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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

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ON _____ **19** _____

DEPARTMENT _____

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CONTROLLED
COPY 285**

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STEVENSVILLE, MI 49127
616-429-8285**

TITLE

USFIC

From Page No. _____

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

code used is MULTIFLO 1.2B

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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8/18/98

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Reference:

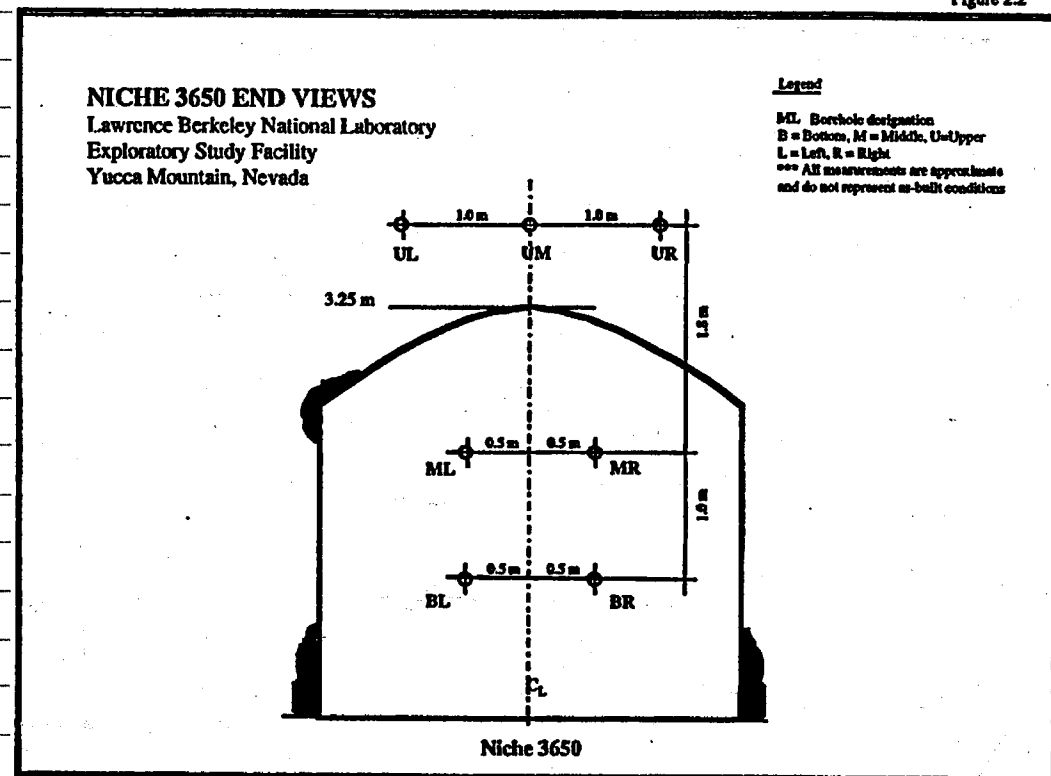
Testing and modeling of seepage into drift, input of
Exploratory Study Facility Test Results to unsaturated
zone models

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 x 10 ⁻¹²	1.9 x 10 ⁻¹⁰	1.6 x 10 ⁻¹²	7.0 x 10 ⁻¹⁴	1.1 x 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 between source & drift ceiling = ~0.65 m

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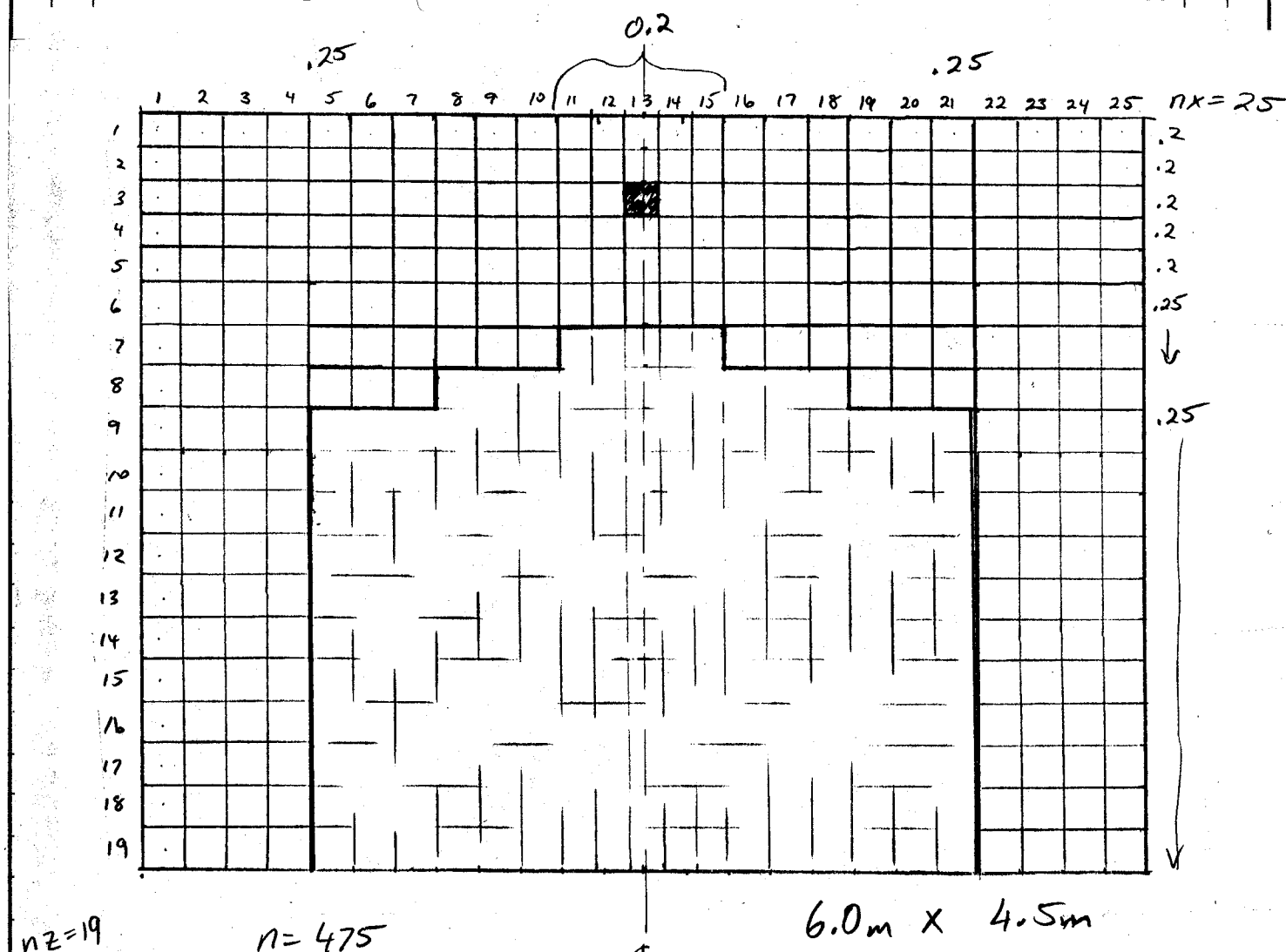
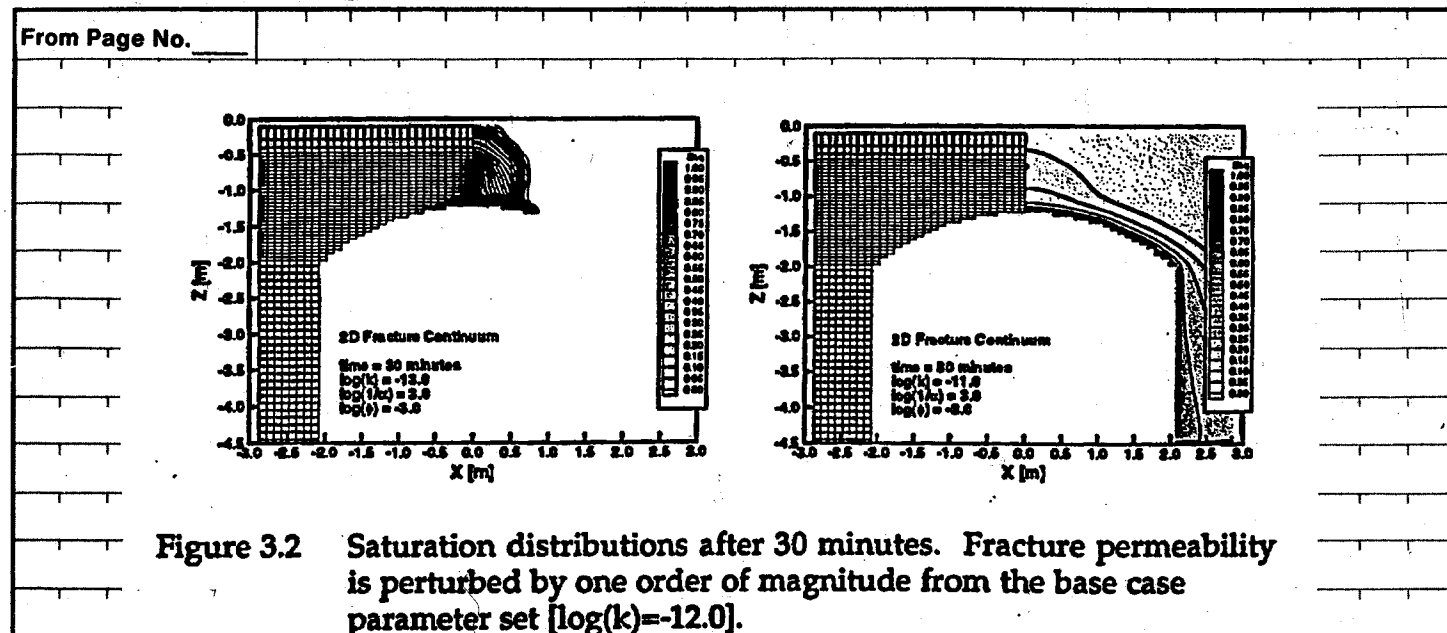
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nz=19

N=475

6.0m X 4.5m

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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 $\lambda = 10^3$ Pa
 $k_s = 2 \times 10^{-2} \text{ m}^2$ $n = 2.7$

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

As at 3 PM & endless futile ~~attempts~~ 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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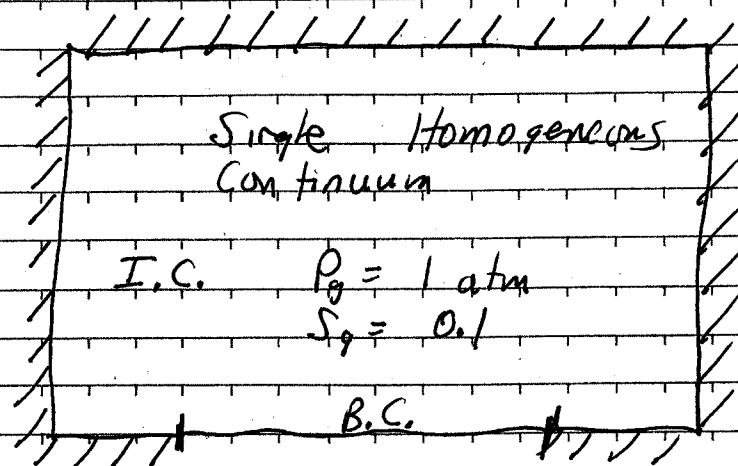
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$$\alpha = 10^{-3} \text{ Pa}^{-1}$$

$$n = 2.7$$

$$k = 2 \times 10^{-12} \text{ m}^2$$

B.C. at $P_g = 1 \text{ atm}$ 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 Auto step and limit
and change $S_g = .2$ on the boundary
then $dt \rightarrow 10^{-22}$ and gets stuck there.

