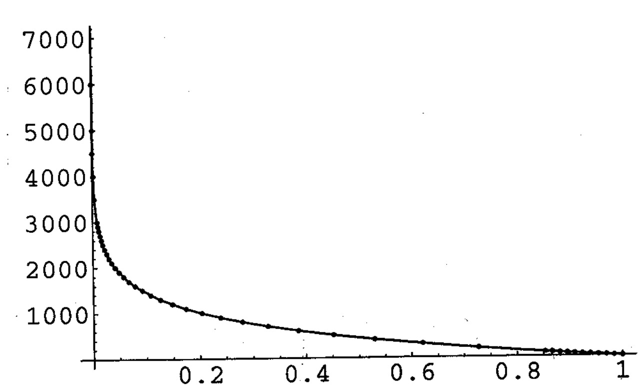
$$0.15544/cm \frac{100cm}{m} \frac{m^3}{998Kg} \frac{s^2}{9.8m} = 1.5893\times10^{-3}\ Pa^{-1}$$

$$0.15544/cm \frac{100cm}{m} = 15.544/m$$

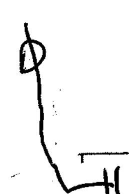
I have to use the TABular option in PCKR Multiflo for the Gardner-Russo model. For $S(\psi)$ the relationship is,

$$S = e^{\alpha\psi/2}\left(1+\frac{\alpha\psi}{2}\right)^{4/5} \qquad -\infty \le \psi \le 0$$

```
In[27]:= a = 1.5893*10^-3;

In[28]:= mf = ReadList["d:\work\exp.dat", Number, RecordLists -> True];

In[29]:= yp = -Log[kr] / a;

In[30]:= << Graphics`

In[31]:= DisplayTogether[ListPlot[mf], Plot[yp, {kr, 0, 1}]]
```



the dots are the points of the $K_r(\psi)$ curve which are entered into the tabular look-up table in multiflo



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$$0.04239\ cm/min \frac{10mm}{cm} \frac{60min}{hr} \frac{24hr}{day} \frac{365day}{y} = 2.228\times10^5\ mm/y$$

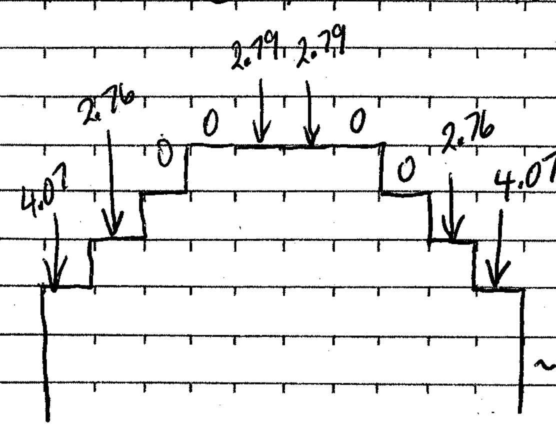
the critical infiltration at which seepage will just occur is (Philip et al 1989)

$$q_x = \frac{K_s}{\Theta_{max}}$$

phillip1.nb   1

```
In[32]:= a = 15.554;   m^-1

In[33]:= l = 2.5;   drift radius m

In[34]:= s = a*l/2

Out[34]= 19.4425

In[35]:= ds = 30;   more terms do not affect the result

In[36]:= tm = Sum[n*BesselI[n, s] / BesselK[n, s] *BesselK[m, s], {n, 1, ds}, {m, -(n-1), n-1}];

In[37]:= q = 1 + 4*Exp[-s] * (s / 2 * (BesselI[0, s] + BesselI[1, s]) + tm)

Out[37]= 40.7972

In[38]:= Ks = 2.228*10^5;   mm/y

In[39]:= qc = Ks / q   critical infiltration at which seepage will begin to occur

Out[39]= 5461.16
```

Multiflo results infiltration $3.16\text{e-}7 \frac{kg}{m^2 s} = 10 \frac{mm}{y}$



Average rate $1.93 \frac{mm}{yr}$

drift outline from page 19

file saved

~dhughson/multiflo/inputbak/multi.19

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Data from Russo & Bouton (1992)

Tables 1 & 2

Gardner - Russo α	Van Genuchten α	factor
0.15544/cm	0.05791/cm	2.68
0.16802/cm	0.06276/cm	2.68
0.23397/cm	0.08689/cm	2.69
0.52470/cm	0.18153/cm	2.89

Avg factor ~ 2.7

$$K = 1\times10^{-13}\,m^2 \frac{998\,\frac{kg}{m^3}\; 9.8\,\frac{m}{s^2}}{1.119\times10^{-3}\,kg/m\cdot s}\; \frac{1000\,mm}{y}\; 60\cdot60\cdot24\cdot365 = 2.756\times10^{4}\,\frac{mm}{y}$$

$10^{-12}\,m^2 = 2.756\times10^{5}\,\frac{mm}{y}$ $\quad 10^{-14}\,m^2 = 2.756\times10^{3}\,\frac{mm}{y}$

$\alpha = 9.7\times10^{-4}\,\frac{s^2 m}{kg}\; 998\,\frac{kg}{m^3}\; 9.8\,\frac{m}{s^2} = 9.487/m$

factor of 2.7 $= 25.61/m$

$\alpha = 3.3\times10^{-3}\,Pa^{-1} = 32.3/m$ $\quad$ fac of 2.7 $= 87.14/m$

$\alpha = 3.3\times10^{-4}\,Pa^{-1} = 3.23/m$ $\quad$ fac of 2.7 $= 8.714/m$

Philip (1989) solution for cylindrical cavities $\quad q^* =$ critical infiltration

$K = 10^{-13}\,m^2 = 2.756\times10^{4}\,\frac{mm}{y}$ $\quad K = 10^{-12}\,m^2 = 2.756\times10^{5}\,\frac{mm}{y}$

DH 11/19/98

α	q^* mm/y	α	q^* mm/y
8.714	1165.7	8.714	11656.7
25.61	417.8	25.61	4177.8
87.14	125.4	87.14	1253.7
200	54.9	200	549.2

$K = 10^{-14}\,m^2 = 2.756\times10^{3}\,\frac{mm}{y}$

α	q^* mm/y
8.714	116.6
25.61	41.8
87.14	12.5
200	5.5

For $\alpha = 9.7\times10^{-3}\,Pa^{-1}$ $= 94.9/m$ or fac of 2.7 $284.6/m$

Series solution does not converge

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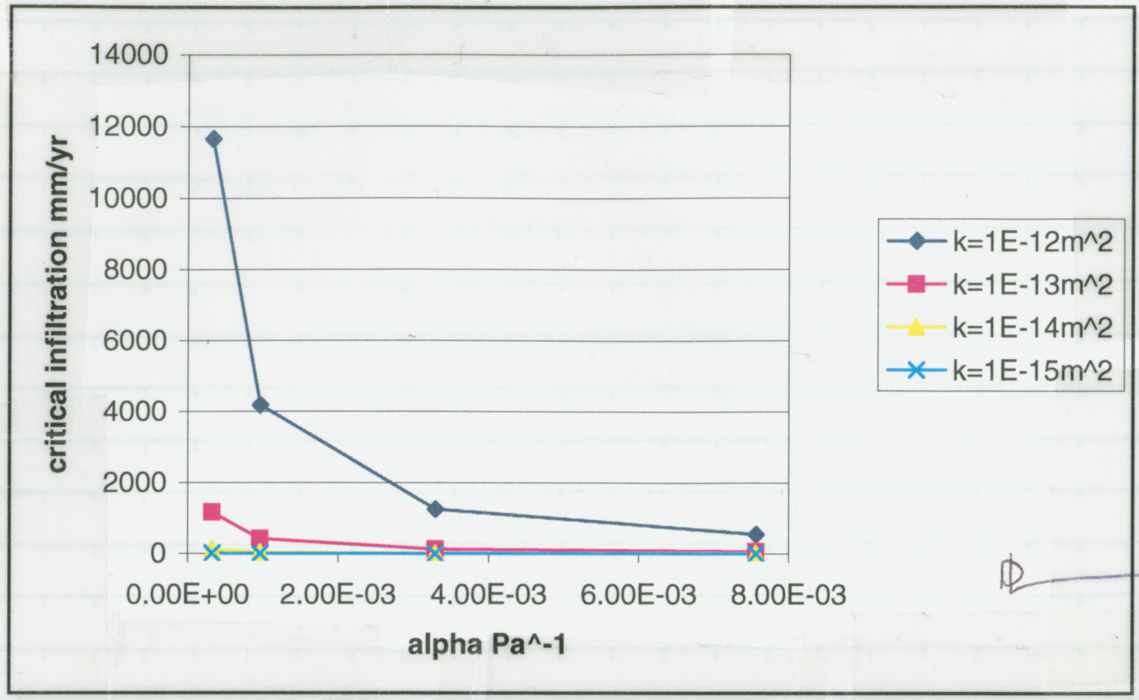
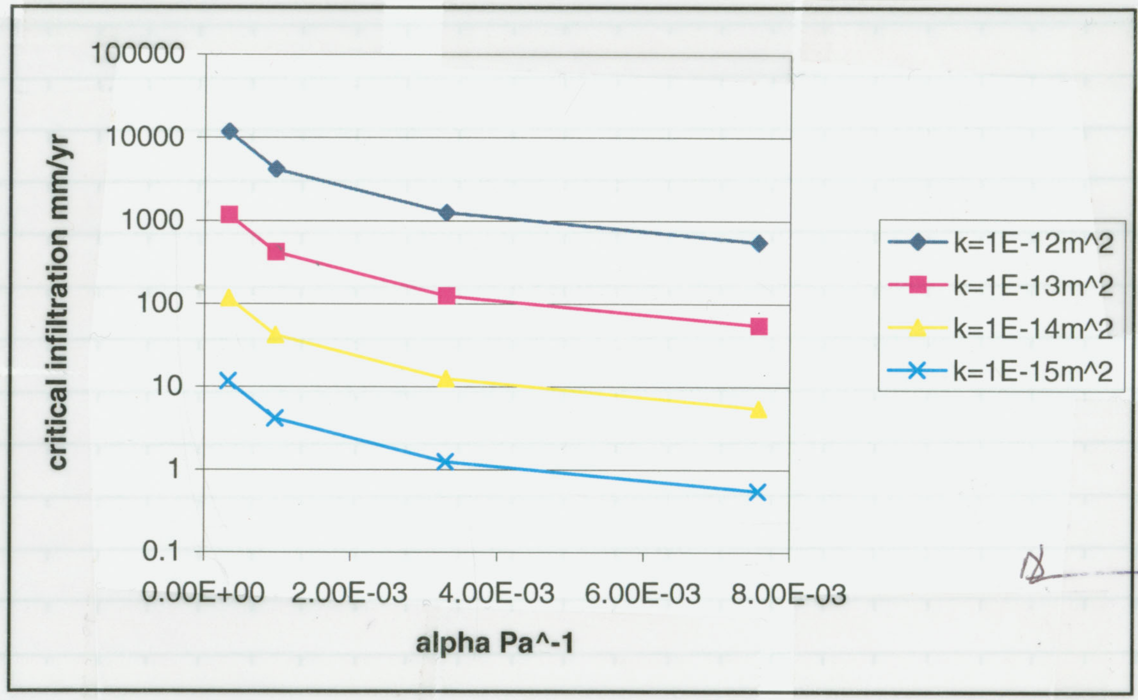


DH



DH

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Maybe the irregular geometry of the drift opening is the reason why the multiflo results are so much different than the analytical solution.

Ref: Philip, J.R. WRR 25(7) p 1531-1540 1989

Analytical solution for a strip-shape cavity

$$\theta_{max}(s,0) = \left[1 - 2s\, esh(0,2s)\right]^{-1} \qquad s = \frac{\alpha l}{2}$$

$$esh(\eta, w) = \int_{\eta}^{\infty} \exp[-w \sinh \eta_1]\, d\eta_1 \qquad l = \text{semiwidth}$$

expansion

$$esh(0,w) \approx \frac{1}{w} - \frac{1}{w^3} + \frac{9}{w^5} - \frac{225}{w^7} + \frac{11025}{w^9} - \frac{893025}{w^{11}} \cdots$$

I think the next term in this series should be

$$+ \frac{(893025) \cdot 11^2}{w^{13}}$$

```
l = 1.;
a = 15.554;
s = a*l/2
7.777
w = 2*s;
esh = 1/w - 1/w^3 + 9/w^5 - 225/w^7 + 11025/w^9 - 893025/w^11;
q1 = 1/(1-2*s*esh)
250.41
k = 2.228*10^5;
qc = k/q1
889.742
```

1 m semiwidth

critical seepage ~890 $\frac{mm}{yr}$

mm/year

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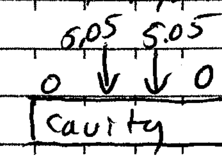
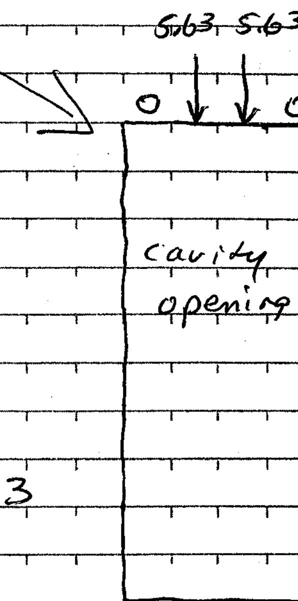
From Page No.___ Multiflo

infiltration rate
$3.17e{-7}$ kg/m²/s = 10.017 $\frac{mm}{yr}$ no seepage
$4e{-7}$ kg/m²/s = 12.6 mm/yr avg rate = 2.82 mm/yr

For a single row strip cavity
infiltration rate
$3.17e{-7}$ kg/m²/s = 10.017 mm/y no seepage
$4e{-7}$ kg/m²/s = 12.6 mm/y avg rate = 2.53 mm/y



OK so it's either the properties of the rock or the properties of the drift



Porosity is 1.24e-4, change this to ~~0.2~~ 0.3
infiltration rate
$3.17e{-7}$ kg/m²/s = 10.017 $\frac{mm}{y}$ no seepage
$4e{-7}$ kg/m²/s = 12.6 mm/y avg rate = 2.53 $\frac{mm}{y}$

Use a large α instead of $P_c = 0$ condition for cavity
1e-5 Pa^{-1} Sr = 0.1 m = 0.633
infiltration rate Opp! – small α DH 11/20/98
$4e{-7}$ kg/m²/s = 12.6 mm/y avg rate = 15.4 mm/yr
α = 1 Pa^{-1}
$4e{-7}$ kg/m²/s = 12.6 mm/y avg rate = 2.59 mm/y
α = ~~10 Pa⁻¹~~ 0.1 Pa^{-1}
$4e{-7}$ kg/m²/s = 12.6 mm/y avg rate = 2.95 mm/yr
α = ~~100 Pa⁻¹~~ 10 Pa^{-1}
$4e{-7}$ kg/m²/s = 12.6 mm/y avg rate = 2.56 mm/yr
α = 100 Pa^{-1}
$4e{-7}$ kg/m²/s = 12.6 mm/y avg rate = 2.55 mm/yr
α = 1000 Pa^{-1} = ~~12.6 mm/y~~ DH 11/20/98
$4e{-7}$ kg/m²/s = 12.6 mm/y avg rate = 2.55 mm/yr
α = 10,000 Pa^{-1}
$4e{-7}$ kg/m²/s = 12.6 mm/y avg rate = 2.54 mm/yr

looks like as $\alpha \to \infty$ seepage rate approaches same result as for $P_c = 0$

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From Page No. ___

Maybe the problem is with the TABular look up form for the Gardner-Russo, maybe $K_r(S_e)$ is not right. What happens when I use the equivalent van Genuchten parameters (p 48)

VanG $K_s = .04348$ cm/min $\alpha = .05791$/cm $n = 1.82323$

$$k = .04348 \frac{cm}{min} \frac{min}{60s} \frac{m}{100cm} 1.119 \times 10^{-3} \frac{kg}{m \cdot s} \frac{m^3}{998 kg} \frac{s^2}{9.8 m} = 8.291 \times 10^{-13} m^2$$

$$\alpha = .05791/cm \frac{100cm}{m} \frac{m^3}{998 kg} \frac{s^2}{9.8 m} = 5.921 \times 10^{-4} \frac{m \cdot s^2}{kg} \quad (Pa^{-1})$$

$$N/m^2 = P_a = \left(\frac{kg\, m}{s^2}\right)/m^2 = \frac{kg}{m \cdot s^2} \quad \cancel{m = 1 - 1/m} \quad \cancel{m = \frac{1}{1-n}} =$$ DH 11/20/98

$\cancel{n = 1 - 1/m} =$ $m = 1 - 1/n = 0.4515$ $S_r = 0.1$

also use TABular $P_c = 0$ for cavity condition

Infiltration

4e-7 kg/m²/s = 12.6 mm/y	no seepage
5e-7 kg/m²/s	no seepage
6e-7 kg/m²/s = 18.96 mm/y	no seepage
7e-7 kg/m²/s = 22.12 mm/y	no seepage
8e-7 kg/m²/s = 25.28 mm/y	no seepage
9e-7 kg/m²/s = 28.44 mm/y	no seepage
1e-7 kg/m²/s = 31.60 mm/y	no seepage
2e-7 kg/m²/s = 63.20 mm/y	no seepage
3e-7 kg/m²/s = 94.80 mm/y	avg rate = 22.176 mm/yr

44.275 44.275
0 0
Cavity

Saturation of liquid at inf = 3e-7 kg/m²/s

.4439 .4623
Cavity

If this were correct then $S_l = 1$ when seepage occurs

these should be e-6 DH 11/20/98

From Page No. ___ Nov 24, 1998 these are the grid blocks in the strip cavity and right above.

these top blocks:
$S_r = \cancel{.01}$ 0.1 DH 11/24/98 $m = .4575$
$\alpha = 5.921e{-4}\ Pa^{-1}$
$k = 8.083e{-13}\ m^2$

$P_g = 1.014e{+5}$ $S_l = .4439$ $P_c = 5071$ $u_l = 0$	$P_g = 1.04e{+5}$ $S_l = .4623$ $P_c = 4717$ $u_l = .04435$ m/y
$P_g = 1.014e{+5}$ $S_l = 0$ $P_c = 0$	$P_g = 1.014e{+5}$ $S_l = .057$ $P_c = 0$

rock
air

these bottom blocks
$P_c = 0$ for all S_l
$k = 1e{-4}\ m^2$

Drips when $P_c = 4717$ but not when $P_c = 5071$ Pa

Gravity potential

$$(0.5m)(9.8\, m/s^2)(998\, kg/m^3) = 4890 \frac{kg}{m s^2} = 4890\ Pa$$

Blocks of $(0.5m)^3$ above the drift opening are too large.

Grid discretization of $0.1m = \Delta z$ above and below

$$(0.1m)(9.8\, m/s^2)(998\, kg/m^3) = 978\ Pa$$

which should give $S_e > 0.87$ above the drift at incipient seepage

Grid refinement around drift on following page

refer to previous grid page 19

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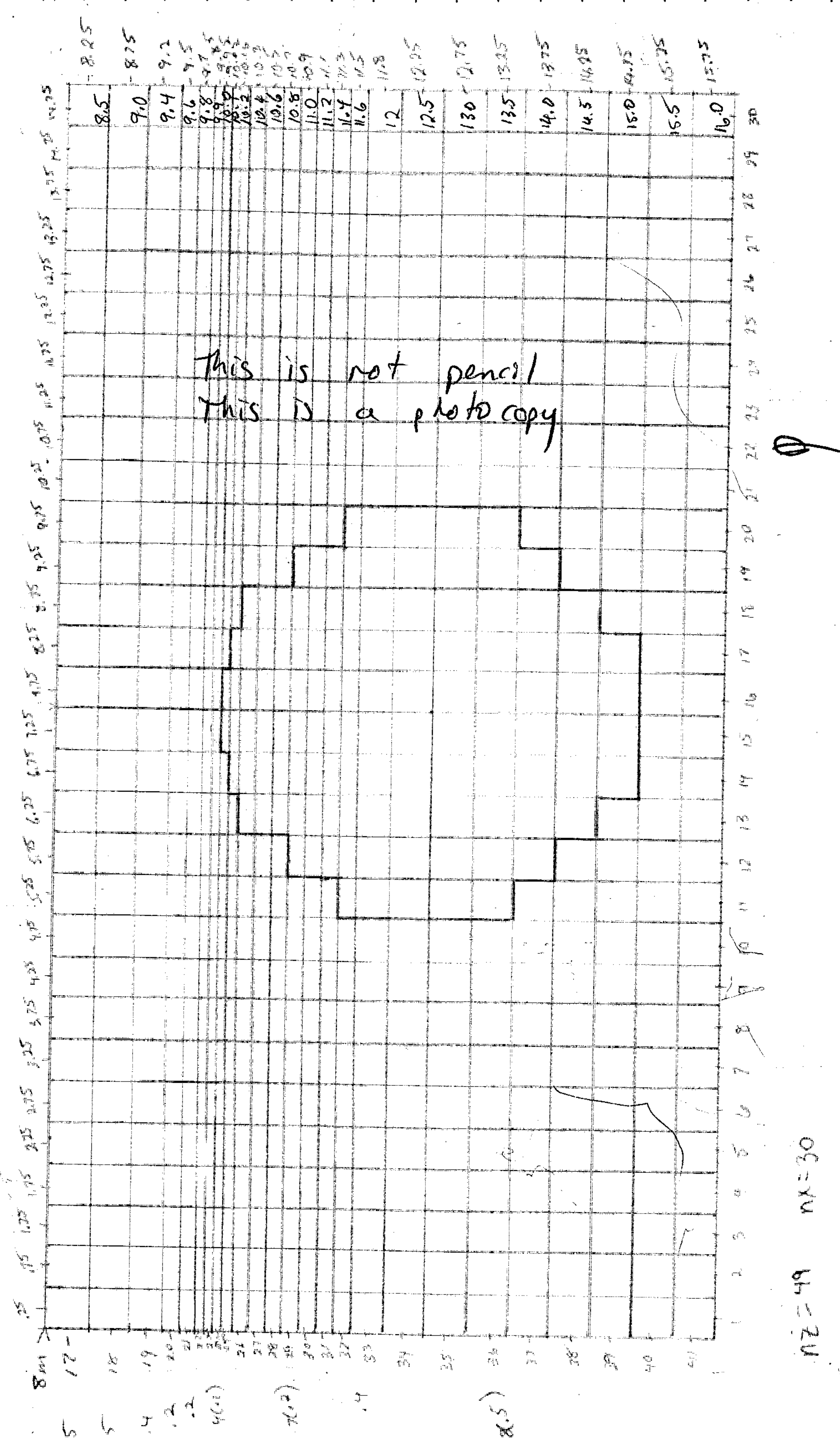

Grid refinement in the area around the top of the drift, refer to page 19, this is the section starting 8m from the top and extending to 4m from the bottom.

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Blocks for strip solution comparison are

$nx = 14$ to 17, $nz = 24$, all other blocks have homogeneous properties van Genuchten $m = 0.4515$

$S_r = .1$ $\alpha = 5.921e\text{-}4\ Pa^{-1}$ $k = 8.083e\text{-}13\ m^2$

DH 11/24/98

~~perc~~ percolation rate	seepage	
3e-6 kg/m²/s = 94.8 mm/yr	no seepage	S_l = .5139 } x = 6.75
4e-6 kg/m²/s = 126.4 mm/yr	no seepage	S_l = .5440 }
5e-6 kg/m²/s = 158.0 mm/yr	no seepage	S_l = .6247 } x = 7.25
6e-6 kg/m²/s = 189.6 mm/yr	no seepage	S_l = .6483
7e-6 kg/m²/s = 221.2 mm/yr	no seepage	S_l = .6686
8e-6 kg/m²/s = 252.8 mm/yr	avg 5.5e-4 mm/yr	S_l = .6866

$S_l = .6233$ $P_c = 2682$	↓ 3.75e-4	↓ 7.30e-4	rock $S_l = .6866$ $P_c = 2171$
$S_l = .01$ $P_c = 0$			strip $S_l = .01$ $P_c = 0$

Change permeability inside opening from $1e\text{-}4\ m^2$ to $8.083e\text{-}13\ m^2$ to simplify things for hand calculation.

Now

8e-6 kg/m²/s = 252.8 mm/y	no seepage	S_l = .6866
9e-6 kg/m²/s = 284.4 mm/y	no seepage	S_l = .7026
1e-5 kg/m²/s = 316.0 mm/y	no seepage	S_l = .7170
2e-5 kg/m²/s = 632.0 mm/y	no seepage	S_l = .8135
2.1e-5 kg/m²/s = 663.6 mm/y	no seepage	S_l = .8203
2.5e-5 kg/m²/s = 790.0 mm/y	no seepage	S_l = .8441
2.8e-5 kg/m²/s = 884.8 mm/y	no seepage	S_l = .8593
3.0e-5 kg/m²/s = 948.0 mm/y	no seepage	S_l = .8685
3.2e-5 kg/m²/s = 1011.2 mm/y	no seepage	S_l = .8769
4.0e-5 kg/m²/s = 1264.0 mm/y	avg 164.8 mm/y	S_l = 0.8819

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Saw previously that for the number 1 ~~Gardner~~ DH 11/24/98 Russo Bouton (1992) Soil, TABular with Gardner parameters caused seepage between 10 and 12.6 mm/yr while the van Genuchten parameters resulted in seepage between 63.2 and 94.8 mm/yr, with $K = 8.083e{-13}\ m^2$ in the drift same as in the rock, van Genuchten parameters cause seepage at higher percolation than analytical solution. Let's return to the TABular Gardner - Russo and see what happens

percolation	seepage	saturation above
2.8e-5 kg/m²/s = 884.8 mm/y	no seepage	.6989
3.8e-5 kg/m²/s = 1200.8 mm/y	avg rate = 128.3 mm/y	S_l = .7293
3.5e-5 kg/m²/s = 1106.0 mm/y	avg rate = 60.5 mm/y	S_l = .7285
3.0e-5 kg/m²/s = 948.0 mm/y	no seepage	S_l = .7130
3.1e-5 kg/m²/s = 979.6 mm/y	no seepage	S_l = .7196
3.2e-5 kg/m²/s = 1011.2 mm/y	no seepage	S_l = .7258
3.3e-5 kg/m²/s = 1042.8 mm/y	avg rate = 15.4 mm/yr	S_l = .7280

$\alpha = 1.5893 \times 10^{-3}\ \frac{ms^2}{kg}\ 998\frac{kg}{m^3}\ 9.8\frac{m}{s^2} = 15.544/m$

$K = 8.083\times10^{-13}\ m^2\ 998\frac{kg}{m^3}\ 9.8 m/s^2 / 1.119\times10^{-3}\ kg/ms = 7.065\times10^{-6}\ m/s$

$K = 2.228\times10^{5}$ mm/yr $l = 1m$ halfwidth

Analytical Solution critical seepage = 891 mm/y

Numerical model critical seepage $\cong$ 1011 to 1043 mm/y

This is a difficult comparison: 1) hard to put Gardner directly into multiflo, have to use Russo model to get $K_r(S_l)$ & have to use TABular form, 2) grid discretization may cause some differences.

However, I did closely predict the S_l in the block above drift for van Genuchten from block ΔZ & gravity potential

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Important Findings

- Block size above cavity makes a big difference as to when seepage occurs (at what percolation)
- Assigning a large K to cavity opening is arbitrary and results in wrong ~~res~~ answers DH 11/24/98
- Using Gardner - Russo and van Genuchten parameters for same soil sample give slightly different but reasonably close results. However Gardner & Van Genuchten alpha's are different. In this case by a factor of about 3
- Using large α to represent the cavity and setting blocks in cavity to $P_c = 0$ give approximately the same results as $\alpha \to \infty$
- Decreasing K_s for given α results in more seepage for given percolation or a lowering of the critical percolation.

If I change the rock parameters to DOE mean representation for fracture continuum can I predict with analytical model when numerical model will seep?

$K = 10^{-13}\ m^2 = 2.756\times10^{4}$ mm/y

$\alpha = 9.7\times10^{-4}\ Pa^{-1} = 9.487/m$ (factor of ~2.7 ≈ 25.6/m)

look for seepage around 41-42 mm/y

⟵ archive
~dhughson/multiflo/inputbak/multi.20

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From Page No. ___ VanGenuchten parameters for DOE fracture continuum

Strip Cavity halfwidth = 1m

percolation	seepage	saturation above
1.e-6 kg/m²/s = 31.6 mm/y	no seepage	S_e = .6615

Note: I had set rock porosity to 1.24e-4 and cavity porosity to 1.0, this resulted in seepage occurring in the outside 2 blocks with above percolation and no seepage into center 2 blocks. S_e = .55 above outer 2 blocks and S_e = .66 above center 2 blocks. Probably not a good idea to set cavity porosity to 1.0 since it gives meaningless & incorrect results.

2e-6 kg/m²/s = 63.2 mm/y avg rate = 19.6 mm/y S_e = .6828
1.5e-6 kg/m²/s = 47.4 mm/y avg rate = 8.8 mm/y S_e = .6799
1.1e-6 kg/m²/s = 34.8 mm/y no seepage
1.4e-6 kg/m²/s = 44.2 mm/y avg rate = 6.6 mm/y
1.3e-6 kg/m²/s = 41.1 mm/y avg rate 4.4 mm/y
1.2e-6 kg/m²/s = 37.9 mm/y avg rate = 2.2 mm/y S_e = .678

seepage between 34.8 and 37.9 mm/y when I had predicted 41-42 mm/y, not bad

I used a 2.7 factor - actually ~ 2.84

With a horizontal cylinder radius 2.5m and the van Genuchten properties m = 0.63 $\alpha = 9.7e{-4}\ Pa^{-1}$, $k = 10^{-13}\ m^2$ ϕ = 1.24e-4 I predict critical seepage around 395 mm/y

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More grid refinement. ~~Applied new previous grid on page 56~~ on page 68 DH 12/2/98 DH 12/2/98

percolation	seepage
1.1e-6 kg/m²/s = 34.76 mm/y	~~negative except for 2 outside blocks, also not symmetrical~~

oops! BC top & bottom asymmetrical
OK, now it's symmetrical with 0 except for outside 2 blocks which are 143.96 mm/y each S_l = .52 P_c = 1298.) over the top blocks at z = 9.95 (no seeping) S_l = .5352 P_c = 1264

5.0e-6 kg/m²/s = 158 mm/y Center 2 blocks leak, next two outside those don't, all the rest do

Top 2 blocks (center) 96.17 mm/y S_l = 0.69 P_c = 955.6

According to the strip solution, the top section should leak at ~144 mm/y so this is in the ball park.

Dec 1, 1998 - Working on seepage report

check for sat above opening Δz = 0.5m
n = 2.7 α = 9.7e-4 k = 8.083e-13

3.16e-7 kg/m²/s = 9.99 mm/yr Avg = 8.23 mm/yr
9.e-8 kg/m²/s = 2.84 mm/y Avg = 1.87 mm/y
9.e-9 kg/m²/s = 0.284 mm/y 0
2e-8 kg/m²/s = .63 mm/y Avg = .218 mm/y

Saturation .076 no leaks
.083 leaks

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From Page No. ___ black sq 10cm above opening

q		seepage
3.3e-7 kg/m²/s	= 10.43 mm/yr	0
5.0e-7 kg/m²/s	= 15.8 mm/y	0
1.0e-6 kg/m²/s	= 31.6 mm/y	0
4.0e-6 kg/m²/s	= 126.4 mm/y	0

Should do this with K = 1e-13 m²
0.5 = ΔZ α = 9.7e-4 n = 2.7

q		seep
2e-8 kg/m²/s	= .632 mm/y	Avg = .475 mm/y
1e-9 kg/m²/s	= .03 mm/y	0
9e-9 kg/m²/s	= .284 mm/y	.174 mm/y
8e-9 kg/m²/s	= .253 mm/y	.147 mm/y
7e-9 kg/m²/s	= 221 mm/y	.121 mm/y
5e-9 kg/m²/s	= .158 mm/y	.07 mm/y
4e-9 kg/m²/s	= .126 mm/y	.046 mm/y
3e-9 kg/m²/s	= .095 mm/y	.022 mm/yr
2e-9 kg/m²/s	= .063 mm/y	.0059 mm/y

~dhughson/multiflo/inputbak/multi.21

0.1 = ΔZ K = 1e-13 m² α = 9.7e-4 Pa⁻¹ n = 2.7

q		seep
1.0e-6 kg/m²/s	= 31.6 mm/y	0
1.0e-5 kg/m²/s	= 316 mm/y	Avg 252.4 mm/y
3.0e-6 kg/m²/s	= 94.8 mm/y	Avg 40.45 mm/y
2.0e-6 kg/m²/s	= 63.2 mm/y	Avg 19.6 mm/y
1.5e-6 kg/m²/s	= 47.4 mm/y	~~Avg~~ 8.8 mm/y
1.4e-6 kg/m²/s	= 44.2 mm/y	DH 12/2/98 Avg 6.0 mm/y
1.1e-6 kg/m²/s	= 34.8 mm/y	0 S_e = .6772
1.2e-6 kg/m²/s	= 37.9 mm/y	2.2 mm/yr

no leak S_l = 0.57 leak 4.4 mm/yr S_l = ~~0.68~~ 0.678

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From Page No. ___ Dec 2, 1998