Change Auto step dpmx 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

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

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Aug 19, 1998

van Genuchten as I'm used to seeing it

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

$$K_r = \sqrt{S} (1 - (1 - S^{1/n})^n)^2$$

van Genuchten for media

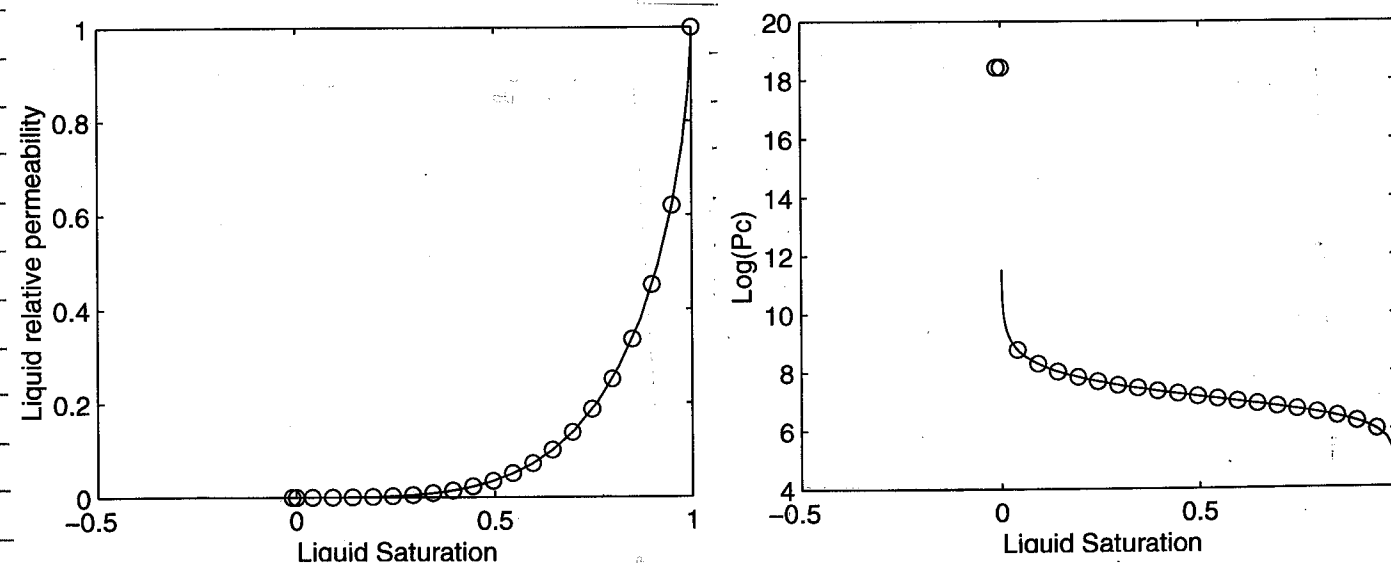
$$P_c = P_g - P_l \quad S_l^{\text{eff}} = \frac{S_g - S_l^r}{S_g^0 - S_l^r} = (1 + |x P_c|^m)^{-n} \quad n = 1 - 1/m$$

$$K_{re} = \sqrt{S_l^{\text{eff}}} (1 - (1 - (S_l^{\text{eff}})^{1/n})^n)^2$$

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

For my single continuum properties $\alpha = 10^{-3} \text{ Pa}^{-1}$
 $SWR_M = S_l^r = .01$ $RPM = n = 1 - 1/2.7 = .63$

Solid line is the function and circles are multiFlo tables



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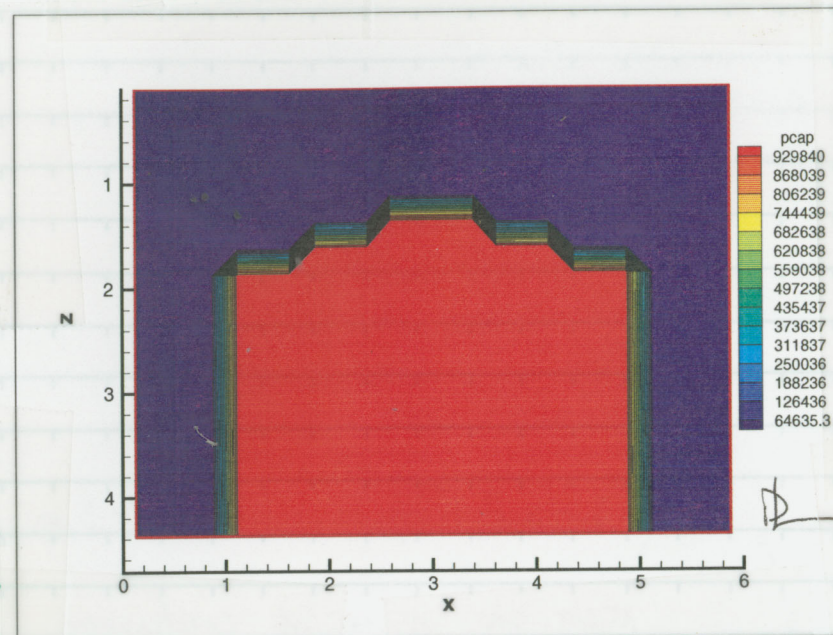
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this is the most extreme variation in media properties I was able to attain with this geometry.

Rock

$$S_r = .01$$

$$\lambda = .63$$

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

$$\phi = .001$$

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

Drift

$$S_r = .001$$

$$\lambda = .95$$

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

$$\phi = 1.0$$

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

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 $S_r = 1e-6$
 $\lambda = .7$ $\alpha = 1.0 \text{ Pa}^{-1}$ $\phi = 1$ $K_s = 2e-2 \text{ m}^2$. Top BC liquid
vel 1mm/year bottom BC $P_g = \text{atm}$ $T = 20^\circ\text{C}$ $S_g = .95$

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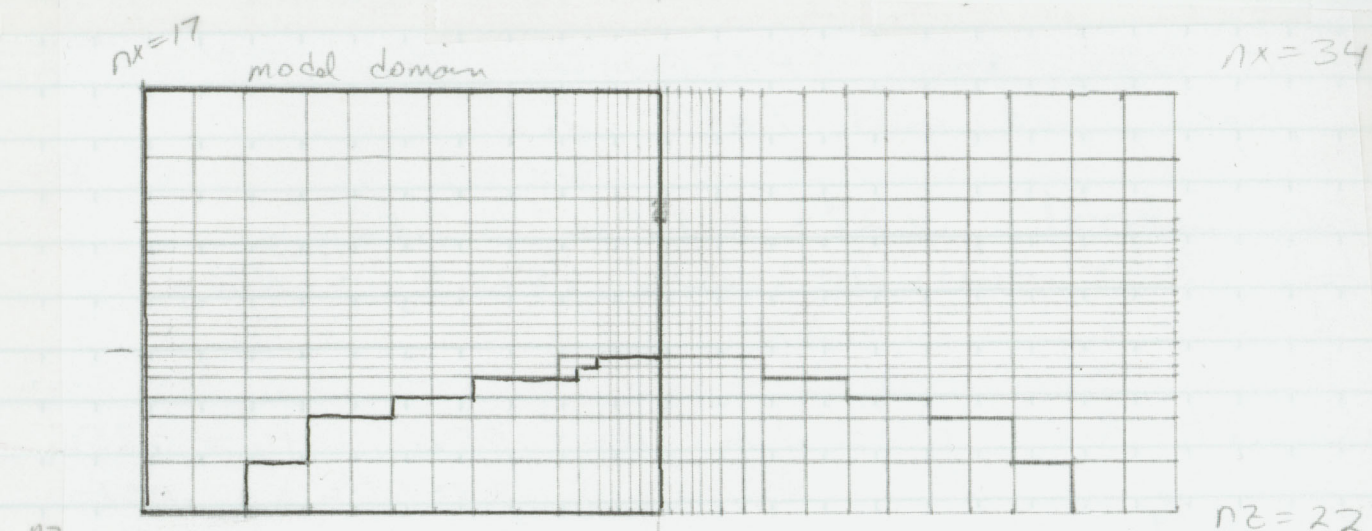
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ny=22

$$\frac{dx}{.25}$$

$$\frac{dz}{.3}$$

$$.25$$

$$.2$$

$$.3$$

$$.1$$

$$6 \times .2$$

$$15 \times .05$$

$$2 \times .1$$

$$2 \times .1$$

$$6 \times .05$$

$$.2$$

$$.25$$

symmetrical around center line

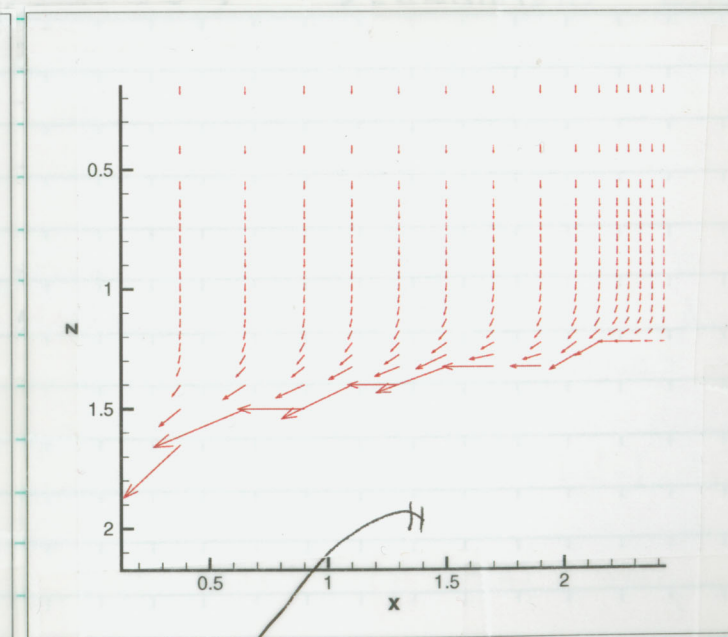
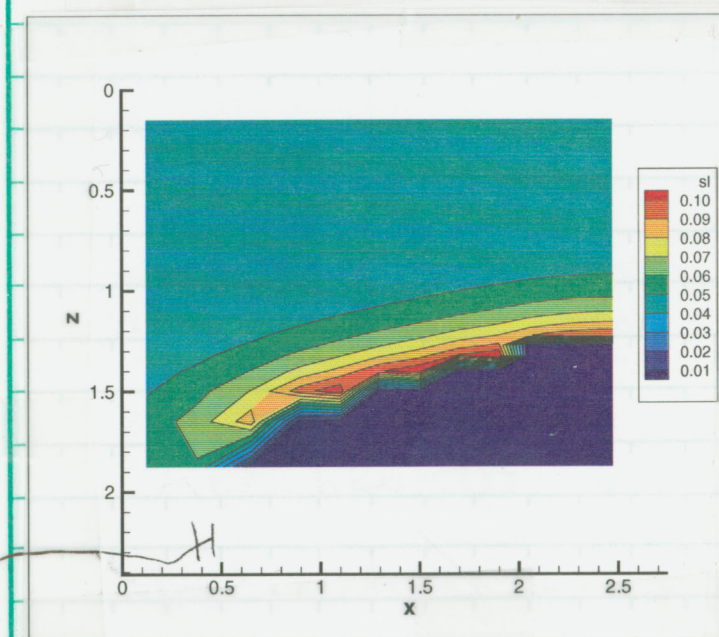
$$dy \sim .2$$

source term at

$$17 \quad 3$$

$$dx = .05$$

$$dz = .1$$



file ~dhughson/multiflo/inputbak/multi.13

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From Page No. Sept 4, 1998

Injection rates from SP33 PLM4, Jun 1998
page 23 and Table 2.1

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

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

$$\frac{(1.01 \text{ g/s}) \left(\frac{\text{kg}}{1000 \text{ g}} \right)}{(0.1 \text{ m})(0.05 \text{ m})(0.25 \text{ m})(.001)} = 808 \text{ kg/m}^3/\text{s}$$

From multi-out source sink summary

time[s]	Qm kgms/s	summ 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? Cumulative mass numbers make
no sense.