Gardner Russo Model $\alpha = 1.5893 \times 10^{-3}$ Pa⁻¹ = 0.15544 /cm
K = 1×10^{-13} m²

q		seep
3.0e-6 kg/m²/s	= 94.8 mm/yr	0
3.5e-6 kg/m²/s	= 110.6 mm/yr	0
4.0e-6 kg/m²/s	= 126.4 mm/y	.03 mm/y S_e = .7278
3.9e-6 kg/m²/s	= 123.2 mm/y	0 S_e = .7229

van Genuchten $\alpha = 5.676 \times 10^{-4}$ Pa⁻¹ n = 2.7 K = 10^{-13} m²

q		seep
3.9×10⁻⁶ kg/m²/s	= 123.2 mm/yr	0
4.0×10⁻⁶ kg/m²/s	= 126.4 mm/y	0
4.1×10⁻⁶ kg/m²/s	= 129.56 mm/y	0
α = 5.886e-4 Pa⁻¹ DH 12/2/98		
4.1×10⁻⁶ kg/m²/s	= ~~12~~ 129.56 mm/y	0
4.2×10⁻⁶ kg/m²/s	= 132.7 mm/y	0
4.3e-6 kg/m²/s	= 135.9 mm/y	0
5.0e-6 kg/m²/s	= 157 mm/y	0
6.0e-6	= 189.6 mm/y	0
7.0e-6 kg/m²/s	= 221 mm/y	Avg 19.5
6.5e-6	= 205.4 mm/y	8.2
6.2e-6 kg/m²/s	= 195.9 mm/y	1.46

Russo Bouton (1992) Table 1 Table 2 First soil sample

Gardner-Russo	van Genuchten
K_s = .04239 cm/min	K_s = .04348 cm/min
α = 0.15544 /cm	α = .05791 /cm
	n = 1.82323
$K_s = 8.083 \times 10^{-13}$ m²	$K_s = 8.291 \times 10^{-13}$ m²
$\alpha = 1.5893 \times 10^{-3}$ Pa⁻¹	$\alpha = 5.921 \times 10^{-4}$ Pa⁻¹
	m = .4515

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numerical model with van Genuchten parameters

q — seep

$3.35e-5$ kg/m²/s = 1058.6 mm/y — 0
$3.39e-5$ kg/m²/s = 1071.2 mm/y — 2.1 mm/y
$3.37e-5$ kg/m²/s = 1064.9 mm/y — 0
$3.380e-5$ kg/m²/s = 1068.1 mm/y — 0

Refined grid [$\alpha = 5.921e-4$/Pa $m = .4515$ $k = 8.291E-13\ m^2$

q — seep

$5.0e-6$ kg/m²/s = 158 mm/yr — 0
$5.e-5$ kg/m²/s = 1580 mm/y — 280/5.158 — Avg 74.7 mm/y — none on top
$4.e-5$ kg/m²/s = 1264 mm/y — 0
$4.3e-5$ kg/m²/s = 1359 mm/y — 0
$4.6e-5$ kg/m²/s = 1453.6 mm/y — 0
$4.7e-5$ kg/m²/s = 1485 mm/y — 0
$4.8e-5$ kg/m²/s = 1517 mm/y — 6.5 mm/y — two outside 58.762 ea — Se = .869
~~$4.9e-5$ kg/m²/s = 1548 mm/y~~ DH 12/4/98

Se over top .834

look for seepage along top strip

$1.0e-4$ = 3156 mm/y — 2 center blocks 1733.6 mm/y each
$8.0e-5$ = 2528 mm/y — 825.34 mm/y each
$7.0e-5$ = 2212 mm/y DH 12/4/98 of 2 center blocks 341.7 mm/y each
$6.0e-5$ = 1896 mm/y — 0
~~5.5e-5~~ $6.5e-5$ = 2054 mm/y — 89.0 mm/y each
$6.4e-5$ kg/m²/s = 2022 mm/y — 38.37 mm/y each
$6.3e-5$ kg/m²/s = 1991 mm/y — 0
$6.2e-5$ kg/m²/s = 1959 mm/y — 0

mf/cr = 1.2

Save

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From Page No. Sensitivity for 2m wide strip

$\alpha = 9.7e-4\ Pa^{-1}$ $m = 0.63$ $K = 10^{-13}\ m^2$
$1.2e-6$ kg/m²/s = 37.9 mm/y — Avg 2.2 mm/y
$1.1e-6$ kg/m²/s = 34.8 mm/y — Avg = 0

Find the Gardner α which produces the same result
~~$\alpha = 3.3e-4\ Pa^{-1}$ $m = 0.63$ $K = 10^{-13}\ m^2$~~ DH 12/4/98
Gardner $\alpha = 2.8e-3\ Pa^{-1}$ $K = 10^{-13}\ m^2$ $q^* = 36.3$ mm/y

$\alpha = 3.3e-4\ Pa^{-1}$ $m = 0.63$ $K = 10^{-13}\ m^2$
$1.2e-6$ kg/m²/s = 37.9 mm/y — 0
$5.0e-6$ kg/m²/s = 158 mm/y — 0
$9.0e-6$ kg/m²/s = 284.4 mm/y — 0
$1.0e-5$ kg/m²/s = 316 mm/y — 0
$1.5e-5$ kg/m²/s = 474 mm/y — 0
$2.0e-5$ kg/m²/s = 632 mm/y — 0
$3.0e-5$ kg/m²/s = 948 mm/y — Avg 116.67 mm/y
$2.1e-5$ kg/m²/s = 663.6 mm/y — 0
$2.5e-5$ kg/m²/s = 790 mm/y — Avg 1.2 mm/y
$2.2e-5$ kg/m²/s = 695.2 mm/y — 0
$2.4e-5$ kg/m²/s = 758.4 mm/y — 0
$2.45e-5$ kg/m²/s = 774.2 mm/y — 0
$2.49e-5$ kg/m²/s = 786.8 mm/y — 0
Gardner $\alpha = 9.526e-4\ Pa^{-1}$ $K = 10^{-13}\ m^2$ $q^* = 293.7$ mm/y
Gardner $\alpha = 6.39e-4\ Pa^{-1}$ $K = 10^{-13}\ m^2$ $q^* = 787.4$ mm/y

DH 12/4/98
α = ~~3.3e-4~~ $3.3e-3\ Pa^{-1}$ $m = .63$ $K = 10^{-13}\ m^2$
$1.0e-6$ kg/m²/s = 31.6 mm/y — Avg = 31.3 mm/y
$1.0e-7$ kg/m²/s = 3.16 mm/y — Avg = 3.0 mm/y
$1.0e-8$ kg/m²/s = 0.316 mm/y — Avg = 0.22 mm/y
$1.0e-9$ kg/m²/s = .0316 mm/y — 0
$5.0e-9$ kg/m²/s = 0.158 mm/y — .07
$4.0e-9$ kg/m²/s = 0.126 mm/y — .05
$3.0e-9$ kg/m²/s = .095 mm/y — .03
$2.0e-9$ kg/m²/s = .063 mm/y — .011
Gardner $\alpha = 9.526e-3\ Pa^{-1}$ $K = 10^{-13}\ m^2$ $q^* = 3.2$ mm/y
Gardner $\alpha = 8.0e-2\ Pa^{-1}$ $K = 10^{-13}\ m^2$ $q^* = 0.045$ mm/y

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$\alpha = 3.3e{-3}\ Pa^{-1}$ $m = .63$ $K = 10^{-14}\ m^2$
1e-9 kg/m²/s = .0316 mm/y Avg = .022 mm/y
1e-10 kg/m²/s = .00316 mm/y 0
5e-10 kg/m²/s = .0158 mm/y Avg .00726 mm/y
4e-10 kg/m²/s = .0126 mm/y Avg .00528 mm/y
3e-10 kg/m²/s = .00948 mm/y Avg .00324 mm/y
2e-10 kg/m²/s = .00632 mm/y Avg .00115 mm/y
Gardner $\alpha = 9.~~256~~526e{-3}\ Pa^{-1}$ $K = 10^{-14}\ m^2$ $q^* = 0.336$ mm/y
Gardner $\alpha = 8.0e{-2}\ Pa^{-1}$ $K = 10^{-14}\ m^2$ $q^* = .0045$ mm/y

---

$\alpha = 9.7e{-4}\ Pa^{-1}$ $m = 0.63$ $K = 10^{-14}\ m^2$
1.0e-6 kg/m²/s = 31.6 mm/y Avg = 25.2 mm/y
1.0e-7 kg/m²/s = 3.16 mm/y 0
5.0e-7 kg/m²/s = 15.8 mm/y 9.33 mm/y
2.0e-7 kg/m²/s = 6.32 mm/y 1.96 mm/y
Gardner $\alpha = 2.8e{-3}\ Pa^{-1}$ $K = 10^{-14}\ m^2$ $q^* = 3.63$ mm/y

---

$\alpha = 3.3e{-4}\ Pa^{-1}$ $m = 0.63$ $K = 10^{-14}\ m^2$
2.43e-6 = 76.8 mm/y Avg = 0
2.5e-6 = 79.0 mm/y Avg = 0.12 mm/y
Gardner $\alpha = 9.526e{-4}\ Pa^{-1}$ $K = 10^{-14}\ m^2$ $q^* = 29.37$ mm/y
Gardner $\alpha = 6.39e{-4}\ Pa^{-1}$ $K = 10^{-14}\ m^2$ $q^* = 78.7$ mm/y

---

$\alpha = 3.3e{-4}\ Pa^{-1}$ $m = 0.63$ $K = 10^{-12}\ m^2$
2.43e-4 = 7679 mm/y 0
2.5e-4 = 7900 mm/y 12.05 mm/y
Gardner $\alpha = 9.526e{-4}\ Pa^{-1}$ $K = 10^{-12}\ m^2$ $q^* = 2937.4$ mm/y
Gardner $\alpha = 6.39e{-4}\ Pa^{-1}$ $K = 10^{-12}\ m^2$ $q^* = 7873.8$ mm/y

---

$\alpha = 9.7e{-4}$ $m = 0.63$ $K = 10^{-12}\ m^2$
1.0e-5 kg/m²/s = 316 mm/y 0
2.0e-5 kg/m²/s = 632 mm/y 195.6 mm/y
~~Gardner α = 9.526e-4 Pa^-1~~ 12/6/98
~~Gardner α = 6.39e~~ DH
Gardner $\alpha = 2.8e{-3}\ Pa^{-1}$ $K = 10^{-12}\ m^2$ $q^* = 363.3$ mm/y

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$\alpha = 3.3e{-3}\ Pa^{-1}$ $m = 0.63$ $K = 10^{-12}\ m^2$
1e-8 kg/m²/s = .316 mm/y 0
DH 12/6/98 2e-8 kg/m²/s = .632 mm/y Avg = 0.115 mm/y
Gardner $\alpha = 9.526e{-3}\ Pa^{-1}$ $K = 10^{-12}\ m^2$ $q^* = 31.7$ mm/y
Gardner $\alpha = 8.0e{-2}\ Pa^{-1}$ $K = 10^{-12}\ m^2$ $q^* = 0.45$ mm/y

---

Sensitivity Analysis With TPA 3.2

Take tpa.inp file from /tpa/7a20K50y-1kr-050

This is the nominal case of the 1000 vector runs

Change # of simulations to 1
Change Fow to constant = 1.0
Change Fmult to constant = 0.01

remove correlation 0.13 between K_s and Fow

dose50y-1.dat dose10y-1.dat

Change Fmult to constant = 0.2

dose50y-2.dat dose10y-2.dat

Change Fmult to constant = 0.5

dose50y-3.dat dose10y-3.dat

Change Fmult to constant = 1.0

dose50y-4.dat dose10y-4.dat

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Project No. 20-1402-861

Book No. 285 TITLE USFIC

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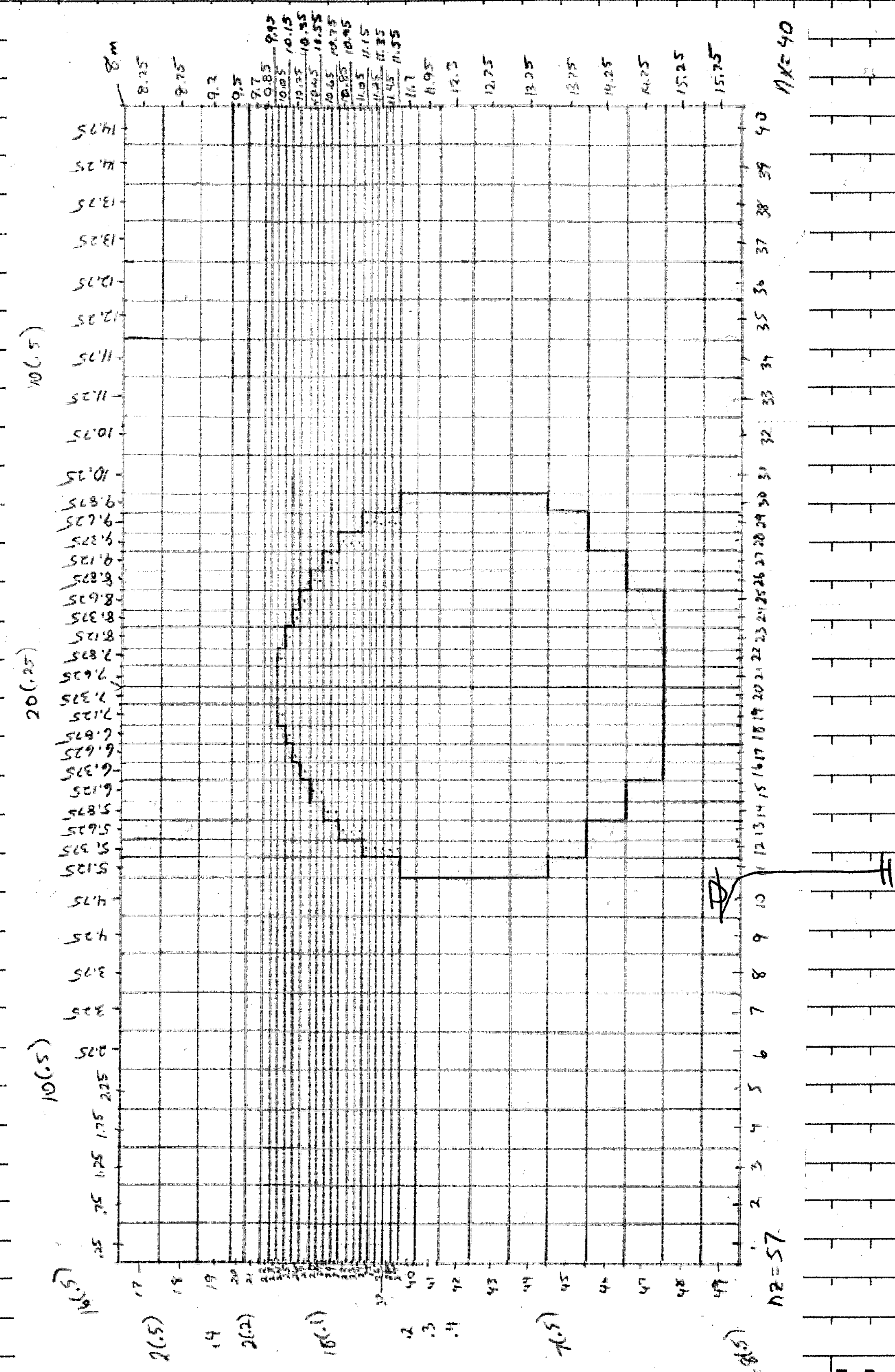

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TITLE USFIC

Project No. 20-1402-861

Book No. 285

From Page No.

$\alpha = \dfrac{b\rho g}{2\sigma \cos\theta}$

b = aperture

$\rho = 998\ kg/m^3$

$g = 9.8\ m/s^2$

$\sigma = 0.072\ N/m$

θ = contact angle

$\dfrac{m\ \frac{kg}{m^3}\ \frac{m}{s^2}}{\left(kg\ \frac{m}{s^2}\right)/m} = \frac{1}{m}$

$\alpha \left(\frac{1}{m}\right)\left(\frac{m^3}{998 kg}\right)\left(\frac{s^2}{9.8 m}\right) = \frac{m s^2}{kg} = Pa^{-1}$

$2s = \alpha l$ l = radius of circular opening $\sim$ 2cm = .02m

If $b \approx 200\ \mu m$ $2s \cong 28 cm$

$b \approx 100\ \mu m$ $2s \cong 14$ cm

Look at 1^{st} 2^{nd} & 3^{rd} refinements of grid for base case properties $\alpha = 9.7e\text{-}4\ Pa^{-1}$ $m = .63$ $K = 10^{-13} m^2$, find the point where flat-topped crown starts to leak.