Calculated 1st arrival time between 50 and 55s

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

What am I doing different?

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D.H.

9/4/98

From Page No. Sept 4 1998

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

Cut flux rate in half, arrival about 100s

Sept 8, 1998 Comparison with Green-Ampt infiltration

$$Kt = \theta_s z_f - \theta_s (H_0 + \psi_f) \ln \left[1 + \frac{z_f}{H_0 + \psi_f} \right]$$

$$\gamma_x = 1000 \rho_a = 1000 \frac{\text{kg m}}{\text{s}^2 \text{ m}^2} \quad \psi_f = \frac{(\gamma_x)}{\rho g}$$

$$\psi_f = \frac{1000 \frac{\text{kg m}}{\text{s}^2 \text{ m}^2}}{1000 \frac{\text{kg}}{\text{m}^3} \cdot 9.8 \frac{\text{m}}{\text{s}^2}} = .102 \text{ m}$$

$$K = \frac{K_p \gamma}{\mu} = \frac{2 \times 10^{-12} \text{ m}^2 \cdot 1000 \frac{\text{kg}}{\text{m}^3} \cdot 9.8 \frac{\text{m}}{\text{s}^2}}{1.119 \times 10^{-3} \frac{\text{kg}}{\text{m} \cdot \text{s}}} = 1.75 \times 10^{-5} \frac{\text{m}}{\text{s}}$$

$$\theta_s = \theta_f - \theta_i \quad \text{maximum is porosity } \phi = .001$$

$$H_0 = 0$$

$$z_f = .65 \text{ m}$$

$$t = 25.5 \text{ s}$$

Called JS Wang 10 AM Sept 8, 1998 @ 510-486-6753

for information to resolve discrepancies between
model arrival times

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9/8/98

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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 b/twn 3 & 4 min - close to 4

Expand in y to 7 slices of .3m

exceed limit for nconn $nconnmx = 7000$

Sept 9, 1998 Apparently 2D vs 3D is
the culprit in the difference b/twn the model
results here and those in Table 1.2
But I have to wait for Painter to
return to recompile meke 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 fhp site
hydra.bnl.gov in pub/properties

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9/16/98

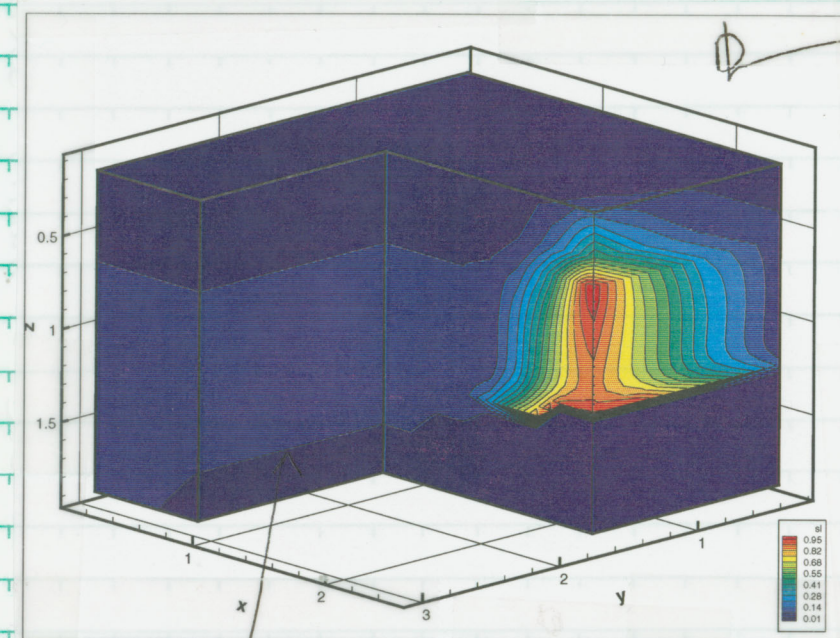
From Page No.

Sept 16, 1998

7 blocks in the y-direction [0.6 .5 .4 .3 .4 .5 .6]m
where injection at 1L is in block .3m

No dripping even at 10 minutes

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



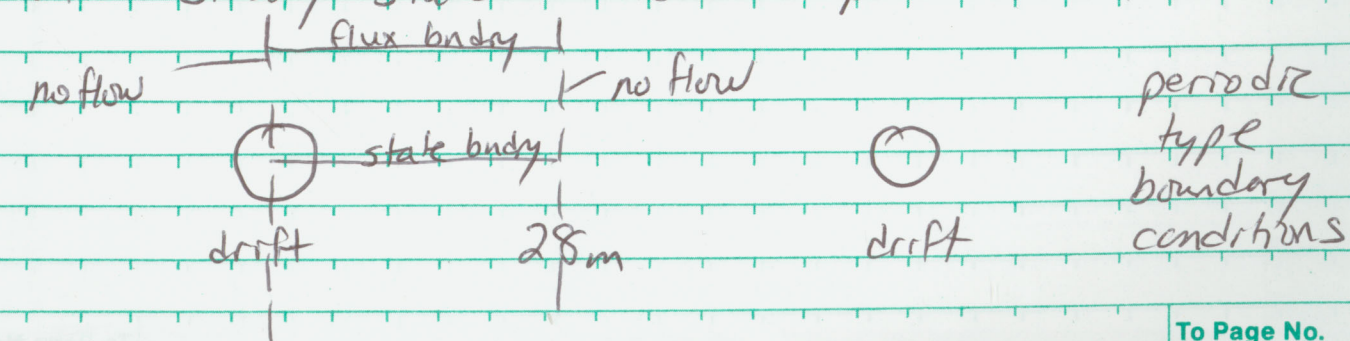
Liquid saturation
at 6 minutes after
start of injection

Drift ceiling is
seen as line
bt 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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9/22/98

9/22/98

From Page No. Sept 22, 1998

TOP BC TYPE 5

$$\text{Flux} = 9 \times 10^{-3} \text{ Kg/m}^2/\text{s} \quad P = 1.014 \times 10^5 \text{ Pa} \quad S_g = 0.1$$

$$T = 20^\circ\text{C}$$

Bottom BC $i = 1 \dots 15$ TYPE 1

$$P = 1.014 \times 10^5 \text{ Pa} \quad T = 20^\circ\text{C} \quad S_g = 0.5$$

$$i = 16 \dots 38$$

$$P = 1.014 \times 10^5 \text{ Pa} \quad T = 20^\circ\text{C} \quad S_g = 0.1$$

this is the flux at which seepage first enters the drift

$$9 \times 10^{-3} \frac{\text{Kg}}{\text{m}^2/\text{s}} \times \frac{1000 \text{ m}^3}{\text{Kg}} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{d}} \times \frac{365.25 \text{ d}}{\text{yr}} \times \frac{1000 \text{ mm}}{\text{m}} = 284018 \text{ mm/yr}$$

284018 mm/yr About 3 orders of magnitude too large

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

$$\alpha_{\text{drift}} = 1.0 / \text{Pa} \quad \text{SCM}$$

Seepage at one block in drift $x = 1.55 \text{ m}$ $y = 7.95 \text{ m}$

$$\text{is } 1.03 \times 10^5 \text{ mm/yr}$$

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

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9/22/98

From Page No. Sept 22, 1998

Change drift α from 1.0 to $1 \times 10^{-3} \text{ Pa}^{-1}$
Everything else remaining the sameSeepage breakthrough btw 6.5×10^{-3} to $6.9 \times 10^{-3} \text{ Kg/m}^2/\text{s}$
or 205124 to 217747 mm/yrFor drift $\alpha = 1 \times 10^{-5} \text{ Pa}^{-1}$ No seepage at $8.9 \times 10^{-4} \text{ Kg/m}^2/\text{s}$ TOP BC Flux
& can't get past runtime error at $9 \times 10^{-4} \text{ Kg/m}^2/\text{s}$

this is probably because seepage is ready to occur

$$9 \times 10^{-4} \text{ Kg/m}^2/\text{s} = 28401 \text{ mm/yr}$$

1 order magnitude in seepage breakthrough perc flux
for 5 order magnitude change in α Fig 3-24 pg 15 D11/23/98
their model shows seepage at 200 mm/yr. Mine at least 28400 mm/yrDifference

1) model geometry their model constrains 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 &
 $P_0 = P_g - P_e = 0$ so $P_g = P_e$

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9/24/98

D11 9/23/98

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 $6.3 \times 10^{-3} \text{ kg/m}^2/\text{s}$ & $S_0 \sim 1$ right above the drift. Assume seepage occurs (source of runtime error)

$\sim 198813 \text{ mm/yr}$ Bottom boundary dominates P_c & S_0 near drift. this & $2LNL$ 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 ~~on 9/28/98~~ as input file archived as

$\sim \text{dhughson/multiflo/inputbak/multi.15}$

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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9/28/98

From Page No. Sept 29, 1998

NZ=40

NX=30

0.25 5.75 6.25 7.75 8.25 8.75 9.25

15m

9.25
10.25
11.25
12.25
13.25
14.25
15.25

20m

Scale 1" = 3m

Block size is $(0.5\text{m})^3$

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9/29/98

From Page No. Sept 29, 1998

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 $4.e-3 kg/m^2/s$.

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

$$4.e-3 \frac{kg}{m^2 s} \cdot \frac{m^3}{1000kg} \cdot \frac{1000mm}{m} \cdot \frac{60s}{min} \cdot \frac{60min}{hr} \cdot \frac{24hr}{day} \cdot \frac{365,25day}{yr} = 126230 mm/yr$$

= 126230 mm/yr So this is the effect of

changing domain, drop from 284,018 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~~ 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 times 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

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

$$K_s = 10^{-13} m^2, \text{ Tabular } P_c = 0 \text{ for drift}$$

$$K_s = 1.e-4 m^2 \text{ for drift}$$

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

seepage into drifts between 0.807 and 0.95 mm/yr

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

$$\text{use drift parameters } S_r = 0.01 \quad m = 0.633$$

$$\alpha = 0.9 / Pa \quad K_s = 1.e-4 m^2$$

0.968 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 multiple ~~with~~ ^{to} 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 TABular 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 Resour. Research 33(8), 1855-1859, 1997

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10/2/98

TITLE

USFIC

From Page No. _____

Besides the saturation function for Gardner, the boundary condition on the down dip 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 ^{10/5/98} volume of the end column of blocks $1 \times 10^{20} \text{ m}^3$ 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
$\alpha_{vg} \text{ m}^{-1}$	3.9	490

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

	fine upper	coarse lower
porosity ϕ	0.39	0.42
$K \text{ m}^2$	2.398×10^{-11}	1.142×10^{-8}
S_r	0.184	0.012
m	0.826	0.543
$\alpha \text{ Pa}^{-1}$	3.98×10^{-4}	0.05

Infiltration $q = 0.48 \text{ cm/d}$

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

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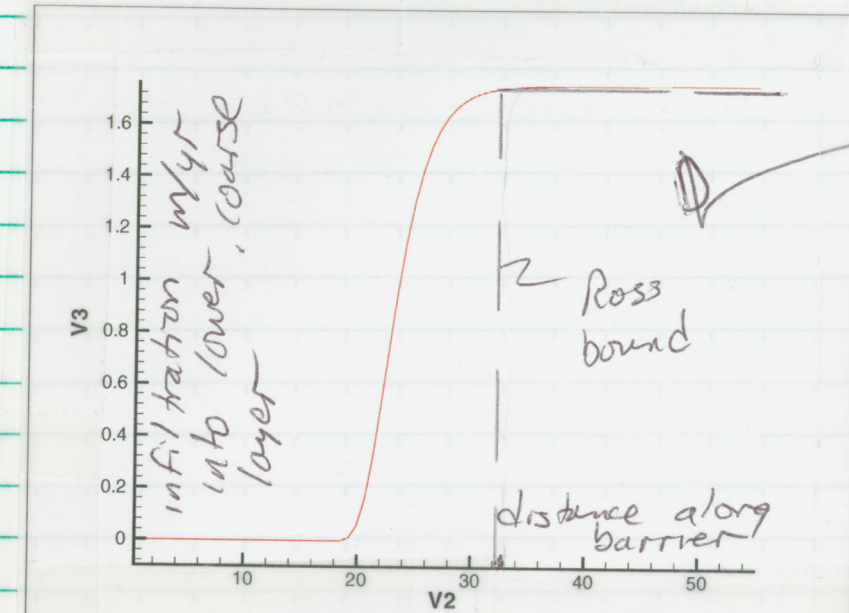
Recorded by

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10/5/98

From Page No. Coarse & Fine layer are each 0.5m thick
& dip at 2.86°

Ross formula $Q_{max} = k_s \tan \phi (k_r d \psi)$ 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 $x = 20m$ is very similar but TOUGH2 doesn't reach a maximum until almost $x = 50m$

```
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

One difference could be discretization

same

~dhughson/
multiFlo/
inputbak/
multi.17

From Page No. Oct 6, 1998

I may have made a mistake in the residual liquid saturation. ^{10/6/98} 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 LUN2 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 $1 \times 10^{20} m^3$. 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

From Page No.

Reference for the first set of models is
 nche 3650 & seepage model on page 5 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 "Here 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

$$K = \frac{\bar{F} b^3}{12} \quad \text{cubic law where } \bar{F} = \text{mean fracture frequency}$$

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

$$\alpha = \frac{b \rho g}{2 \gamma \cos \theta} \quad \rho = 998 \frac{\text{kg}}{\text{m}^3} @ 20^\circ \text{C}$$

$$\gamma = 0.072 \text{ N/m} \quad \theta = \text{contact angle (assumed} = 0)$$

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$$\text{or alternatively } S_{uc} = \frac{1}{2} \left[1 + \text{erf} \left| \frac{\log \bar{b} - \beta}{\sqrt{\gamma/2}} \right| \right]$$

$$\beta = \sigma^2 \ln 10 + \gamma_0 \quad \gamma_0 = \log \bar{b}$$

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

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

$$\bar{F} = 1.88/\text{m}$$

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

$$\alpha = \frac{(8.61 \times 10^{-5} \text{ m}) (998 \frac{\text{kg}}{\text{m}^3}) (9.8 \frac{\text{m}}{\text{s}^2})}{2 (0.072 \text{ kg/s}^2)} = 5.85/\text{m}$$

$$= 5.98 \times 10^{-4} / \text{Pa}$$

as compared to α used = $0.97 \times 10^{-3} / \text{Pa}$

Reasoning used to hold α uniform at

$9.7 \times 10^{-4} / \text{Pa}$ 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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With $K_s = 10^{-13} \text{ m}^2$ & varying α , rest of van Genuchten parameters constant, seepage first occurs into the drift with $\alpha = 5.1 \times 10^{-4} \text{ Pa}$ at percolation 2 mm/year.

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

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

$$\text{Top area} = 15 \text{ m} \times 0.5 \text{ m} = 7.5 \text{ m}^2$$

$$q = 6.34 \times 10^{-8} \text{ Kg/m}^2/\text{s}$$

$$\left(6.34 \times 10^{-8} \text{ Kg/m}^2/\text{s}\right) (7.5 \text{ m}^2) \frac{\text{m}^3}{998 \text{ Kg}} \frac{60 \text{ s}}{\text{min}} \frac{60 \text{ min}}{\text{hr}} \frac{24 \text{ hr}}{\text{day}} \frac{365.25 \text{ d}}{\text{year}}$$

$$= 1.503571 \times 10^{-2} \text{ m}^3/\text{year} = 2.005 \text{ mm/year}$$

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

$$\text{infiltration} \quad 6.34 \times 10^{-8} \text{ Kg/m}^2/\text{s} \quad 1.504 \times 10^{-2} \text{ m}^3/\text{yr}$$

not how I want to do it D_H

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Infiltration

 $\text{Kg/m}^2/\text{s}$ m^3/yr mm/yr

Cumulative Seepage

 m^3/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	0.330366989	3.2578×10^{-1}

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

$$10 \text{ blocks}^{aa} \text{ with footprint } (0.5 \text{ m})^2 = 0.25 \text{ m}^2$$

$$\text{area} = 2.5 \text{ m}^2$$

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

$$\text{fraction} = 0.977$$

file used to produce this data archived as

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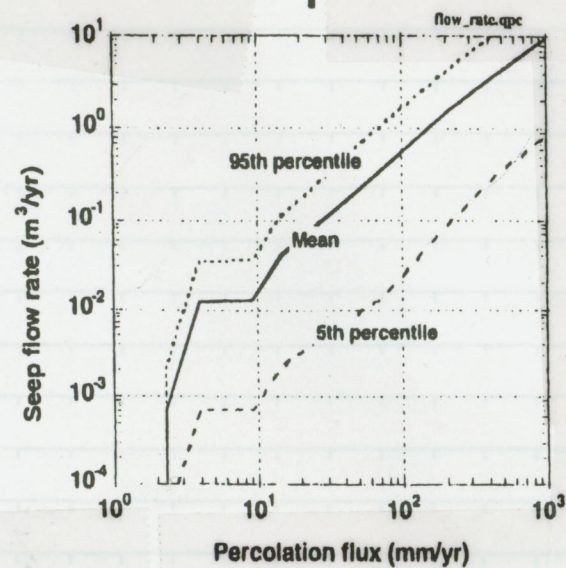
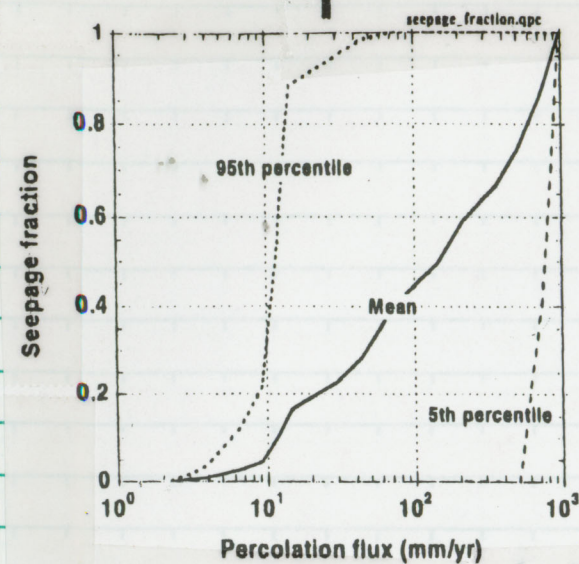
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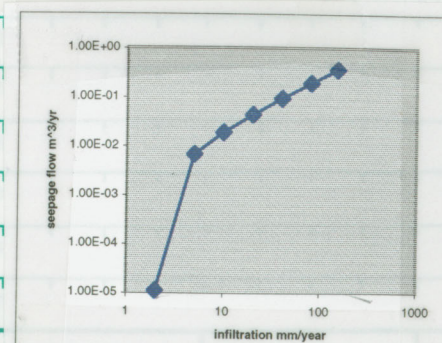
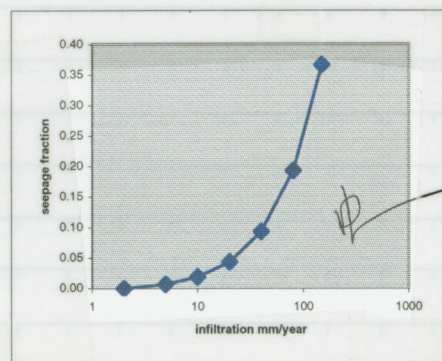
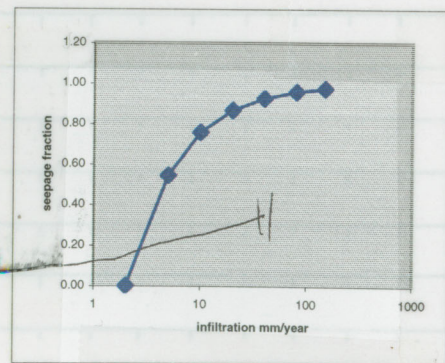
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Oct 8, 1998



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 variable 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

$K_s/m^2/s$	$m^3/year$		
$6.34e-8$	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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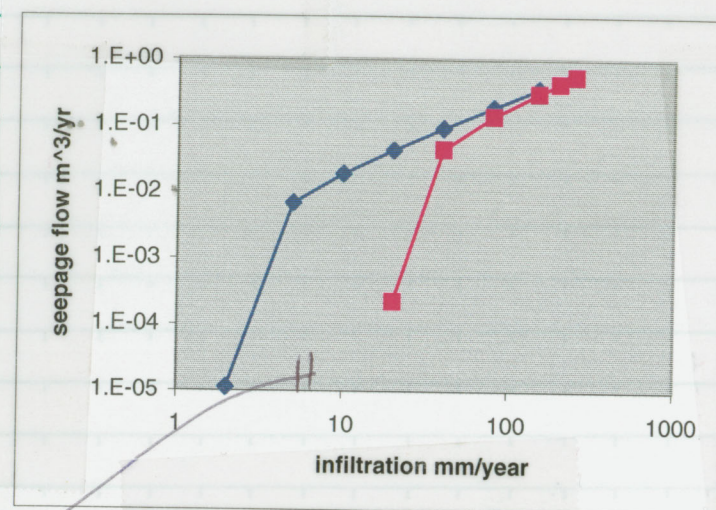
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Red line is from holding α constant at $5.1 \times 10^{-4} / \text{Pa}$ and changing K_s from 10^{-13} to 10^{-12} m^2

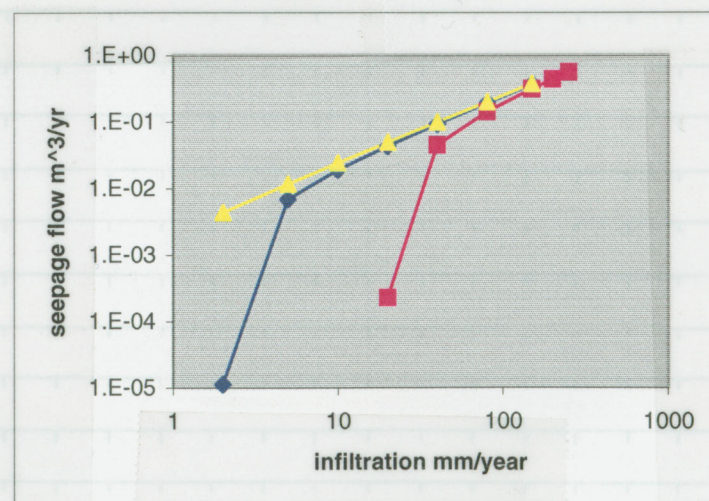
Notice how changing one parameter by 1 order of

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 = $5.1 \times 10^{-4} / \text{Pa}$ & change K_s to 10^{-14} m^2

Infiltration $K_g / \text{m}^2 / \text{s}$	seepage m^3 / year
6.34×10^{-8}	4.36578×10^{-3}
1.58×10^{-7}	1.17611×10^{-2}
3.17×10^{-7}	2.42663×10^{-2}
6.34×10^{-7}	4.92936×10^{-2}
1.27×10^{-6}	9.96360×10^{-2}
2.54×10^{-6}	0.200353
4.75×10^{-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 dropped 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 providesBoundary condition
on vertical seepage flux↓ ↓ ↓ ↓ ↓ $z_{inf} = \text{uniform \& constant}$ Discrete Fracture Model
Ignore matrix flux
Ignore fracture intersections

Drift

seepage = $f(z_{inf}, \text{fracture distribution, fracture properties})$ Assume: Flow in each fracture can be described
by a 2D form of Richard's Eq. (steady state)

For a fracture parallel to gravity:

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

Isotropic

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

$$\frac{\partial}{\partial x} (K \frac{\partial \psi}{\partial x}) + \frac{\partial}{\partial z} (K \frac{\partial \psi}{\partial z}) - \frac{\partial K}{\partial z} = 0$$

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

Kirchoff transformation:

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

using the Gardner model

$$K(\psi) = K_s e^{\alpha \psi}$$

Leibnitz Rule:

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

Frc

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

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

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

$$\frac{\partial K}{\partial z} = \frac{\partial (e^{\alpha \psi})}{\partial z}$$

$$\Theta = \int_{-\infty}^{\psi} e^{\alpha \psi} d\psi = \frac{e^{\alpha \psi}}{\alpha} \Big|_{-\infty}^{\psi} = \frac{e^{\alpha \psi}}{\alpha}$$

$$\alpha \Theta = e^{\alpha \psi}$$

$$\alpha = \text{constant} \quad \text{so} \quad \frac{\partial K}{\partial z} = \alpha \frac{\partial \Theta}{\partial z}$$

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

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

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

normalize

$$\theta = \frac{\Theta - \Theta_0}{\Theta_0}$$

$$\xi = \frac{x}{l} \quad \eta = \frac{z}{l}$$

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

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

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

where ∇ is on the
transformed coordinates

$$\text{let } s = \frac{\alpha l}{2}$$

$$\text{then } \nabla^2 \theta = 2s \frac{\partial \theta}{\partial \eta}$$

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

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

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

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

$$\text{Substitute in } \frac{\partial^2 \partial}{\partial s^2} + \frac{\partial^2 \partial}{\partial \eta^2} = 2s \frac{\partial \partial}{\partial \eta}$$

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

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

$$\begin{aligned} \frac{\partial^2 H}{\partial s^2} e^{s\eta} + \frac{\partial^2 H}{\partial \eta^2} e^{s\eta} + 2 \frac{\partial \partial}{\partial \eta} s - \partial s^2 + s^2 &= 2s \left(\frac{\partial H}{\partial \eta} e^{s\eta} + \partial s + s \right) \\ &= 2s \frac{\partial H}{\partial \eta} e^{s\eta} + 2\partial s^2 + 2s^2 \end{aligned}$$