3^{rd} refinement shown on Page 68

q		seep
$1.2e\text{-}6\ kg/m^2/s$	= 37.92 mm/y	0
$4.0e\text{-}6\ kg/m^2/s$	= 126.4 mm/y	83.5 Avg mm/y
$3.0e\text{-}6\ kg/m^2/s$	= 94.8 mm/y	8.66 mm/y at top Avg 46.6 mm/y
$2.5e\text{-}6\ kg/m^2/s$	= 79 mm/y	0 at top Avg 26.8 mm/y
$2.9e\text{-}6\ kg/m^2/s$	= 91.64 mm/y	4.13 at top Avg 42.26 mm/y
$2.8e\text{-}6\ kg/m^2/s$	= 88.48 mm/y	0 at top Avg 38.48 mm/y

3^{rd} grid refinement file archive

~dhughson/multiflo/inputbak/multi.24

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From Page No.

2nd grid refinement shown on Page 56
base case properties $\alpha = 9.7e-4\ Pa^{-1}$ $m = 0.63$
$K = 10^{-13}\ m^2$

q		seep	
1.2e-6 kg/m²/s = 37.92 mm/y	0 on top	Avg = 42.85 mm/y	
1.3e-6 kg/m²/s = 41.08 mm/y	0 on top	Avg = 46.85 mm/y	
1.4e-6 kg/m²/s = 44.24 mm/y	0 on top	Avg = 50.85 mm/y	
1.5e-6 kg/m²/s = 47.4 mm/y	0 on top	Avg = 54.85 mm/y	
1.6e-6 kg/m²/s = 50.56 mm/y	0 on top	Avg = 58.84 mm/y	
1.7e-6 kg/m²/s = 53.72 mm/y	0 on top	Avg = 62.82 mm/y	
1.8e-6 kg/m²/s = 56.88 mm/y	0 on top	Avg = 66.8 mm/y	
1.9e-6 kg/m²/s = 60.04 mm/y	0 on top	Avg = 70.78 mm/y	
2.0e-6 kg/m²/s = 63.2 mm/y	4.6 mm/y outside top	Avg = 74.5 mm/y	
2.1e-6 kg/m²/s = 66.36 mm/y	10.75 mm/y outside top	Avg = 78.12 mm/y	
2.2e-6 kg/m²/s = 69.52 mm/y	16.82 mm/y outside top	Avg = 81.74 mm/y	
2.3e-6 kg/m²/s = 72.68 mm/y	22.87 mm/y outside top	Avg = 85.37 mm/y	
2.4e-6 kg/m²/s = 75.84 mm/y	28.94 mm/y outside top	Avg = 88.99 mm/y	
2.5e-6 kg/m²/s = 79.0 mm/y	35.02 mm/y outside top	Avg = 92.61 mm/y	
2.6e-6 kg/m²/s = 82.16 mm/y	41.08 mm/y outside top	Avg = 96.23 mm/y	
2.7e-6 kg/m²/s = 85.32 mm/y	47.15 mm/y outside top	Avg = 99.84 mm/y	
2.8e-6 kg/m²/s = 88.48 mm/y	53.21 mm/y outside top	Avg = 103.45 mm/y	
2.9e-6 kg/m²/s = 91.64 mm/y	59.27 mm/y outside top	Avg = 107.06 mm/y	
3.0e-6 kg/m²/s = 94.80 mm/y	65.34 mm/y outside top	Avg = 110.67 mm/y	
3.1e-6 kg/m²/s = 97.96 mm/y	2.68 mm/y on TOP	Avg = 114.25 mm/y	

~dhughson/multiflo/inputbak/multi.25

1st grid refinement shown ~~of~~ on Page 19 (DH 12/14/98)
base case properties $\alpha = 9.7e-4\ Pa^{-1}$ $m = 0.63$ $K = 10^{-13}\ m^2$

q	seep	
3.16e-7 kg/m²/s = 9.99 mm/y	9.79 mm/y on top	Avg = 11.82 mm/y
9.5e-10 kg/m²/s = .03 mm/y	0 on top	Avg = 0
9.5e-9 kg/m²/s = 0.3 mm/y	0.24 mm/y on top	Avg = 0.27 mm/y
1.9e-9 kg/m²/s = .06 mm/y	.013 on top	Avg = .015 mm/y
1.8e-9 kg/m²/s = .0569 mm/y	.010 on top	Avg = .012 mm/y
1.7e-9 kg/m²/s = .0537 mm/y	.00674 on top	Avg = .0093 mm/y

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q	seep	
1.6e-9 kg/m²/s = .0506 mm/y	.0035 mm/y on top	Avg = .0068 mm/y
1.5e-9 kg/m²/s = .0474 mm/y	2.25e-4 mm/y on top	Avg = 4.4e-3 mm/y
1.4e-9 kg/m²/s = .0442 mm/y	0 on top	Avg = 2.28e-3 mm/y

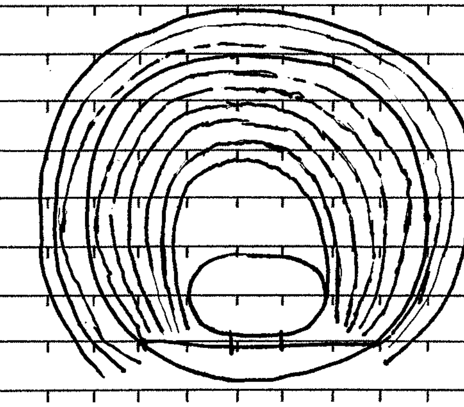
~dhughson/multiflo/inputbak/multi.26

Dec 21, 1998 Drip Shop Start 8:15 AM

Ron - overview
Ron - comment on ventilation
Goodluck - TM effects on permeability - Increase with heat-time
Murphy - changes in properties & formation of heterogeneities
Dani Or - fracture conductivity & film flow

Dec 22, 1998 Drip Shop discussion 8:10 AM

unstructured grid refinement for seepage models
100% RH same as being in water
50% RH & above important
fracture clusters - fractures through Ptn
how many containers get wet how much water falls on these cannisters



fritted glass - porous glass
on one side - or ceramic
control pressure in ceramic
to control film size
diamond cut grooves to
edge for dripping

2- scales to look at
scaling issue

visual microscope - image analysis

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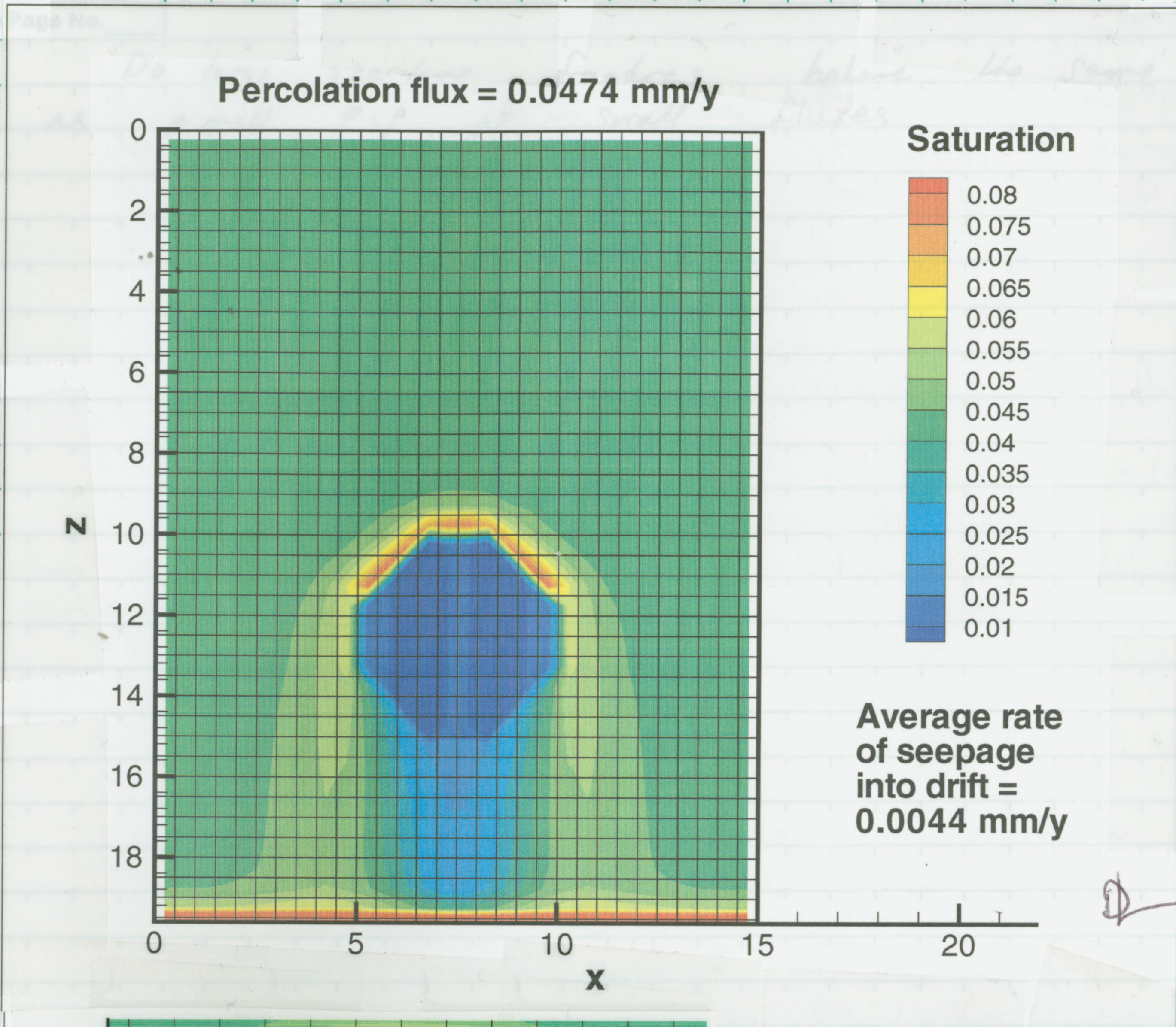

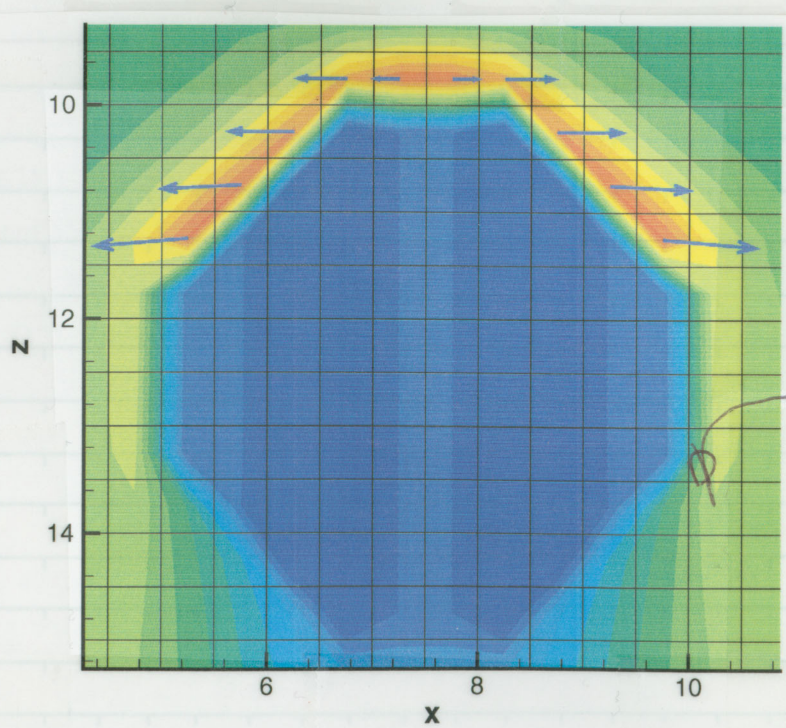

Presented at dripstop
Dec 21, 1998
~dhughson/multiflo/
seep/strucapdiv

refire1.plt
refire1.lay
refire1.prt
close1.prt

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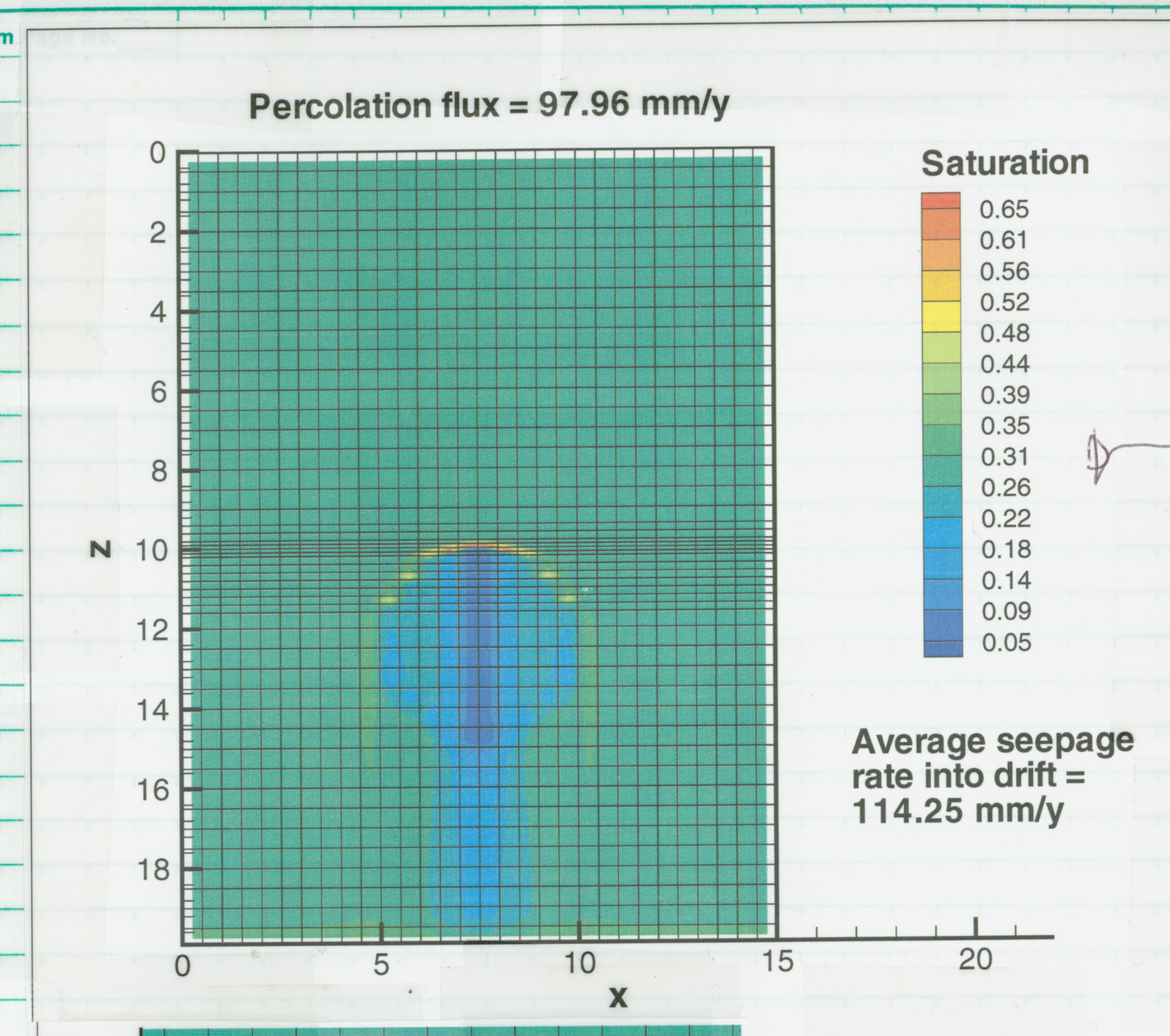

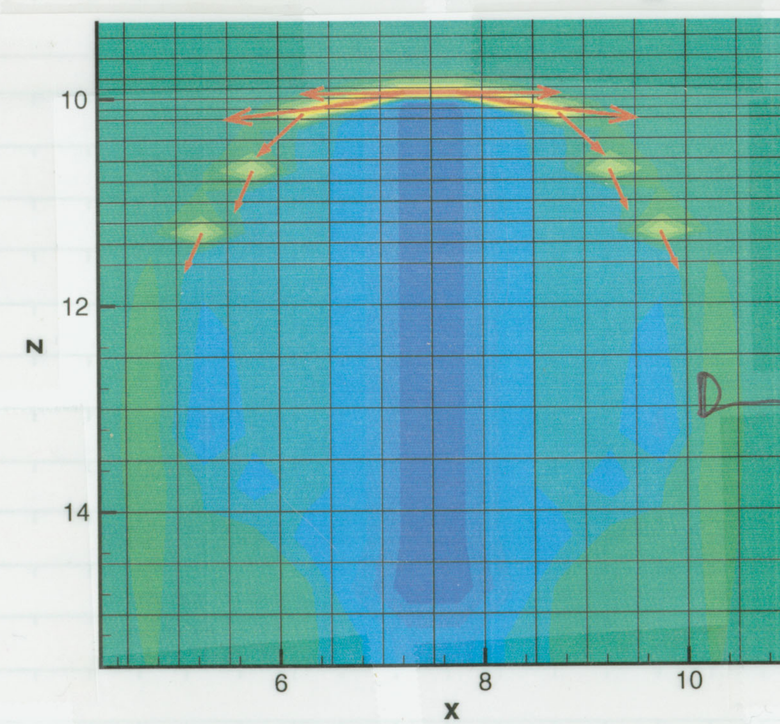

Presented at dripstop
Dec 21, 1998
~dhughson/multiflo/
seep/strucapdw/

refire2.plt
refire2.lay
refire2.prt
close2.prt

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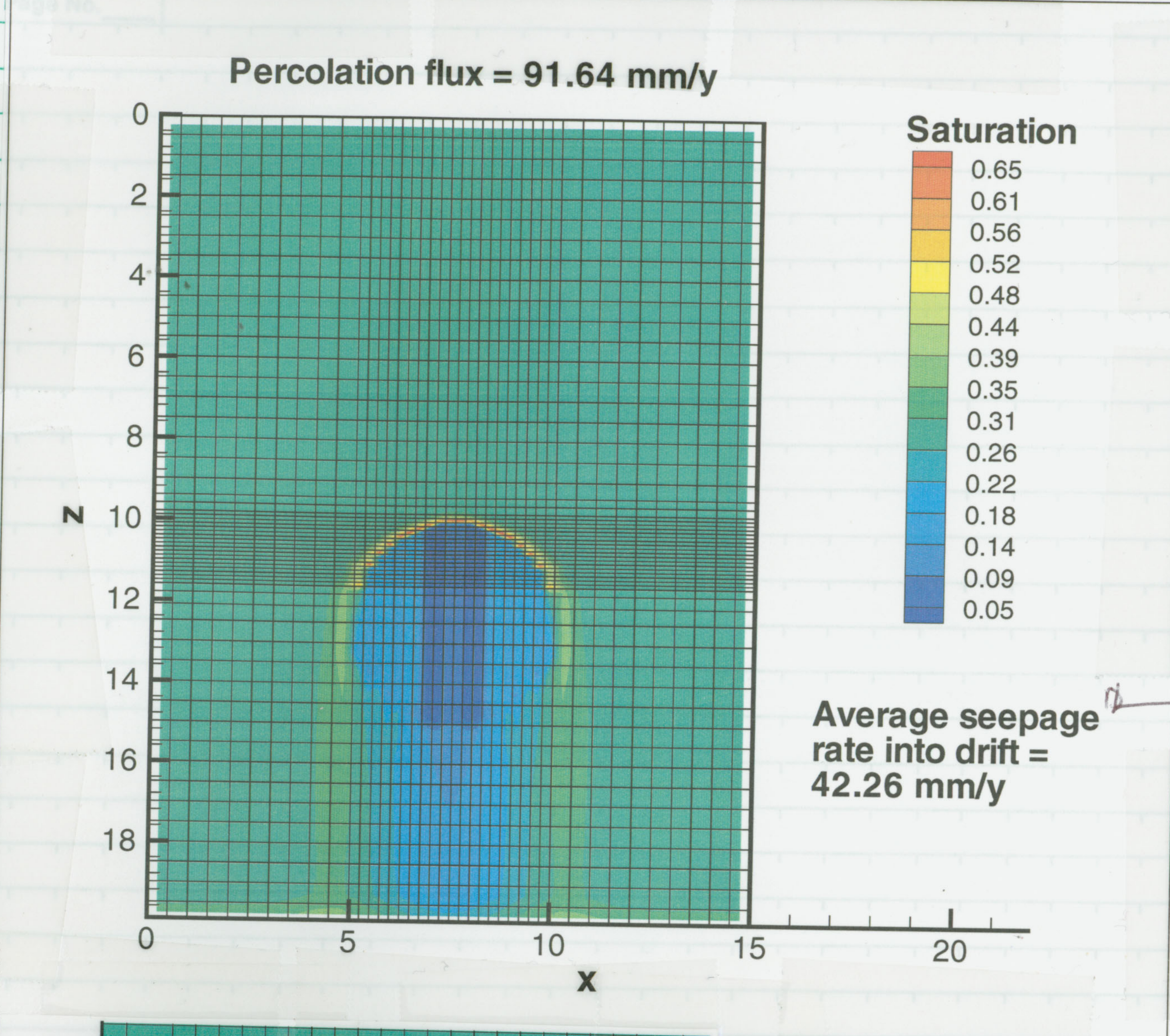
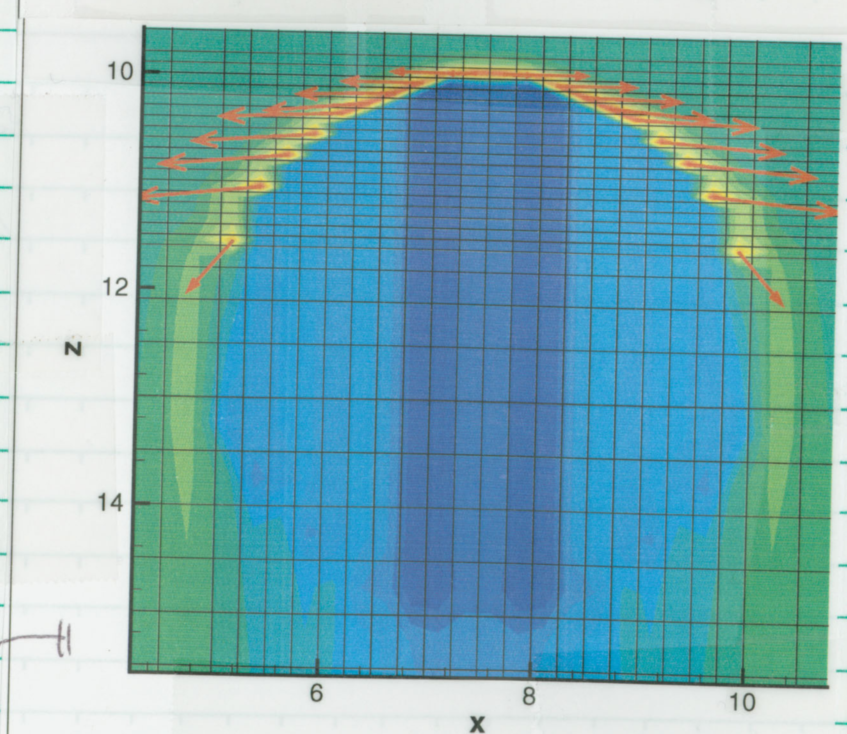
From Page No.





Presented at dripshop
Dec 21, 1998
~dhughson/multiflo/seep/strucap.dir

refine3.plt
refine3.lay
refine3.prt
close3.prt

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TITLE USFIC Book No. 285

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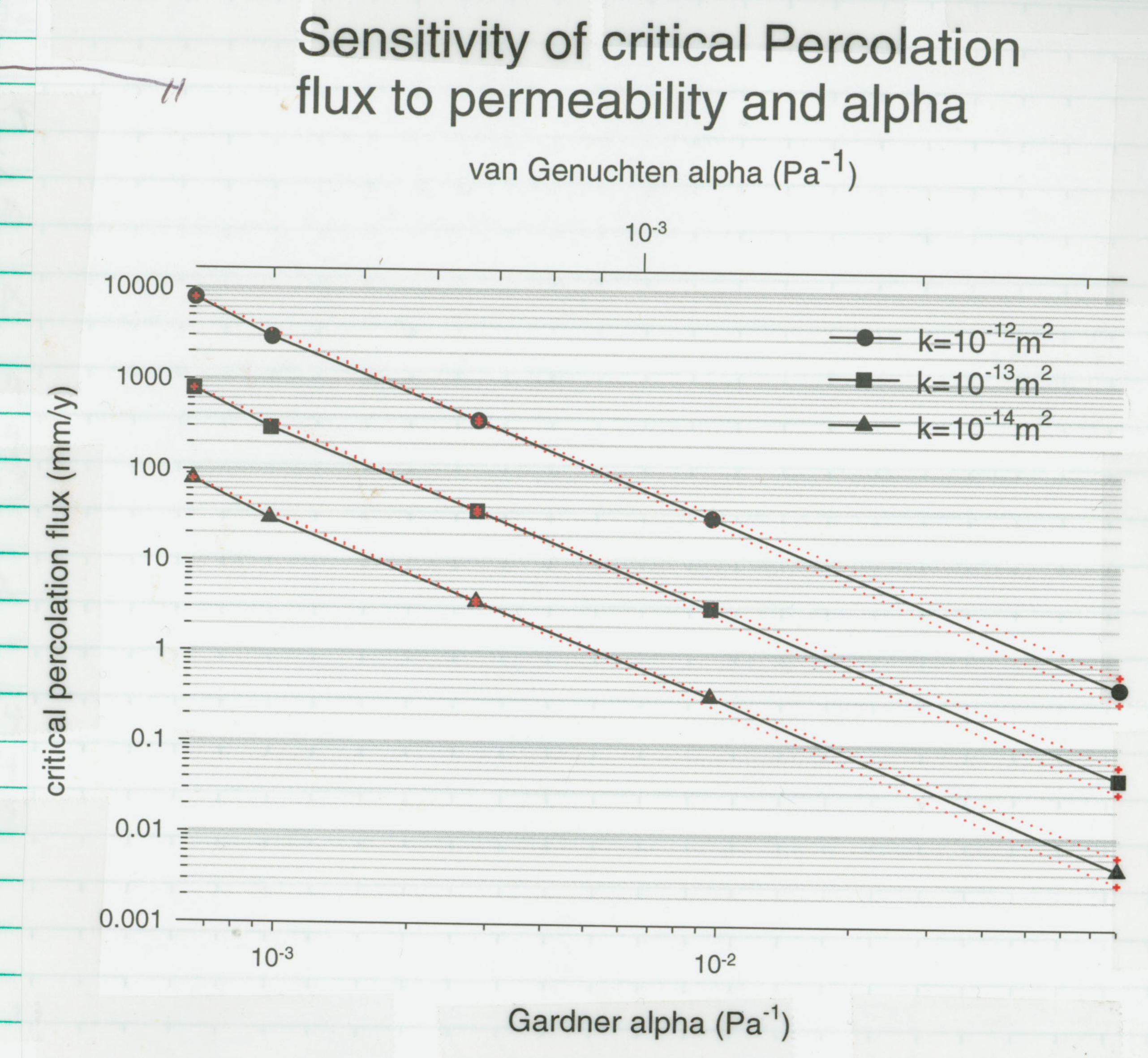

Presented at dripshop Dec 21, 1998
Black line is Philip 1989 solution (page 52)
with $l =$ ~~0.5m~~ 1.0m DH 12/30/98

Red dotted lines are multiflo results from pages 65-67
start with ~dhughson/multiflo/inputbak/multi.22 on top of pg 65
Sigma Plot File at D:\work\aksens.JNB

2nd grid refinement pg 56 look at velocity output
with bcflxsq.f and bcsq.dat → bcsq.refine2

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From Page No. ___ Sensitivity graph on page 75 and data pages 65 to 67 done with grid refinement 2 pg 56

Redo using grid refinement 3 pg 68 where 2m strip runs from column 17 to column 23 row 24

Constant $S_r = .01$ $m = 0.63$ $\phi = 1.24e{-4}$

First set $\alpha = 9.7e{-4}\ Pa^{-1}$ $K = 10^{-13}\ m^2$

q		seep
1.1e-6 ~~kg~~ kg/m²/s	= 34.8 mm/y	Avg = 3.14 mm/y
1.0e-6 kg/m²/s	= 31.6 mm/y	Avg = 1.38 mm/y]
0.9e-6 kg/m²/s	= 28.44 mm/y	0

DH 12/31/98

Gardner α = 3.1e-3 /Pa q^* = 29.7 mm/y

Set $\alpha = 3.3e{-4}\ Pa^{-1}$ $K = 10^{-13}\ m^2$

q		seep
2.5e-5 kg/m²/s	= 790 mm/y	Avg 33.2 mm/y
2.45e-5 kg/m²/s	= 774.2 mm/y	Avg 24.0 mm/y
2.40e-5 kg/m²/s	= 758.4 mm/y	Avg 14.8 mm/y
2.35e-5 kg/m²/s	= 742.6 mm/y	Avg 5.6 mm/y]
2.3e-5 kg/m²/s	= 726.8 mm/y	0

Gardner α = 6.5e-4 /Pa q^* 738.5 mm/y

Set $\alpha = 3.3e{-3}\ Pa^{-1}$ $K = 10^{-13}\ m^2$

q		seep
2.0e-9 kg/m²/s	= .063 mm/y	Avg .014 mm/y
1.0e-9 kg/m²/s	= .0316 mm/y	Avg 1.77e-6 mm/y
8.0e-10 kg/m²/s	= .0253 mm/y	Avg 8.2e-6 mm/y
1.0e-10 kg/m²/s	= .00316 mm/y	0
5.0e-10 kg/m²/s	= .0158 mm/y	Avg 2.7e-8 mm/y
4.0e-10 kg/m²/s	= .0126 mm/y	Avg 6.75e-3 mm/y
3.0e-10 kg/m²/s	= .0095 mm/y	Avg 0

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Gardner α = ~~5x10^-1 Pa^-1~~ ~~q*~~ = 1.7e-1 /Pa q^* = .00997 mm/y

DH 12/31/98

Save as ~dhughson/multiflo/inputbak/multi.27

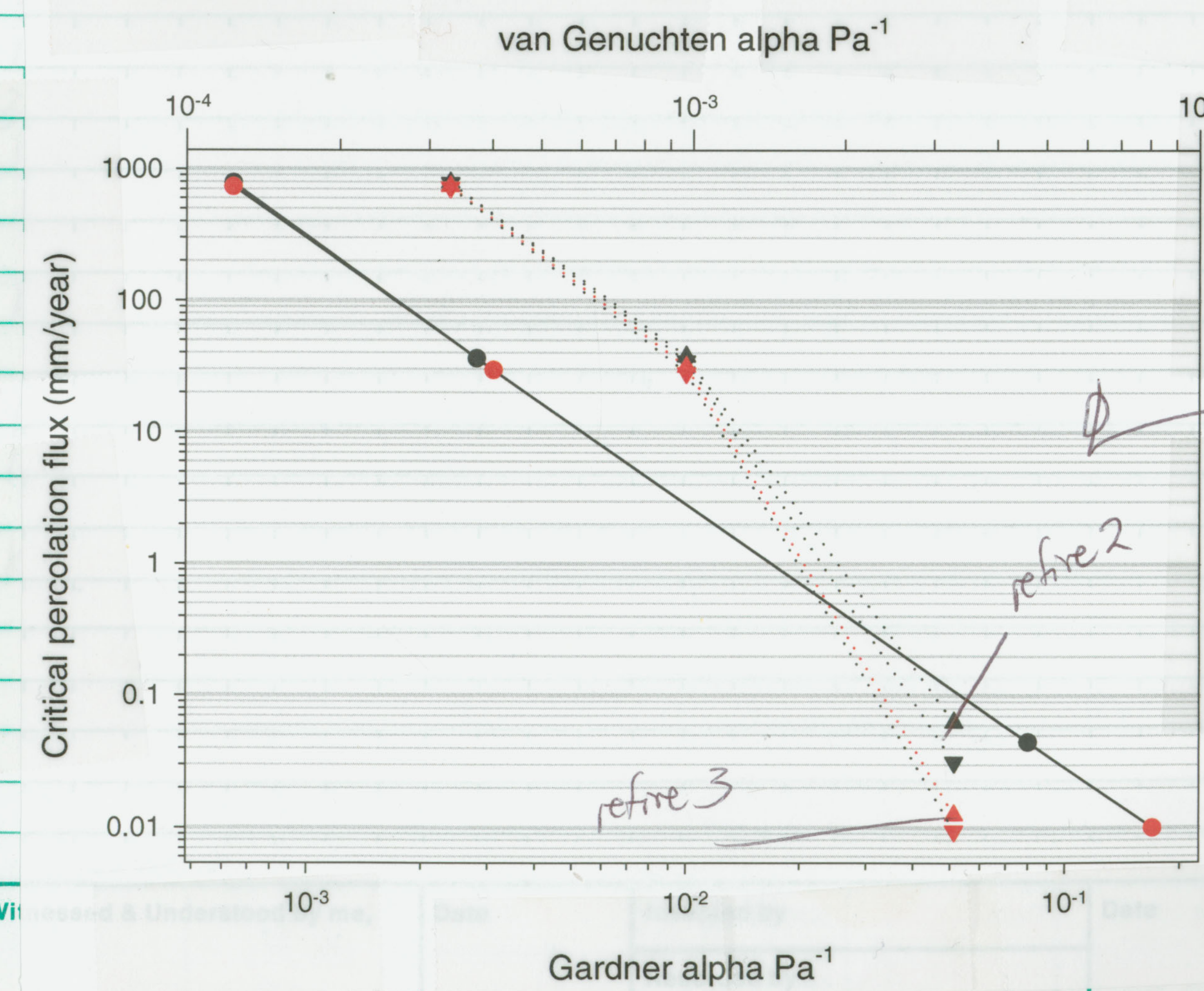
Data for refine 2 set ~~α = 9.7e-4~~ $K = 10^{-13}\ m^2$ (pg 65)