$$\begin{aligned} \frac{\partial^2 H}{\partial s^2} + \frac{\partial^2 H}{\partial \eta^2} &= 2s \frac{\partial H}{\partial \eta} - 2s \frac{\partial \partial}{\partial \eta} e^{-s\eta} + 3s^2 \partial e^{-s\eta} + s^2 e^{-s\eta} \\ &= 2s \frac{\partial H}{\partial \eta} - 2s e^{-s\eta} \left(\frac{\partial H}{\partial \eta} e^{s\eta} + \partial s + s \right) + 3s^2 \partial e^{-s\eta} + s^2 e^{-s\eta} \\ &= 2s \frac{\partial H}{\partial \eta} - 2s \frac{\partial H}{\partial \eta} - 2s^2 \partial e^{-s\eta} - 2s^2 e^{-s\eta} + 3s^2 \partial e^{-s\eta} + s^2 e^{-s\eta} \\ &= s^2 \partial e^{-s\eta} - s^2 e^{-s\eta} \\ &= s^2 e^{-s\eta} (\partial - 1) = s^2 H \end{aligned}$$

then

$$\nabla^2 H = s^2 H$$

Helmholtz Eq.

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

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

$$\text{for radial coordinates } x = r \sin \phi \quad z = r \cos \phi$$

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

Critical seepage

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

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

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

$$\partial_{\max} \approx 2s + 3 - \frac{3}{s} + \frac{21}{s^2} - \dots$$

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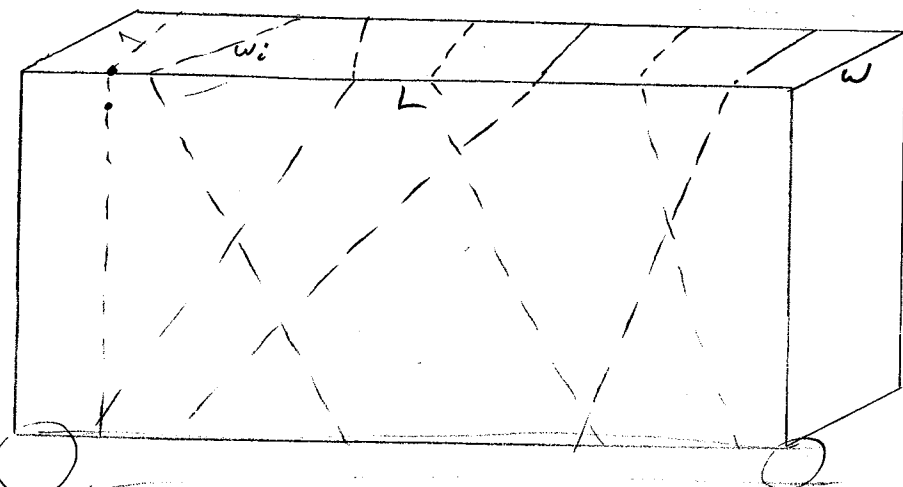
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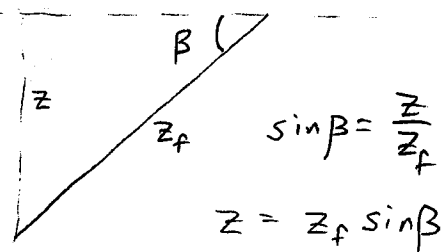
$q_{inf} =$
uniform
&
constant

n fractures each with aperture b_i so that

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

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In 1D for fracture dipping at angle β



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

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

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

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

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

$$q_i = K_i$$

$$K_i = K_{s_i} e^{\alpha_i \psi}$$

$$(q_{inf})LW = \sum_{i=1}^n w_i b_i K_i$$

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

Nov 11, 1998

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

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 give
us the postulated silica precipitation from the
thermal pulse?

2-102 - "better estimates of discrete fractures"

But fractures are by their very nature "discrete fractures"
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

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1998

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 sample 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 $\alpha = 2 \times 10^{-4} \text{ Pa}^{-1}$ instead of the original value of $\alpha = 9.73 \times 10^{-4} \text{ Pa}^{-1}$ "

Given the highly uncertain technique used to derive this parameter, the total lack of data, and the natural heterogeneity, don't you think the variability ~~it~~ might be larger than this? 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 distribution 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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Nov 11, 1998

From Page No. Nov 12, 1998

Resulting from the UA review,

Need to find out in a systematic 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 5m 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-UA TBD pg 2-112 (rev 0)
range of α $3.3e-4$, $9.7e-4$, $3.3e-3$ Pa^{-1} $\sigma_a = 0.5$ $\sigma_a^2 = 0.25$ range of K 10^{-14} 10^{-13} 10^{-12} m^2
Chap 2 TSPA-UA TBD pg 2-91spherical corr 2m for $K < 10^{-12.5}$ m^2

corr 4m vertical & NS and

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

using SGSIM and histogram in fig 2-54

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1998

From Page No. Nov 13, 1998

Generate random K field, set for correlations $\pi_x = 2\text{m}$ $\pi_y = 2\text{m}$ $\pi_z = 4\text{m}$, 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 $\alpha = \text{constant } 9.7e-4$ Pa^{-1} $m = 0.633$ $\phi = \text{constant } = 1.24e-4$

Nov 16, 1998

Infiltration Rate (mm/year) cummsecp (m^3/y) Avg seep (mm/yr)2 mm/yr = $6.38e-8$ $\text{kg}/\text{m}^2/\text{s}$ 4.188e-2 1.67

* All blocks in drift ceiling were dripping

10 mm/yr = $3.16e-7$ $\text{kg}/\text{m}^2/\text{s}$ 0.2038 8.15↑ random K field saved as 3drank.1
seed # is 123456789new field seed = 716357912 272638459 3drank.2
log10 mean = 72.1329 geom mean = $7.36452e-13$ $\sigma_F^2 = 0.147$
min = $2.67e-14$ max = $1.51e-11$ m^2 2 mm/yr = $6.34e-8$ $\text{kg}/\text{m}^2/\text{s}$ 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

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

Infiltration Rate Cumulative (m³/yr) Average seepage mm/yr
* 10 to compare w/

3/D case

4 - DH 11/17/98 4.7456e-3 DH 11/17/98
2mm/yr = 6.38e-8 kg/m²/s 4.777e-3 1.898

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

2mm/yr = 6.34e-8 kg/m²/s 4.124e-3 m³/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 $K = 1.779e-13 \text{ m}^2$

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

In both cases, however, with $\alpha = 9.7e-4 \text{ Pa}^{-1}$ 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 $K = 10^{-13} \text{ m}^2$

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From Page No. Nov 17, 1998

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

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

Infiltration Rate Cumulative Seepage m³/y Average seepage mm/yr

6.34e-8 kg/m²/s = 2mm/yr 4.847e-3 m³/y 1.938 mm/yr

3.16e-7 kg/m²/s = 10mm/yr 2.479e-2 m³/y 9.91 mm/yr

3.16e-8 kg/m²/s = 1mm/yr 2.351e-3 m³/y 0.940 mm/yr

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

3.16e-8 kg/m ² /s = 1mm/yr	0	0
6.34e-8 kg/m ² /s = 2mm/yr	0	0
3.16e-7 kg/m ² /s = 10mm/yr	0	0
6.33e-7 kg/m ² /s = 20mm/yr	0	0
1.58e-6 kg/m ² /s = 50mm/yr	5.7216e-2 m ³ /y	22.88 mm/yr
3.16e-6 kg/m ² /s = 100mm/yr	8.179e-2 m ³ /y	71.538 mm/yr
1.11e-6 kg/m ² /s = 35mm/yr	2.164e-2 m ³ /y	8.655 mm/yr
8.86e-7 kg/m ² /s = 28mm/yr	5.932e-3 m ³ /y	2.372 mm/yr

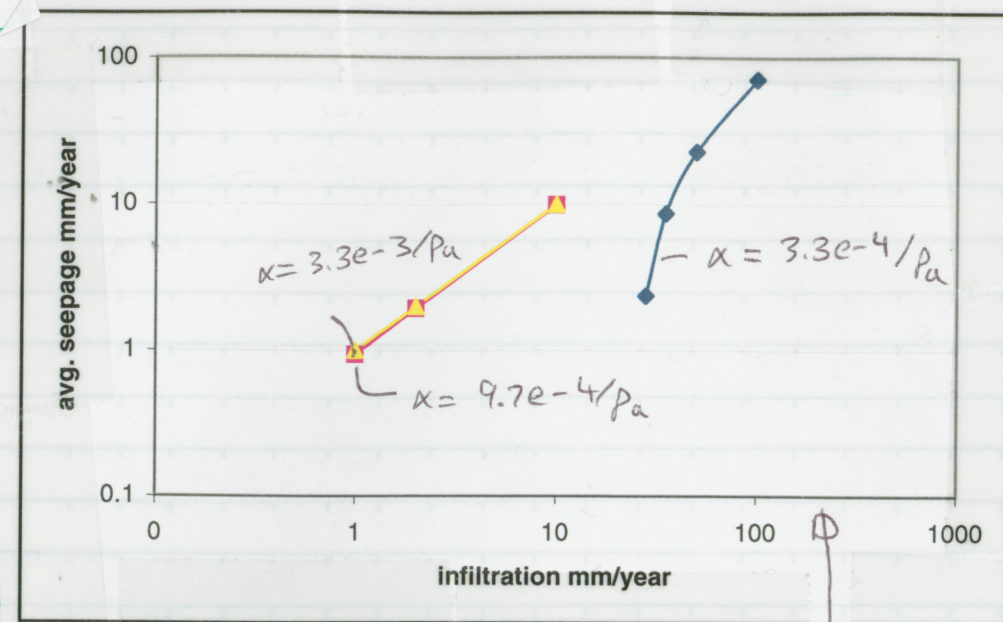
DH 11/17/98
 $\alpha = 3.3e-4 \text{ Pa}^{-1}$

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

Graph on next page

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

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

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

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

Time to check this model geometry against the Philip Solution.

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

Analytical solution

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

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

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

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

Ref:

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

From Page No.

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

Gardner Russo Parameters

Van Genuchten Parameters

$$K_s = 0.04239 \text{ cm/min}$$

$$\alpha = 0.15544 / \text{cm}$$

$$0.04348 \text{ cm/min} = K_s$$

$$0.05791 / \text{cm} = \alpha$$

$$1.82323 = n$$

$$0.04239 \frac{\text{cm}}{\text{min}} \frac{\text{min}}{60\text{s}} \frac{\text{m}}{100\text{cm}} 1.119 \times 10^{-3} \frac{\text{kg}}{\text{m}^3} \frac{\text{m}^3}{998\text{Kg}} \frac{\text{s}^2}{9.8\text{m}} = 8.083 \times 10^{-13} \text{ m}^2$$

$$0.15544 / \text{cm} \frac{100\text{cm}}{\text{m}} \frac{\text{m}^3}{998\text{Kg}} \frac{\text{s}^2}{9.8\text{m}} = 1.5893 \times 10^{-3} \text{ Pa}^{-1}$$

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

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

$$S = e^{\frac{\alpha \psi}{2}} \left(1 + \frac{\alpha \psi}{2}\right)^{-\frac{1}{2}} \quad -\infty \leq \psi \leq 0$$

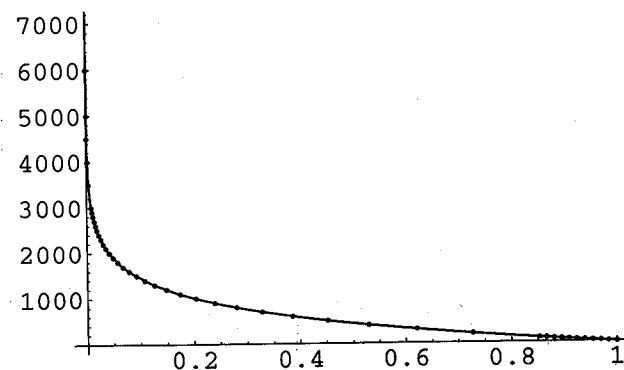
```
In[27]:= a = 1.5893 * 10^-3;
```

```
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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USFIC

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$$0.04239 \text{ cm/min} \frac{10\text{mm}}{\text{cm}} \frac{60\text{min}}{\text{hr}} \frac{24\text{hr}}{\text{day}} \frac{365\text{days}}{\text{yr}} = 2.228 \times 10^5 \text{ mm/yr}$$

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

$$q_c = \frac{K_s}{\alpha_{\max}}$$

phillip1.nb

```
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
```

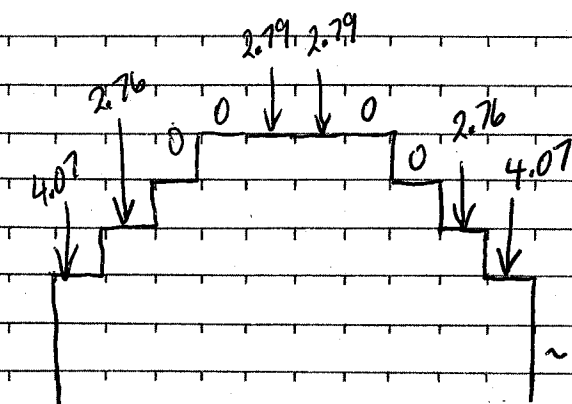
```
In[38]:= Ks = 2.228 * 10^5;
```

```
In[39]:= qc = Ks / q
```

```
Out[39]= 5461.16
```

critical infiltration at which
seepage will begin to occur

MultFlo results infiltration $3.16 \times 10^{-7} \frac{\text{kg}}{\text{m}^2 \text{s}} = \frac{10\text{mm}}{\text{yr}}$



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

drift outline from page 19

file saved

~dhughson/multiflo/inputbak/multi.19

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Data from Russo & Burton (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

$$K = 1 \times 10^{-13} \text{ m}^2 \frac{998 \text{ kg}}{\text{m}^3} \frac{9.8 \text{ m}}{\text{s}^2} \frac{1000 \text{ mm}}{\text{m}} \frac{60 \cdot 60 \cdot 24 \cdot 365}{\text{y}} = 2.756 \times 10^4 \frac{\text{mm}}{\text{y}}$$

$$1.119 \times 10^{-3} \text{ kg/m.s}$$

$$= 2.756 \times 10^4 \frac{\text{mm}}{\text{y}}$$

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

$$\alpha = 9.7 \times 10^{-4} \frac{\text{s}^2 \text{ m}}{\text{kg}} \frac{998 \text{ kg}}{\text{m}^3} \frac{9.8 \text{ m}}{\text{s}^2} = 9.487 / \text{m}$$

$$\text{factor of } 2.7 = 25.61 / \text{m}$$

$$\alpha = 3.3 \times 10^{-3} \text{ Pa}^{-1} = 3.23 / \text{m} \quad \text{fac of } 2.7 = 8.714 / \text{m}$$

$$\alpha = 3.3 \times 10^{-4} \text{ Pa}^{-1} = 3.23 / \text{m} \quad \text{fac of } 2.7 = 8.714 / \text{m}$$

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

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

$$\alpha \quad q^* \frac{\text{mm}}{\text{y}}$$

$$8.714 \quad 1165.7$$

$$25.61 \quad 417.8$$

$$87.14 \quad 125.4$$

$$200 \quad 54.9$$

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

$$\alpha \quad q^* \frac{\text{mm}}{\text{y}}$$

$$8.714 \quad 116.6$$

$$25.61 \quad 41.8$$

$$87.14 \quad 12.5$$

$$200 \quad 5.5$$

$$\text{For } \alpha = 9.7 \times 10^{-3} \text{ Pa}^{-1} \\ = 94.9 / \text{m} \text{ or fac of } 2.7 \\ 284.6 / \text{m}$$

Series solution does not converge

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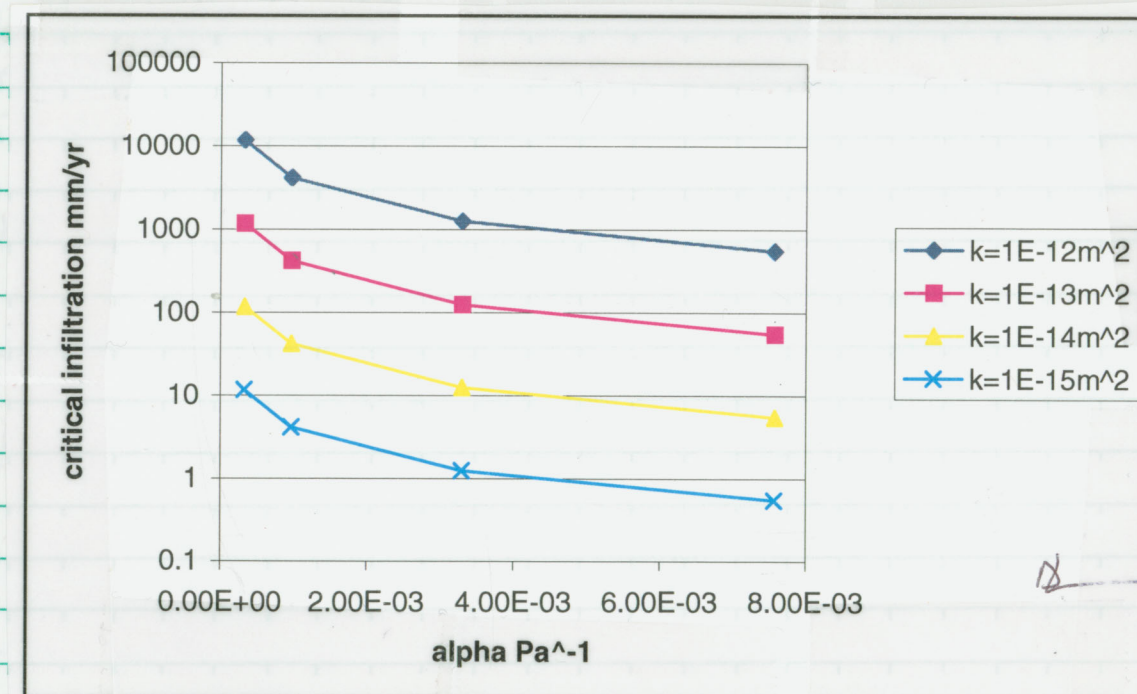
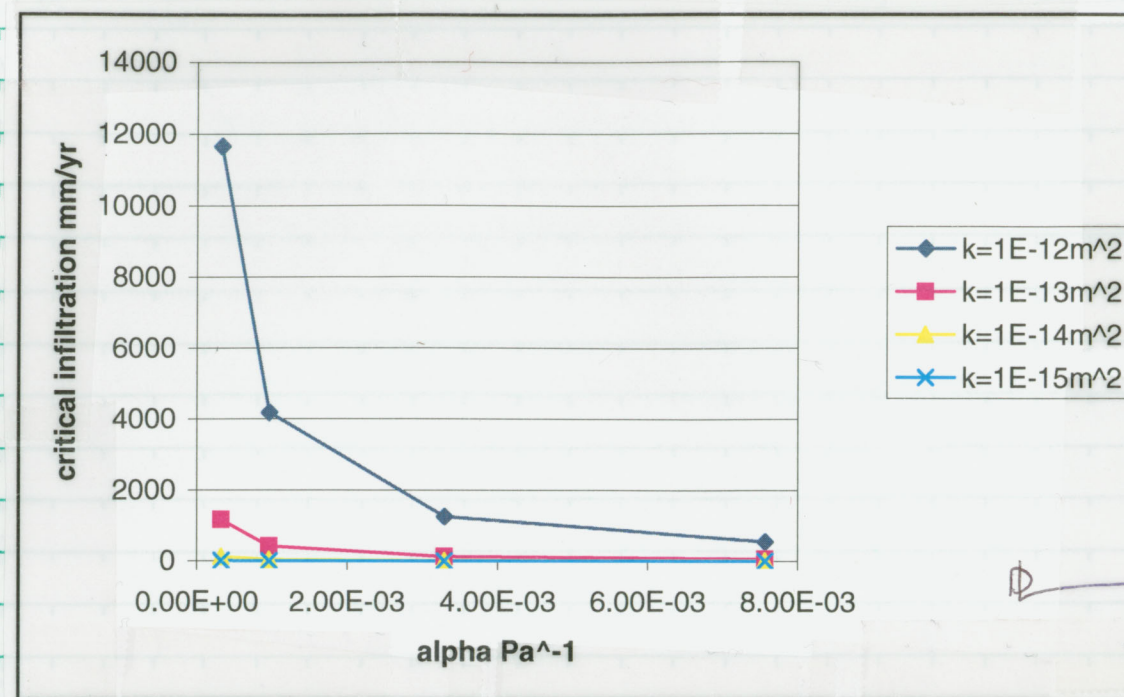
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2008