DH 12/31/98

VGα	Hi	Low	Gα	q*
3.3e-4	790	786.8	6.39e-4	787.4
9.7e-4	37.9	34.8	2.8e-3	36.3
3.3e-3	.063	.0316	8.0e-2	.045

Data for refine 3 set $K = 10^{-13}\ m^2$ (pg 76)

VGα	Hi	Low	Gα	q*
3.3e-4	742.6	726.8	6.5e-4	738.5
9.7e-4	31.6	28.44	3.1e-3	29.7
3.3e-3	.0126	.0095	1.2e-1	.00997



φ → 4

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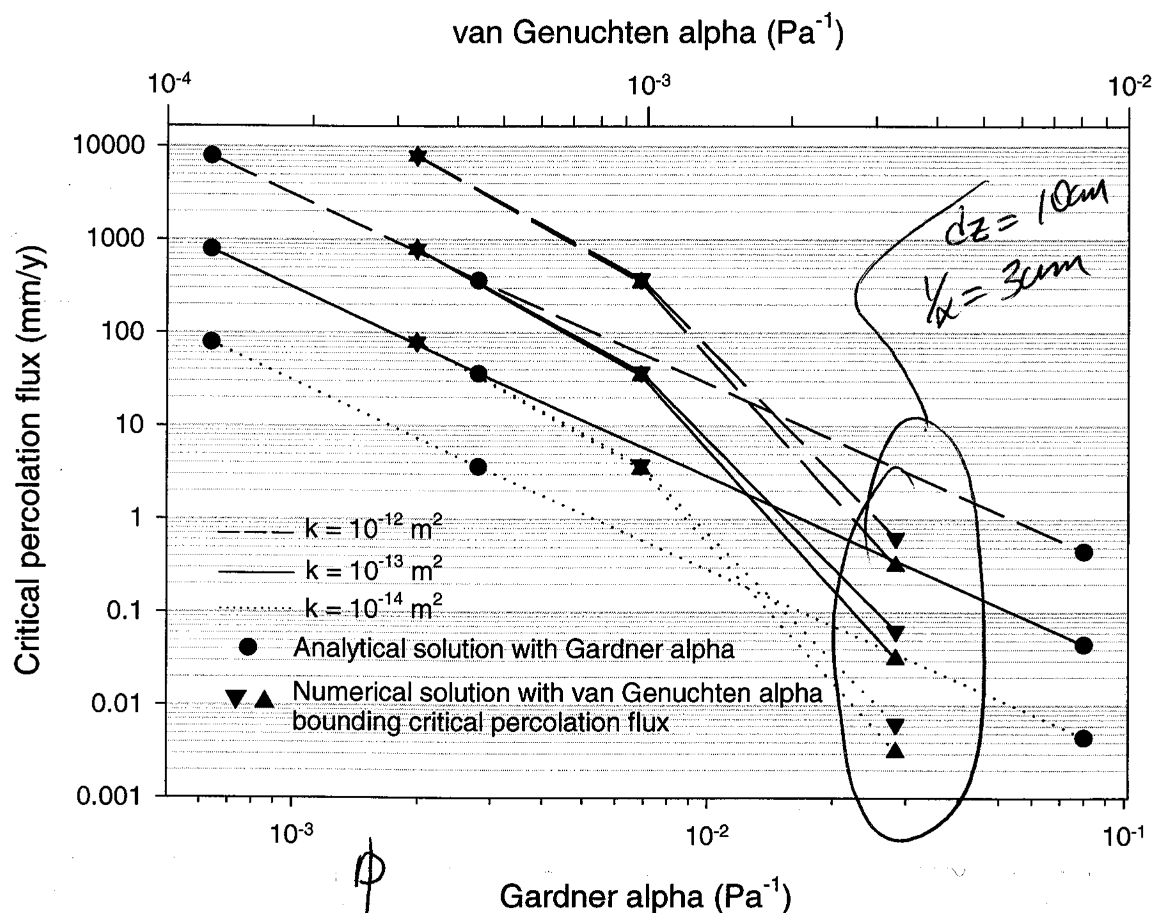
DH Dec 31

From Page No.

Plot on page 75 with stretched axis on top caused van Genuchten to be incorrect. Here is the SAME DATA Plotted correctly. This is with grid refinement #2 and 2m wide strip

Sensitivity of critical percolation flux to permeability and alpha



DH

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From Page No. Grid refinement #4 from refine 2 pg 56

$\alpha = 3.3e{-3}\ Pa^{-1}$ capillary rise ~ 3cm

9.9
.05
23 – 9.925
23 9.95
.025 9.975 24 – 9.9625
.025 10.0 25 – 9.9875
.025 10.025 26 –
24 .025 10.05 27
.05 28
~~Add two 4 rows at drift crown~~ 10.1
DH 1/4/99
29

$k = 10^{-13}\ m^2$ $\alpha = 3.3e{-3}\ Pa^{-1}$

q		seep
3.16e-8 kg/m²/s =	1.0 mm/y	0
6.33e-8 kg/m²/s =	2.0 mm/y	0
9.49e-8 kg/m²/s =	3.0 mm/y	0
1.27e-7 kg/m²/s =	4.01 mm/y	0
3.16e-7 kg/m²/s =	10 mm/y	Avg 2.7 mm/y
1.58e-7 kg/m²/s =	5 mm/y	0
1.9e-7 kg/m²/s =	6 mm/y	Avg = 5.6e-2 mm/y

$K = 10^{-12}\ m^2$ $\alpha = 3.3e{-3}\ Pa^{-1}$

q		seep
1.9e-6 kg/m²/s =	60.04 mm/y	Avg = 0.56 mm/y
1.6e-6 kg/m²/s =	50.56 mm/y	0

$K = 10^{-14}$ $\alpha = 3.3e{-3}\ Pa^{-1}$

q		seep
1.9e-8 kg/m²/s =	0.6 mm/y	5.6e-3 mm/y
1.7e-8 kg/m²/s =	.537 mm/y	0

~dhughson/multiflo/inputbak/multi.29

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		Recorded by DH	Jan 4 1999

Project No. 20-1402-861
Book No. 285 TITLE USFIC

From Page No.___ Grid refine 4

$\alpha = 9.7e{-}4\ Pa^{-1}$ $K = 10^{-14}\ m^2$

q		seep
2.0e-7 kg/m²/s =	6.3 mm/y	0
3.0e-7 kg/m²/s =	9.48 mm/y	0
4.0e-7 kg/m²/s =	12.64 mm/y	0
5.0e-7 kg/m²/s =	15.8 mm/y	Avg .826 mm/y

$\alpha = 9.7e{-}4\ Pa^{-1}$ $K = 10^{-13}\ m^2$

q		seep
4.0e-6 kg/m²/s =	126.4 mm/y	0
5.0e-6 kg/m²/s =	158.0 mm/y	8.26 mm/y

$\alpha = 9.7e{-}4\ Pa^{-1}$ $K = 10^{-12}\ m^2$

q		seep
4.0e-5 kg/m²/s =	1264 mm/y	0
4.5e-5 kg/m²/s =	1422 mm/y	0
4.7e-5 kg/m²/s =	1485 mm/y	14.56 mm/y

$\alpha = 3.3e{-}4\ Pa^{-1}$ $K = 10^{-12}\ m^2$

q		seep
3.16e-4 kg/m²/s =	9985 mm/y	0
4.0e-4 kg/m²/s =	12640 mm/y	Avg = 1263 mm/y
3.5e-4 kg/m²/s =	11060 mm/y	Avg = 80 mm/y
3.4e-4 kg/m²/s =	10744 mm/y	0

$\alpha = 3.3e{-}4\ Pa^{-1}$ $K = 10^{-13}\ m^2$

q		seep
3.4e-5 kg/m²/s =	1074.4 mm/y	0 DH 1/6/99
3.5e-5 kg/m²/s =	1106 mm/y	Avg 8.04 mm/y

$\alpha = 3.3e{-}4\ Pa^{-1}$ $K = 10^{-14}\ m^2$

q		seep
3.5e-6 kg/m²/s =	110.6 mm/y	.804 mm/y
3.4e-6 kg/m²/s =	107.4 mm/y	0

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Project No. 20-1402-861
Book No. 285

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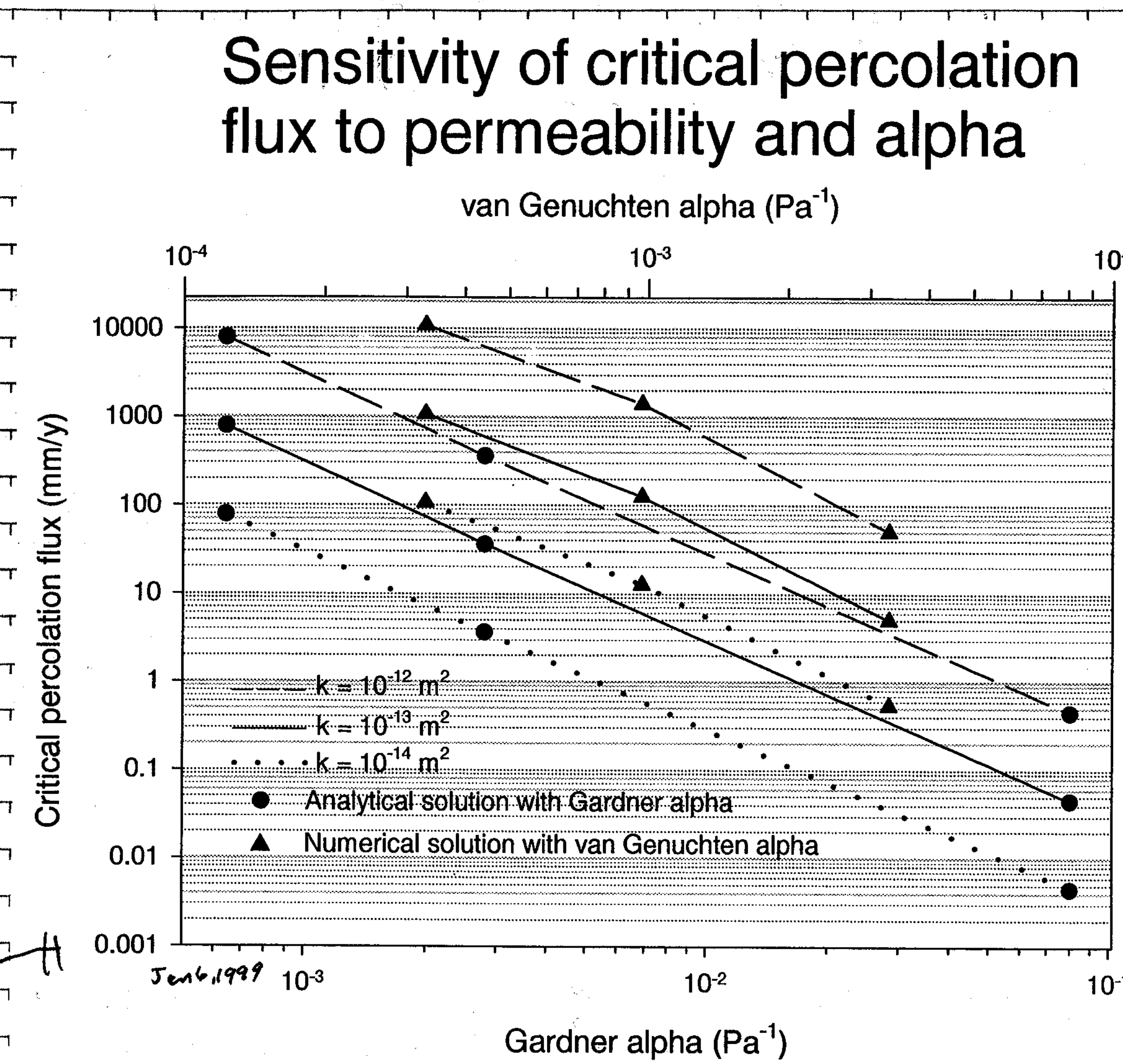
Grid Refine 4



DH Jan 6, 1999

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From Page No.

Question: How will surface irregularities of the drift wall (possibly due to rockfall) affect seepage as modeled by the porous media continuum approach.

Approach 1 Use quasi-linearized Richard's Eq transformed to Helmholtz in polar coord. and find solution for perturbation in boundary shape.

Approach 2 Use multiflo with structured and unstructured grid.

DH 1/6/99

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Approach 2A – Multiflo with unstructured grid shown on following pages

Properties $\alpha = 9.7e-4\ Pa^{-1}$ $k = 1e-13\ m^2$

Flux at which top strip $x = 7.35$ to 7.65 $y = 9.99$ starts to drop for unperturbed boundary

q_{in}		seep
2.0e-5	632 mm/yr	0
2.1e-5		0
2.2e-5		0
2.3e-5		0
2.4e-5		0
2.5e-5	790 mm/yr	0
2.6e-5	822 mm/yr	top 2 blocks 3.82e-3 each

7.91e-6 250 mm/yr

DH 1/6/99

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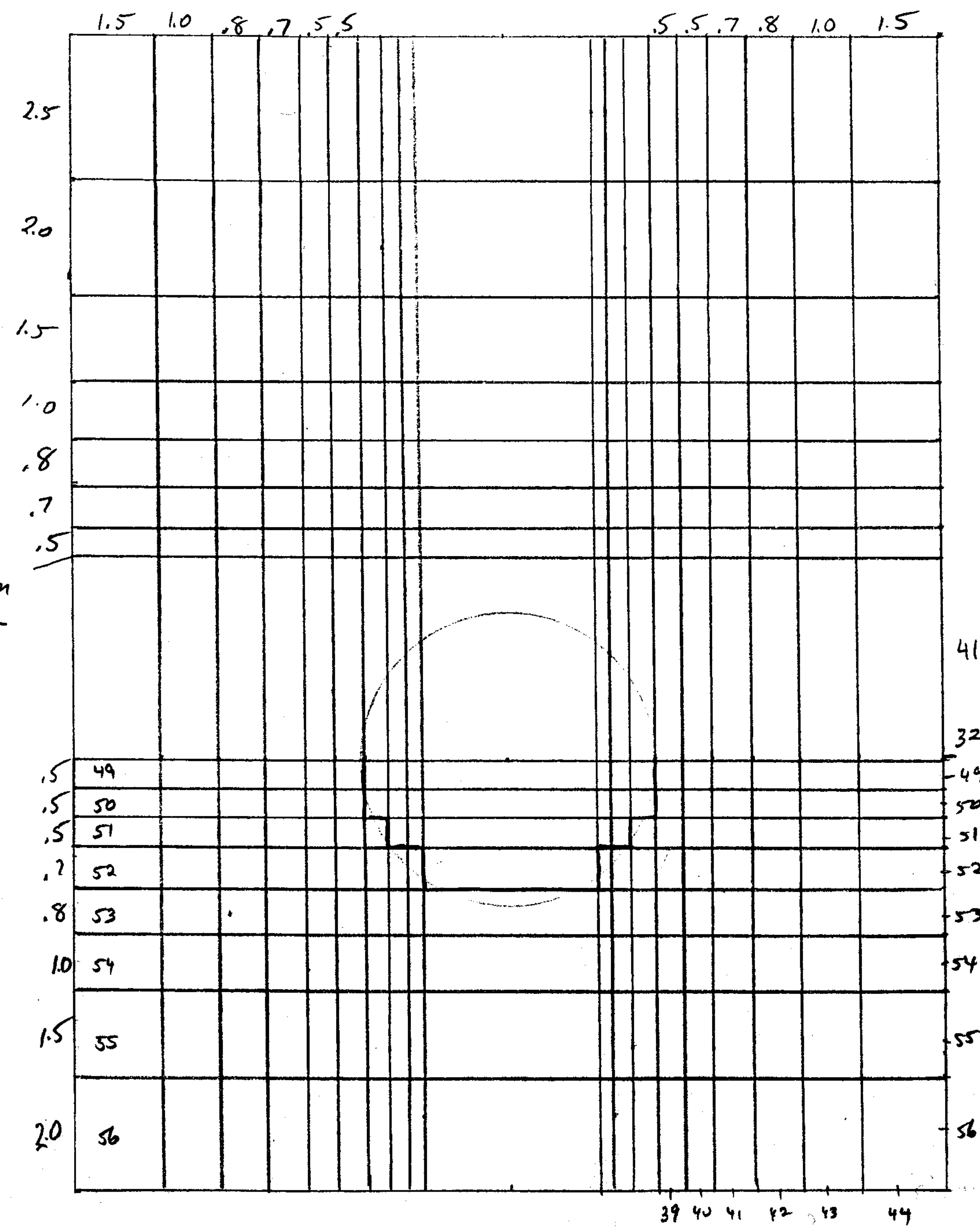
$nx = 44$
$nz = 56$