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Maybe the irregular geometry of the drift opening is the reason why the multi-pro 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

$$U_{max}(s, 0) = [1 - 2s \operatorname{esh}(0, 2s)]^{-1} \quad s = \frac{\alpha l}{2}$$

$$\operatorname{esh}(\eta, w) = \int_{\eta}^{\infty} \exp[-w s \sinh \eta] ds, \quad l = \text{semiwidth}$$

expansion

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

I think the next term in this series should be

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

$$l = 1.;$$

$$a = 15.554;$$

$$s = a \cdot l / 2$$

$$7.777$$

$$w = 2 \cdot s;$$

$$\operatorname{esh} = 1/w - 1/w^3 + 9/w^5 - 225/w^7 + 11025/w^9 - 893025/w^{11};$$

$$q1 = 1 / (1 - 2 \cdot s \cdot \operatorname{esh})$$

$$250.41$$

$$k = 2.228 \cdot 10^5; \text{ mm/year}$$

$$qc = k / q1$$

$$889.742$$

critical seepage $\sim 890 \frac{\text{mm}}{\text{yr}}$

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From Page No. Multi-pro

infiltration rate

$$3.17 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 10.017 \frac{\text{mm}}{\text{yr}}$$

no seepage

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \text{ mm/yr}$$

$$\text{avg rate} = 2.82 \frac{\text{mm}}{\text{yr}}$$

For a single row strip cavity

infiltration rate

$$3.17 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 10.017 \frac{\text{mm}}{\text{yr}}$$

no seepage

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \frac{\text{mm}}{\text{yr}}$$

$$\text{avg rate} = 2.53 \frac{\text{mm}}{\text{yr}}$$

505 505
0 ↓ 0
cavity

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

563 563
0 ↓ 0
cavity opening

Porosity is $1.24 \cdot 10^{-4}$, change this to ~~0.2~~ 0.3

infiltration rate

$$3.17 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 10.017 \frac{\text{mm}}{\text{yr}}$$

no seepage

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \frac{\text{mm}}{\text{yr}}$$

$$\text{avg rate} = 2.53 \frac{\text{mm}}{\text{yr}}$$

Use a large α instead of $P_c = 0$ condition for cavity
 $1 \cdot 10^{-5} \text{ Pa}^{-1}$ $S_r = 0.1$ $m = 0.633$

infiltration rate

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \frac{\text{mm}}{\text{yr}}$$

$$\text{avg rate} = 15.4 \frac{\text{mm}}{\text{yr}}$$

$$\alpha = 1 \text{ Pa}^{-1}$$

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \frac{\text{mm}}{\text{yr}}$$

$$\text{avg rate} = 2.59 \frac{\text{mm}}{\text{yr}}$$

$$\alpha = 10 \text{ Pa}^{-1}$$

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \frac{\text{mm}}{\text{yr}}$$

$$\text{avg rate} = 2.95 \frac{\text{mm}}{\text{yr}}$$

$$\alpha = 100 \text{ Pa}^{-1}$$

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \frac{\text{mm}}{\text{yr}}$$

$$\text{avg rate} = 2.56 \frac{\text{mm}}{\text{yr}}$$

$$\alpha = 1000 \text{ Pa}^{-1}$$

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \frac{\text{mm}}{\text{yr}}$$

$$\text{avg rate} = 2.55 \frac{\text{mm}}{\text{yr}}$$

$$\alpha = 10000 \text{ Pa}^{-1}$$

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \frac{\text{mm}}{\text{yr}}$$

$$\text{avg rate} = 2.55 \frac{\text{mm}}{\text{yr}}$$

$$4 \cdot 10^{-7} \text{ kg/m}^2/\text{s} = 12.6 \frac{\text{mm}}{\text{yr}}$$

$$\text{avg rate} = 2.54 \frac{\text{mm}}{\text{yr}}$$

Opp! = small α
looks like α 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)

$$\text{VanG } K_s = .04348 \text{ cm/min } \alpha = .05791/\text{cm} \quad n = 1.82323$$

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

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

$$\frac{N}{\text{m}^2} = P_a = \left(\frac{\text{kg} \cdot \text{m}}{\text{s}^2} \right) / \text{m}^2 = \frac{\text{kg}}{\text{m} \cdot \text{s}^2} \quad m = 1 - \frac{1}{n} = 1 - \frac{1}{1.82323} = .4515$$

also use TABular $P_c = 0$ for cavity condition

Infiltration

$$4\text{e-}7 \text{ kg/m}^2/\text{s} = 12.6 \text{ mm/y} \quad \text{no seepage}$$

$$5\text{e-}7 \text{ kg/m}^2/\text{s} \quad \text{no seepage}$$

$$6\text{e-}7 \text{ kg/m}^2/\text{s} = 18.96 \text{ mm/y} \quad \text{no seepage}$$

$$7\text{e-}7 \text{ kg/m}^2/\text{s} = 22.12 \text{ mm/y} \quad \text{no seepage}$$

$$8\text{e-}7 \text{ kg/m}^2/\text{s} = 25.28 \text{ mm/y} \quad \text{no seepage}$$

$$9\text{e-}7 \text{ kg/m}^2/\text{s} = 28.44 \text{ mm/y} \quad \text{no seepage}$$

$$1\text{e-}7 \text{ kg/m}^2/\text{s} = 31.60 \text{ mm/y} \quad \text{no seepage}$$

$$2\text{e-}7 \text{ kg/m}^2/\text{s} = 63.20 \text{ mm/y} \quad \text{no seepage}$$

$$3\text{e-}7 \text{ kg/m}^2/\text{s} = 94.80 \text{ mm/y} \quad \text{avg rate} = 22.176 \text{ mm/y}$$

Saturation of liquid at int = $3\text{e-}7 \text{ kg/m}^2/\text{s}$

4439 4623

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

Cavity

Here
should
be
e-6

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From Page No. NW24, 1998 these are the grid blocks in the
strip cavity and right above

these top blocks:

$$S_r = 0.1 \quad m = .4575$$

$$\alpha = 5.921 \times 10^{-4} \text{ Pa}^{-1}$$

$$K = 8.083 \times 10^{-13} \text{ m}^2$$

$$P_g = 1.014 \times 10^5$$

$$S_g = .4439$$

$$P_c = 5071$$

$$u_1 = 0$$

$$u_2 = .04435 \text{ m/y}$$

$$P_g = 1.04 \times 10^5$$

$$S_g = .4623$$

$$P_c = 4717$$

$$u_1 = 0$$

$$u_2 = .04435 \text{ m/y}$$

these bottom blocks

$$P_c = 0 \text{ for all } S_i$$

$$K = 1 \times 10^{-4} \text{ m}^2$$

$$P_g = 1.014 \times 10^5$$

$$S_g = 0$$

$$P_c = 0$$

$$P_g = 1.04 \times 10^5$$

$$S_g = .057$$

$$P_c = 0$$

rock
arr

Drops when $P_c = 4717$ but not when $P_c = 5071$ P_a

Gravity potential

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

Blocks at $(0.5 \text{ m})^3$ above the drift opening are
too large.

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

$$(0.1 \text{ m}) (9.8 \text{ m/s}^2) (998 \frac{\text{kg}}{\text{m}^3}) = 978 \text{ Pa}$$

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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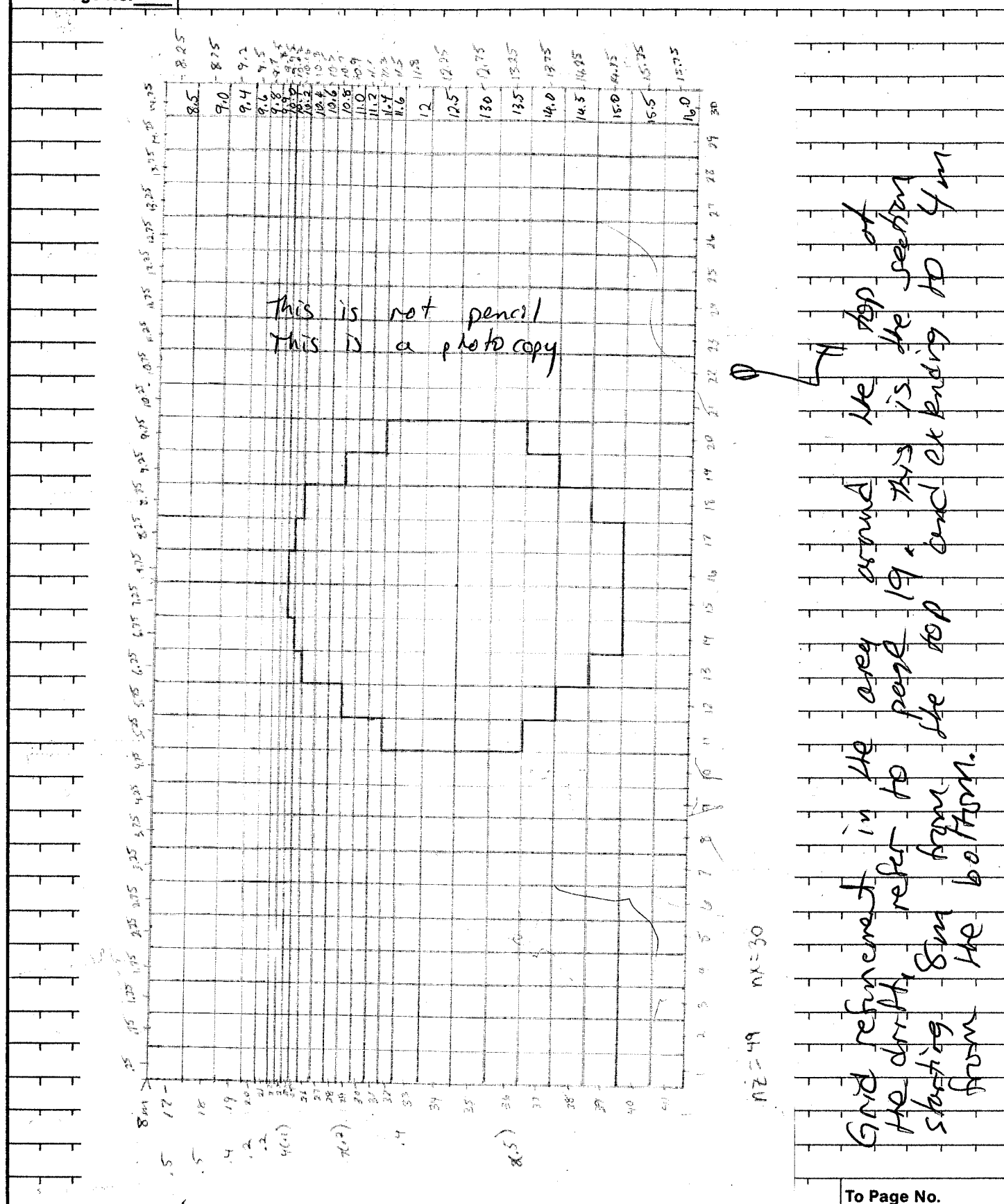
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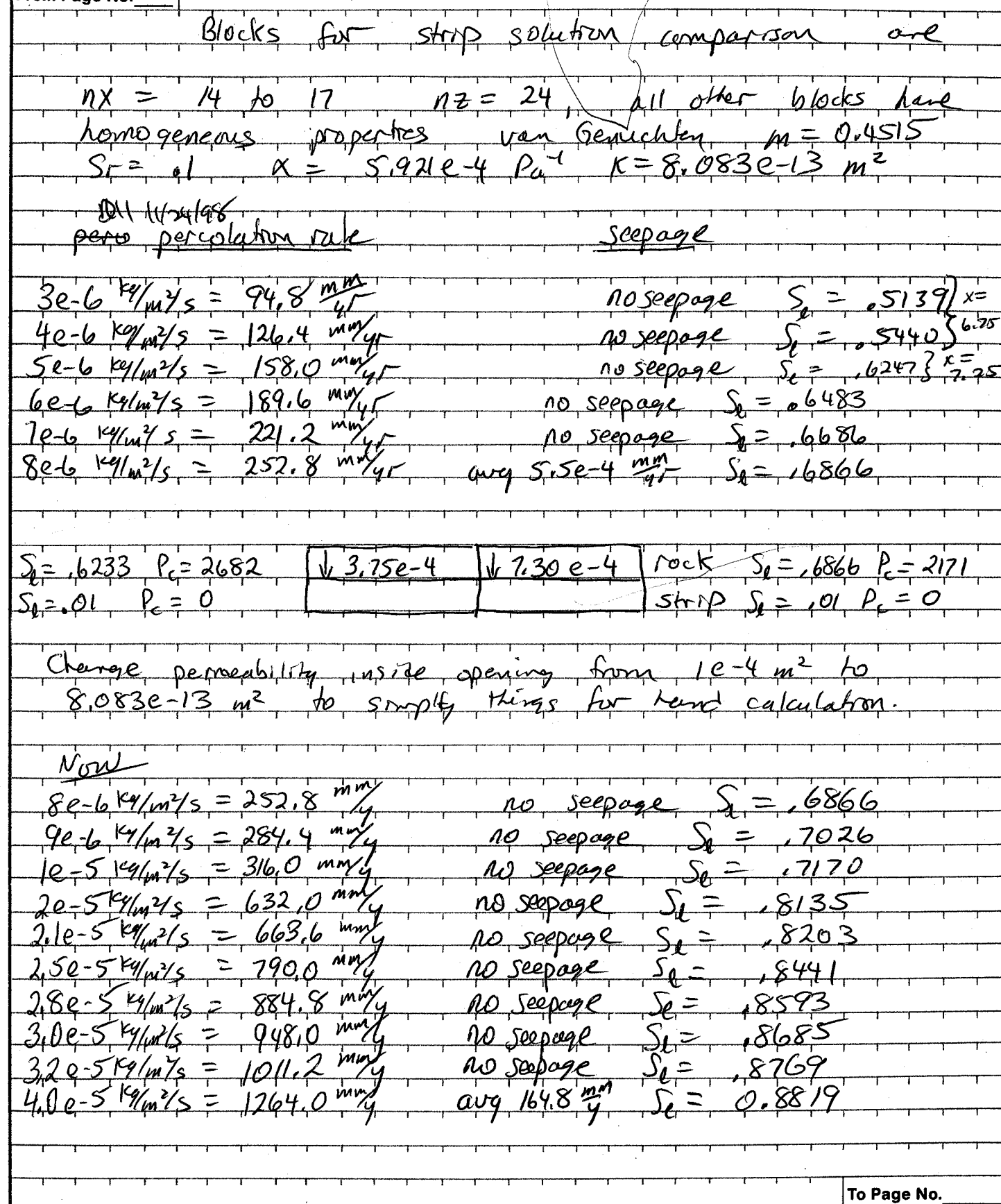
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Saw previously that for the number 1 ~~Gardner~~ Russo Boulton (1992) Soil, TABular with Gardner parameters caused seepage between 10 and 12.6 mm/y while the van Genuchten parameters resulted in seepage between 63.2 and 94.8 mm/y, with $K = 8.083 \times 10^{-13} \text{ m}^2$ 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
$2.8 \times 10^{-5} \text{ kg/m}^2/\text{s} = 884.8 \text{ mm/y}$	no seepage	.6989
$3.8 \times 10^{-5} \text{ kg/m}^2/\text{s} = 1200.8 \text{ mm/y}$	avg rate = 128.3 mm/y	$S_e = .7293$
$3.5 \times 10^{-5} \text{ kg/m}^2/\text{s} = 1106.0 \text{ mm/y}$	avg rate = 60.5 mm/y	$S_e = .7285$
$3.0 \times 10^{-5} \text{ kg/m}^2/\text{s} = 948.0 \text{ mm/y}$	no seepage	$S_e = .7130$
$3.1 \times 10^{-5} \text{ kg/m}^2/\text{s} = 979.6 \text{ mm/y}$	no seepage	$S_e = .7196$
$3.2 \times 10^{-5} \text{ kg/m}^2/\text{s} = 1011.2 \text{ mm/y}$	no seepage	$S_e = .7258$
$3.3 \times 10^{-5} \text{ kg/m}^2/\text{s} = 1042.8 \text{ mm/y}$	avg rate = 15.4 mm/y	$S_e = .7280$