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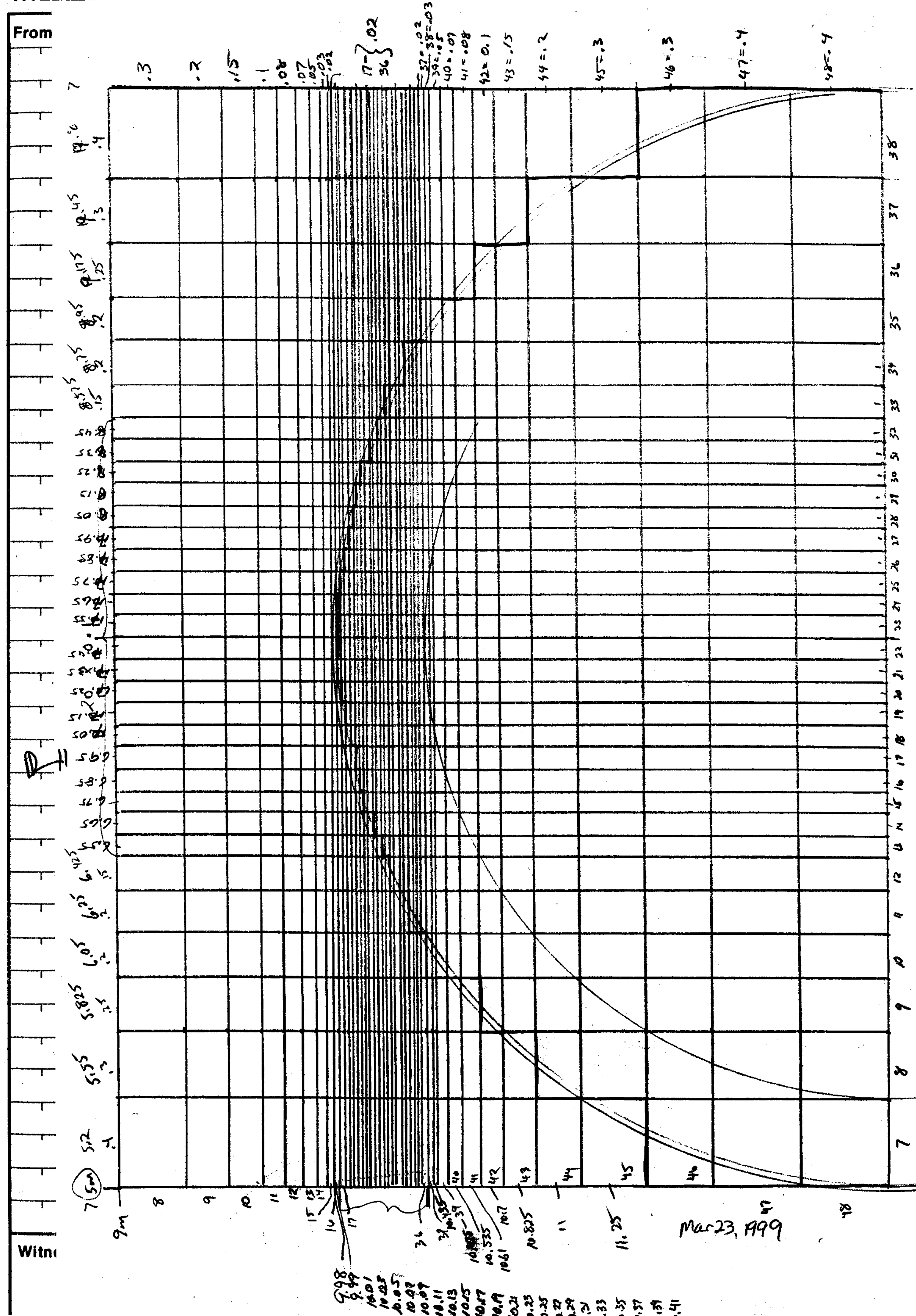
From



Mar 23, 1999

Witn

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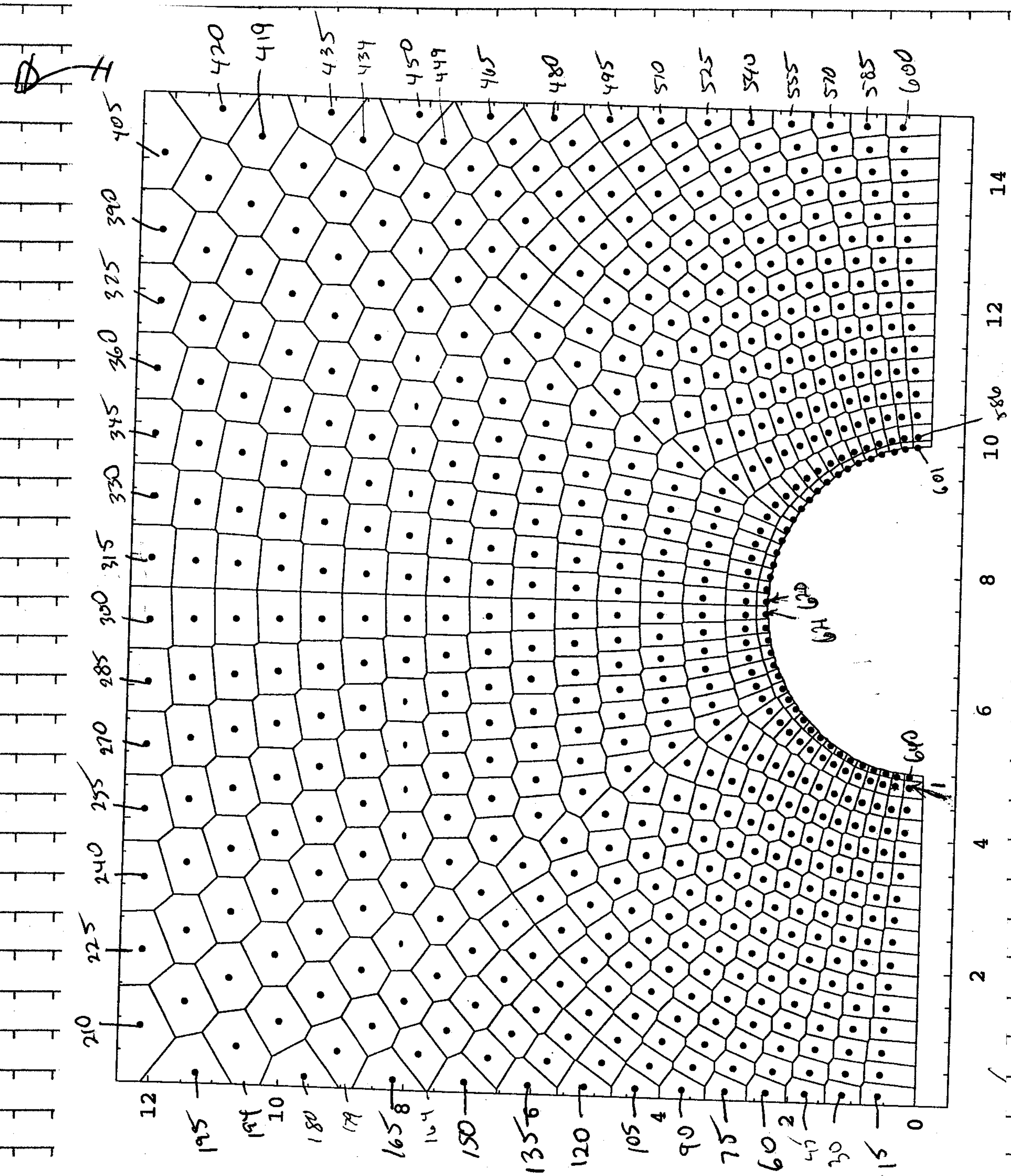

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For the unstructured grid, look for flux which results in $S_\ell \approx 1$ $P_c \approx 0$ at nodes 620, 621

BC at TOP itype 3 liquid vel in m/year

QBC	S_ℓ	P_c
2.0e-2	0.7047	929
3.0e-2	0.7585	831.2
5.0e-2	0.8293	699.5
8.0e-2	0.8923	569.1
2.0e-1	0.9829	274.7
3.0e-1	0.9985	111.9
4.0e-1	1.0	0
3.5e-1	0.9999	39.95

Change S_ℓ at bottom boundary from 0.5 to 0.8

3.5e-1	0.9995	76.27

Change S_ℓ at bottom bndr from 0.8 to 0.9

3.5e-1	0.9992	89.32

Change S_ℓ at bottom bndr from 0.8 to 0.95

3.5e-1	0.9989	97.67
4.0e-1	0.9999	32.57

oops! that's S_g on the boundary, not S_ℓ

S_ℓ on bottom bndry = 0.9 $S_g = 0.1$

3.5e-1	1.0	0
3.0e-1	1.0	0
2.5e-1	0.9998	50.80

0.25 m/year = 250 mm/year

Bottom BC makes a difference in the result

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From Page No. ___ Apr 2, 1999

The structured grid on pages 84, 85 has difficulty converging to a solution and, when it does, gives ambiguous results. The grid on page 86 gives good results but is affected by the BC on other side of the half circle. New grid, following page.

Use exponential Gardner model (Table lookup in Multiflo) to compare with Philip's solution

$$S_e = \frac{\theta-\theta_r}{\theta_s-\theta_r} = \exp\left(-\frac{\alpha|\psi|}{2}\right)\left(1+\frac{\alpha|\psi|}{2}\right)^{\frac{2}{m+2}} \qquad m \overset{?}{=} 1/2$$

Russo & Bouton WRR 28(7) p 1911-1925, 1992

$$K(\psi) = K_s \exp(-\alpha|\psi|)$$

$$VG \quad \frac{\theta-\theta_r}{\theta_s-\theta_r} = \frac{S-S_r}{1-S_r} = \left[1+(\alpha|P_c|)^m\right]^{\frac{1}{m}-1} = S_e$$

confusion of too many m's

$$K(\psi) = K_s \sqrt{S_e}\left(1-(1-S^{1/n})^{n}\right)^2$$

use this

$$K_s\sqrt{S_e}\left(1-(1-S^{1/n})^{n}\right)^2 \qquad \left(1+(\alpha|P_c|)^m\right)^{-n} \qquad n = 1-1/m \qquad m = \frac{1}{1-n}$$

Plotting K vs ~~ψ~~ P_c for VG and GR (vanGenuchten & Gardner-Russo) I find that

$\alpha_G = 4.85e\text{-}4$ /Pa gives approximately similar behavior near $P_c = 0$, $S_e = 1$ as does VG $= 9.7e\text{-}4\ Pa^{-1}$

$$Pa = \frac{N}{m^2} = \frac{kg\,m/s^2}{m^2} = \frac{kg}{m s^2} \qquad \left(4.85e\text{-}4\ \frac{ms^2}{kg}\right)\left(998\frac{kg}{m^3}\right)\left(9.8\frac{m}{s^2}\right) = 4.74\ m^{-1}$$

$$1e\text{-}13\ m^2\ \frac{(998\frac{kg}{m^3})\ 9.8\ m/s^2}{1.119e\text{-}3\ \frac{kg}{m\,s}}\ 1000\frac{mm}{m}\ (60\cdot60\cdot24\cdot365)\frac{s}{y} = 2.756e4\ mm/yr$$

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According to the Philip solution, threshold percolation flux = 2022.6 mm/yr

Flux	At nodes 651 & 652	P_c	S_e
1.0e-2 m/y =	10 mm/yr	1.5131e4 Pa	0.3554
1.0e-1 m/y =	100 mm/yr	4565	0.6025
1.0 m/y =	1000 mm/yr	0	1.0
0.5 m/y =	500 mm/yr	0	1.0
0.2 m/y =	200 mm/yr	2054	.8405
0.3 m/y =	300 mm/yr	1019	.9323
0.4 m/y =	400 mm/yr	345.6	.9808
0.44 m/y =	440 mm/yr	132.1	.9932
0.46 =	460 mm/yr	0	1.0

~~.48~~ $4.85e\text{-}4\ \frac{ms^2}{kg}\ 998\ kg/m^3\ 9.8\ \frac{m}{s^2} = 4.74\ m^{-1} = \alpha_G$

$s = \frac{\alpha l}{2} = (4.74/m)(2.5m)/2 = 5.93$ From Philip 1989

eq (81) boundary layer solution $q^* = 2007$ mm/yr

1) Boundary condition flux not set right in multiflo
2) no-flow boundaries too close together

0.45 m/y 450 mm/yr 0 1.0

3) Saturation - Pressure relationship for Gardner model

First, change top BC from type 3 to type 5

Units kg/m²/s Top area (15m)(10m) = 150 m²

$$\left(0.4\ m/yr\right)\left(998\frac{kg}{m^3}\right)\frac{yr}{60\cdot60\cdot24\cdot365\ s} = 1.266e\text{-}5\ kg/m^2/s$$

	P_c	S_e	
1.266e-5 kg/m²/s = 400 mm/yr	252.8	.9864	Type 5 BC

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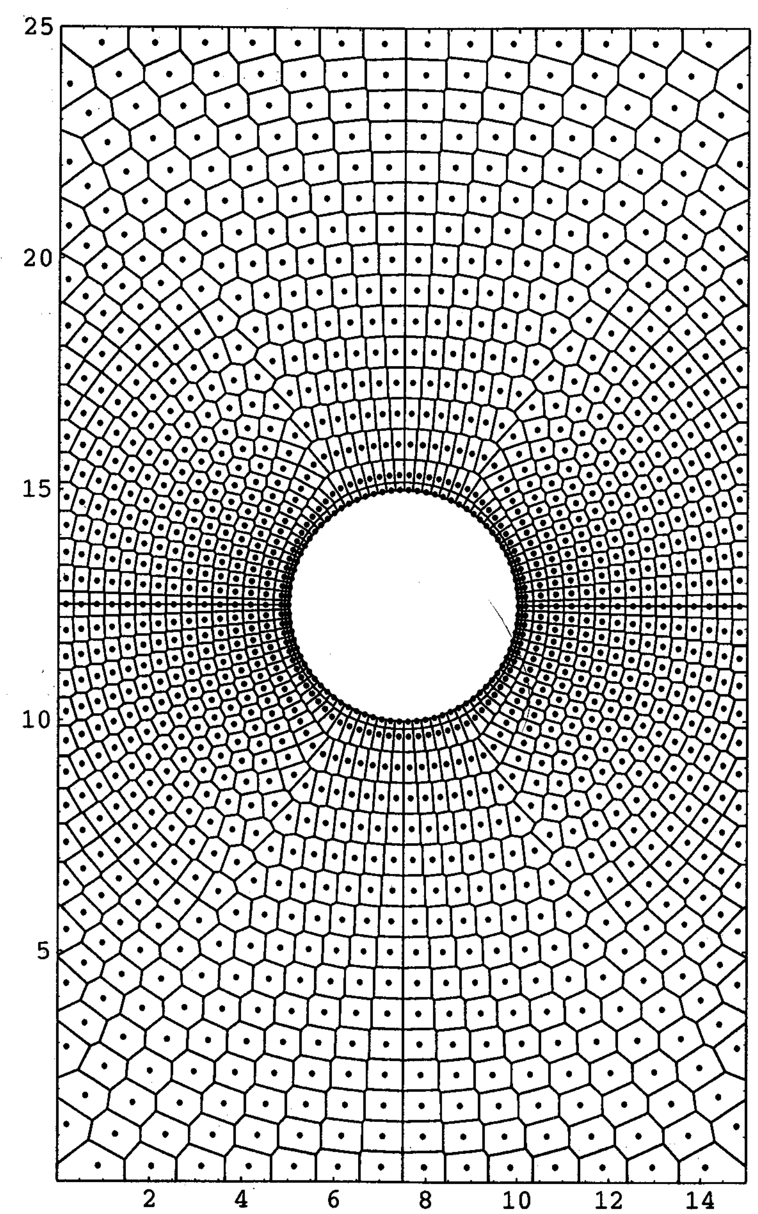
Regarding 2) on previous page. New grid 25m wide. Type 5 BC.

Flux	Pc	Se
1.266e-5 kg/m²/s = 400 mm/yr	565.4	.9664
change bottom BC from Sg = 0.6 to Sg = 0.05		
1.266e-5 kg/m²/s = 400 mm/yr	0	1.0



Input file using this grid x = 15 m
z = 25m archived as
~dhughson/multiflo/inputbak/multi.30

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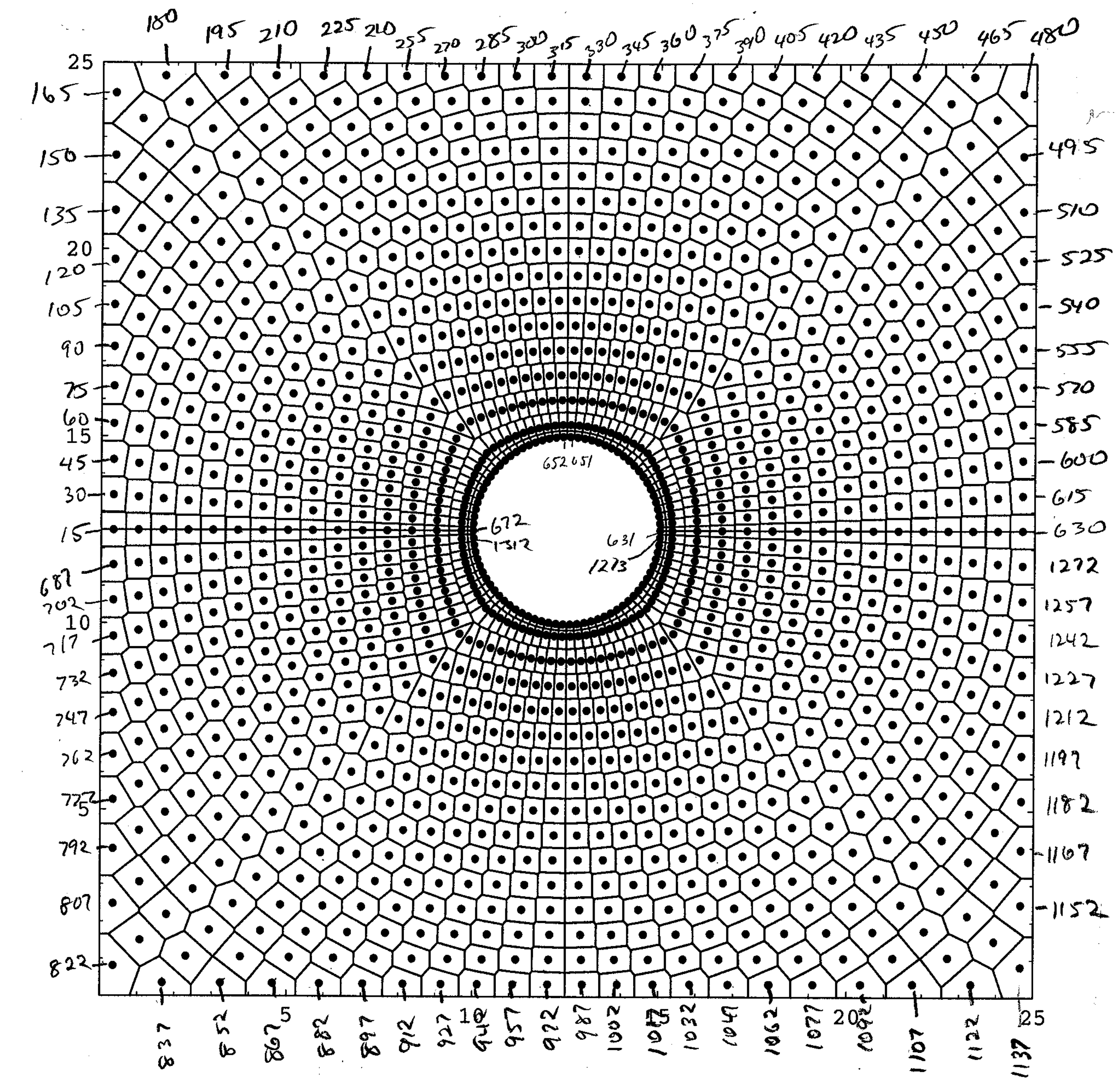

Threshold on page 93-94

~dhughson/multiflo/inputbak/multi.31

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Runs on page 89 are from a version of metra which has bugs in the unstructured grid and gives erroneous results. The bug has not been entirely fixed but a version shows improved but still erroneous results. Check on critical seepage to see how this is changing.

flux	at node 652	P_c	Se
1.266e-6 kg/m²/s		705.8	.8260

Mohan has corrected some errors in metra. The 25m x 5m test case I created to compare structured & unstructured grid ~~results~~ shows identical results.

~dhughson/multiflo/test   test-str.dat
test-uns.dat

Run with grid on page 91 and vg parameters
$\alpha = 9.7e\text{-}4\ Pa^{-1}$ $n = 0.63$ $S_r = .01$ $k = 1e\text{-}13\ m^2$
top bc itype 5

flux	at node 651, 652	P_c	Se
1.266e-6 kg/m²/s =	40 mm/yr	1534	.4282
1.266e-5 kg/m²/s =	400 mm/yr	846	.7504
4.0e-5 kg/m²/s =	1264 mm/yr	440.9	.9417
4.2e-5 kg/m²/s =	1327 mm/yr	418.6	.949
4.5e-5 kg/m²/s =	1422 mm/yr	385.4	.9587
4.9e-5 kg/m²/s =	1548 mm/yr	341.3	.9698
5.5e-5 kg/m²/s =	1740 mm/yr	273.8	.983
5.7e-5 kg/m²/s =	1801 mm/yr	250.5	.9866
6.1e-5 kg/m²/s =	1927.6 mm/yr	201.6	.9925
6.2e-5 kg/m²/s =	1959 mm/yr	188.8	.9937
6.4e-5 kg/m²/s =	2022 mm/yr	162.1	.9958
6.6e-5 kg/m²/s =	2085.5 mm/yr	133.7	.9975
6.8e-5 kg/m²/s =	2149 mm/yr	103.0	.9988
7.0e-5 kg/m²/s =	2212 mm/yr	68.97	.9996

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Flux	at node 651, 652	P_c	Se
7.1e-5 kg/m²/s =	2243.5 mm/yr	50.25	.9998
7.2e-5 kg/m²/s =	2275 mm/yr	29.92	.9999
7.3e-5 kg/m²/s =	2307 mm/yr	very slow to	

Flux entered as kg/m²/s & converted to mm/yr by

$$\frac{m^3}{998\,kg}\ \frac{60\,s}{min}\ \frac{60\,min}{hr}\ \frac{24\,hr}{day}\ \frac{365\,day}{yr}$$

Using Table Lookup for Gardner – Russo ~~model~~ model
Density 998.3 kg/m³

Flux		P_c	Se
6.4e-5 kg/m²/s	2022 mm/yr	108.5	.9273
7.5e-5 kg/m²/s	2369 mm/yr	755.9	.9529
8.5e-5 kg/m²/s	2685 mm/yr	496.2	.9713
9.5e-5 kg/m²/s	3001 mm/yr	264.8	.9858
1.05e-4 kg/m²/s	3317 mm/yr	58.65	DH ~~.9967~~ .9971 DH
1.10e-4 kg/m²/s	3475 mm/yr	0	4/12/99 1.0
1.07e-4 kg/m²/s	3380 mm/yr	19.6	.9990
1.08e-4 kg/m²/s	3412 mm/yr	0	1.0
1.075e-4 kg/m²/s	3396 mm/yr	9.982	.9995
1.079e-4 kg/m²/s	3408.5 mm/yr	stuck in convergence	
1.078e-4 kg/m²/s	3405 mm/yr	4.226	.9998

Table lookup corresponds to $\alpha_G = 4.85e\text{-}4\ Pa^{-1}$
for $K_{rw} = e^{-\alpha_G P_w}$ – convert to L/T and L^{-1}

At 20°C $\rho_w = 0.99821$ $\mu_w = 1002 \times 10^{-6}\ Pa \cdot s$

$$K = \frac{k\rho g}{\mu} = \frac{(1 \times 10^{-13}\ m^2)(998.21\ \frac{kg}{m^3})(9.8\ m/s^2)}{1002 \times 10^{-6}\ \frac{\frac{kg\,m}{s^2}\,s}{m^2}} = 9.763 \times 10^{-7}\ \frac{m}{s}$$

60·60·24·365 · 1000

$$= 3.07884\ mm/yr \times 10^{4}$$

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$\alpha_G = 4.85 \times 10^{-4}\ Pa^{-1}$ $\left(\dfrac{\frac{kg\,m}{s^2}}{m^2}\right)^{-1}$ $\dfrac{m\,s^2}{kg}$

$4.85 \times 10^{-4} \left(\dfrac{kg}{m\,s^2}\right)^{-1} \left(\dfrac{m^3}{998.21\ kg}\right)^{-1} \left(\dfrac{s^2}{9.8\ m}\right)^{-1} =$

$4.85 \times 10^{-4}\ \dfrac{m\,s^2}{kg}\ 998.21 \dfrac{kg}{m^3}\ 9.8 \dfrac{m}{s^2} = 4.7445\ m^{-1}$

Philip threshold = 2257.6 mm/yr

From MF 3408 mm/yr

archive
~dhughson/multiflo/inputbak/multi.31

Look for cause of 2258 vs 3408 discrepancy

1) Flow rate make any difference?
2) Grid refinement — Sharp gradient in vicinity of drift

1) Flow rate — change k from 1e-13 to 1e-14 m^2
Philip threshold = 225.76 mm/yr

flux		Pc	Se
9.0e-6 kg/m²/s	= 284.3 mm/yr	376.4	.9790
1.0e-5 kg/m²/s	= 315.9 mm/yr	159.3	.9918
1.07e-5 kg/m²/s	= 338.0 mm/yr	19.61	.990
1.078e-5 kg/m²/s	= 340.6 mm/yr	4.235	.9998

Essentially no difference. Need a new grid with refinement around drift wall

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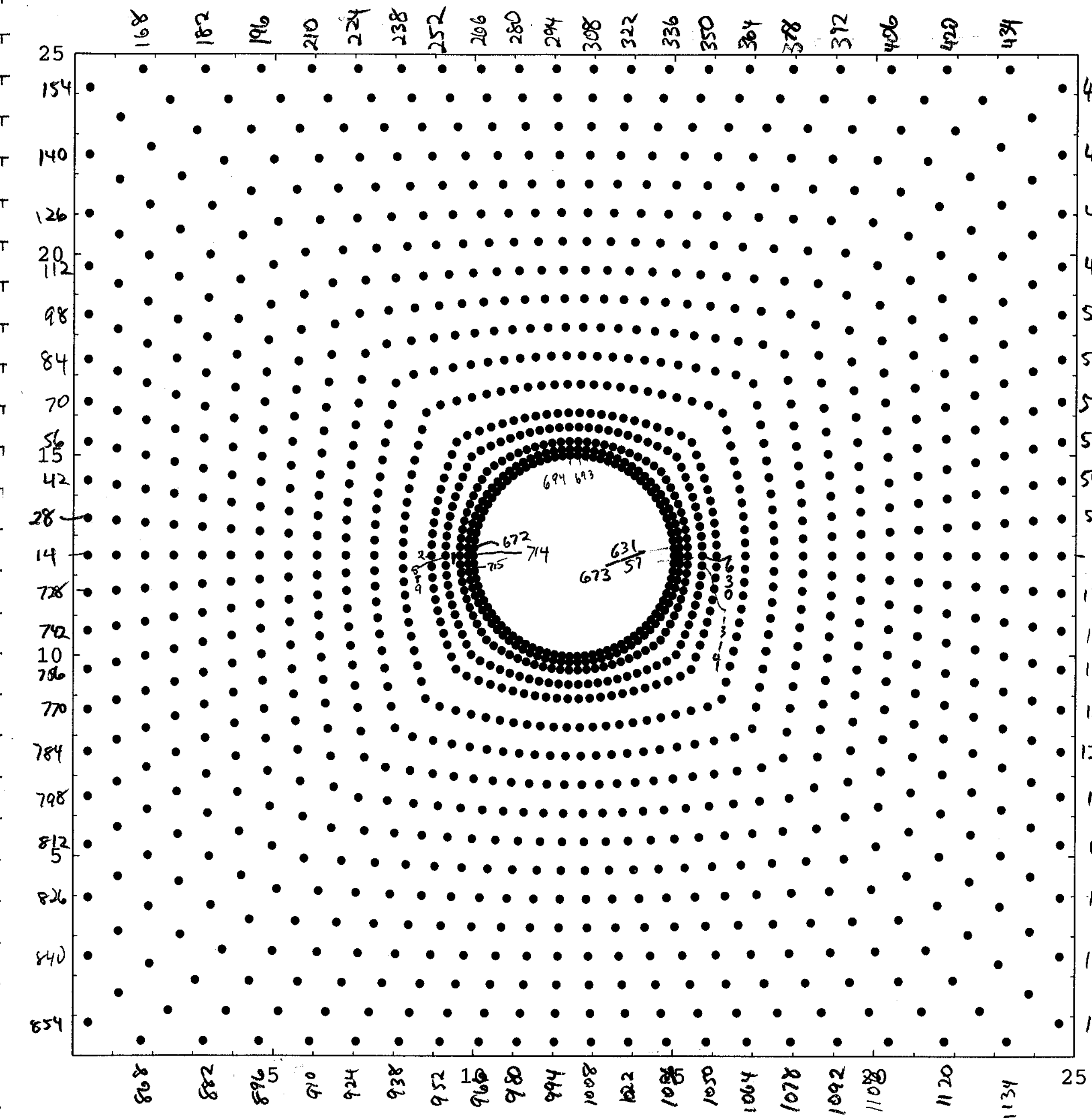

NOTE: The pencil entries above were cited and printed out to the principal investigator. Due to the size of the print it was [?] agreed to leave this page "as is."

Inner circle is 1cm from driftwall, next circle out is 16cm from driftwall

~dhughson/multiflo/inputbak/multi.32

CNWRA QA 8/11/2000

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flux at nodes 693, 694	Pc	Se
1.028e-5 = 340.6 mm/yr	4546	.6058
3.0e-5 kg/m²/s = 947.8 mm/yr	2291	.8189
5.0e-5 kg/m²/s = 1579.6 mm/yr	1171	.9202
6.0e-5 kg/m²/s = 1895.6 mm/yr	790.3	.9504
7.0e-5 kg/m²/s = 2211.5 mm/yr	472.4	.9728
8.0e-5 kg/m²/s = 2527.4 mm/yr	194.6	.9898
9.0e-5 kg/m²/s = 2843.4 mm/yr	0	1.0
8.5e-5 kg/m²/s = 2685.4 mm/yr	68.74	.9966
8.6e-5 kg/m²/s = 2717 mm/yr	44.44	.9978
8.7e-5 kg/m²/s = 2748.6 mm/yr	20.45	.9990
~~8.8e-5~~ 8.78e-5	2774 mm/yr	1.636	.9999

DH 4/14/99

Philip solution = 2257.6 mm/yr threshold

changing (refining grid from pg 91 to pg 95.

changed MF threshold from 3408 mm/yr

to 2774 mm/yr

ONE MORE GRID REFINEMENT

node 693 – 15.008 ← OK
node 651 – 15.158 move to ~~16cm~~ 16cm DH 4/14/99
node 609 – 15.7126 ← now @ 16 cm OK

≈ 2720

~dhughson/multflo/inputbak/multi.33 for Gardner Russo m = 0.5

~dhughson/multflo/inputbak/multi.32

	Pc	Se
~~6.0e-5 kg/m²/s~~	~~750.4~~	~~.9534~~
7.0e-5 kg/m²/s	432.7	.9754
8.0e-5 kg/m²/s	154.6	.9920
8.4e-5 kg/m²/s	53.59	.9974
8.45e-5 kg/m²/s = 2670 mm/y	41.04	.9980
8.5e-5 kg/m²/s = 2685.4 mm/y	28.76	.9986
8.6e-5 kg/m²/s = 2717 mm/yr	4.5	.9998

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change Russo m parameter from 0.5 to 0.9

Flux	Pc	Se
8.0e-5 kg/m²/s	154.6	.988

Try Russo m parameter of 0.1

Flux	Pc	Se
8.0e-5 kg/m²/s	154.6	.9975

Try Russo m parameter of 0.0

Flux	Pc	Se
8.0e-5 kg/m²/s	154.6	.9993
8.1e-5 kg/m²/s	128.8	.9995
8.2e-5 kg/m²/s	103.4	.9997
8.3e-5 kg/m²/s	78.35	.9998
8.4e-5 kg/m²/s	53.5	.9999
8.5e-5 kg/m²/s	28.76	1.0
8.6e-5 kg/m²/s = 2717 mm/yr	4.5	1.0

Grid	Threshold flux
pg 91	3408 mm/yr
pg 95	2774 mm/yr
another row around drift no room in this notebook	2720 mm/yr
change Russo m	2717 mm/yr

ADDITIONAL INFORMATION FOR SCIENTIFIC NOTEBOOK #: 285

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