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

$$K = 8.083 \times 10^{-13} \text{ m}^2 \frac{998 \text{ kg}}{\text{m}^3} \frac{9.8 \text{ m}}{\text{s}^2} / 1.119 \times 10^{-3} \text{ kg/m}^2/\text{s} = 7.065 \times 10^{-6} \text{ m}^2/\text{s}$$

$$K = 2.228 \times 10^5 \text{ mm/y} \quad l = 1 \text{ m halfwidth}$$

Analytical solution critical seepage = 891 mm/y

Numerical model critical seepage $\approx$ 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 $K_r(S_e)$ & have to use TABular form. 2) grid discretization may cause some differences.

However, I did closely predict the S_e in the block above drift for van Genuchten from block sz & 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 answers
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- 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 $\alpha \rightarrow \infty$
- 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 it predict with analytical model when numerical model will seep?

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

$$\alpha = 9.7 \times 10^{-4} \text{ Pa}^{-1} = 9.487 / \text{m} \quad (\text{factor of } \sim 3.7 \approx 25.6 / \text{m})$$

look for seepage around 41-42 mm/y

← archive

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From Page No. Van Genuchten parameters for DGE fracture continuum
Strip Cavity halfwidth = 1m

percolation $1.0 \times 10^{-6} \text{ kg/m}^2/\text{s} = 31.6 \text{ mm/y}$ seepage no seepage saturation above $S_e = .6615$

Note: I had set rock porosity to 1.24×10^{-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.

$2.0 \times 10^{-6} \text{ kg/m}^2/\text{s} = 63.2 \text{ mm/y}$ avg rate = 19.6 mm/y $S_e = .6828$
 $1.50 \times 10^{-6} \text{ kg/m}^2/\text{s} = 47.4 \text{ mm/y}$ avg rate = 8.8 mm/y $S_e = .6799$
 $1.10 \times 10^{-6} \text{ kg/m}^2/\text{s} = 34.8 \text{ mm/y}$ no seepage
 $1.40 \times 10^{-6} \text{ kg/m}^2/\text{s} = 44.2 \text{ mm/y}$ avg rate = 6.6 mm/y
 $1.30 \times 10^{-6} \text{ kg/m}^2/\text{s} = 41.1 \text{ mm/y}$ avg rate = 4.4 mm/y
 $1.20 \times 10^{-6} \text{ kg/m}^2/\text{s} = 37.9 \text{ mm/y}$ 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 $m = 0.63$
 $\alpha = 9.70 \times 10^{-4} \text{ Pa}^{-1}$ $K = 10^{-13} \text{ m}^2$ $\phi = 1.24 \times 10^{-4}$
 I predict critical seepage around 395 mm/y

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More grid refinement. ~~Added over pressure graph~~
~~on page 68~~ on page 68 ~~12/2/98~~

percolation $1.1 \times 10^{-6} \text{ kg/m}^2/\text{s} = 34.76 \text{ mm/y}$ seepage
 (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
 $S_e = .52$ $P_c = 1298$ over the top blocks
 at $z = 9.95$ (no seeping) $S_e = .5352$ $P_c = 1264$

$5.0 \times 10^{-6} \text{ kg/m}^2/\text{s} = 158 \text{ mm/y}$ Center 2 blocks leak, next two outside those don't, all the rest do

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

According to the strip solution, the top section should leak at $\sim 144 \text{ mm/y}$ so this is in the ball park.

Dec 1, 1998 - Working on seepage report

check for sat above opening $\Delta z = 0.5 \text{ m}$
 $n = 2.7$ $\alpha = 9.70 \times 10^{-4}$ $K = 8.083 \times 10^{-13}$

$3.16 \times 10^{-7} \text{ kg/m}^2/\text{s} = 9.99 \text{ mm/y}$ Avg = 8.23 mm/y
 $9.0 \times 10^{-8} \text{ kg/m}^2/\text{s} = 2.84 \text{ mm/y}$ Avg = 1.87 mm/y
 $9.0 \times 10^{-9} \text{ kg/m}^2/\text{s} = 0.284 \text{ mm/y}$ Avg = 0
 $2.0 \times 10^{-8} \text{ kg/m}^2/\text{s} = 0.63 \text{ mm/y}$ Avg = 0.218 mm/y

Saturation .076 no leaks
 .083 leaks

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From Page No. blank sra 10cm above opening

2

Seepage

$$3.3e-7 \text{ kg/m}^2/\text{s} = 10.43 \text{ mm/y}$$

$$5.0e-7 \text{ kg/m}^2/\text{s} = 15.8 \text{ mm/y}$$

$$1.0e-6 \text{ kg/m}^2/\text{s} = 31.6 \text{ mm/y}$$

$$4.0e-6 \text{ kg/m}^2/\text{s} = 126.4 \text{ mm/y}$$

0

0

0

0

Should do this with $K = 1e-13 \text{ m}^2$

$$0.5 = \Delta z \quad \alpha = 9.7e-4 \quad n = 2.7$$

9

seep

$$2e-8 \text{ kg/m}^2/\text{s} = .632 \text{ mm/y}$$

$$\text{Avg} = .475 \text{ mm/y}$$

$$1e-9 \text{ kg/m}^2/\text{s} = .03 \text{ mm/y}$$

0

$$9e-9 \text{ kg/m}^2/\text{s} = .284 \text{ mm/y}$$

$$.174 \text{ mm/y}$$

$$8e-9 \text{ kg/m}^2/\text{s} = .253 \text{ mm/y}$$

$$.147 \text{ mm/y}$$

$$7e-9 \text{ kg/m}^2/\text{s} = .221 \text{ mm/y}$$

$$.121 \text{ mm/y}$$

$$5e-9 \text{ kg/m}^2/\text{s} = .158 \text{ mm/y}$$

$$.07 \text{ mm/y}$$

$$4e-9 \text{ kg/m}^2/\text{s} = .126 \text{ mm/y}$$

$$.046 \text{ mm/y}$$

$$3e-9 \text{ kg/m}^2/\text{s} = .095 \text{ mm/y}$$

$$.022 \text{ mm/y}$$

$$2e-9 \text{ kg/m}^2/\text{s} = .063 \text{ mm/y}$$

$$.0059 \text{ mm/y}$$

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$$0.1 = \Delta z \quad K = 1e-13 \text{ m}^2 \quad \alpha = 9.7e-4 \text{ Pa}^{-1} \quad n = 2.7$$

9

seep

$$1.0e-6 \text{ kg/m}^2/\text{s} = 31.6 \text{ mm/y}$$

$$1.0e-5 \text{ kg/m}^2/\text{s} = 316 \text{ mm/y}$$

$$3.0e-6 \text{ kg/m}^2/\text{s} = 94.8 \text{ mm/y}$$

$$2.0e-6 \text{ kg/m}^2/\text{s} = 63.2 \text{ mm/y}$$

$$1.5e-6 \text{ kg/m}^2/\text{s} = 47.4 \text{ mm/y}$$

$$1.4e-6 \text{ kg/m}^2/\text{s} = 44.2 \text{ mm/y}$$

$$1.1e-6 \text{ kg/m}^2/\text{s} = 34.8 \text{ mm/y}$$

$$1.2e-6 \text{ kg/m}^2/\text{s} = 37.9 \text{ mm/y}$$

$$\text{Avg} = 252.4 \text{ mm/y}$$

$$\text{Avg} = 40.45 \text{ mm/y}$$

$$\text{Avg} = 19.6 \text{ mm/y}$$

$$\text{Avg} = 8.8 \text{ mm/y}$$

$$\text{Avg} = 6.6 \text{ mm/y}$$

$$\text{Avg} = 2.2 \text{ mm/y}$$

$$S_e = .6772$$

no leak $S_e = 0.57$ leak 4.4 mm/y $S_e = 0.68$ 0.678

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$$\text{Gardner Russo Model} \quad \alpha = 1.5893 \times 10^{-3} \text{ Pa}^{-1} \quad K = 1 \times 10^{-13} \text{ m}^2$$

$$K = 1 \times 10^{-13} \text{ m}^2$$

9

seep

$$3.0e-6 \text{ kg/m}^2/\text{s} = 94.8 \text{ mm/y}$$

$$3.5e-6 \text{ kg/m}^2/\text{s} = 110.6 \text{ mm/y}$$

$$4.0e-6 \text{ kg/m}^2/\text{s} = 126.4 \text{ mm/y}$$

$$3.9e-6 \text{ kg/m}^2/\text{s} = 123.2 \text{ mm/y}$$

0

0

0

0

$$.03 \text{ mm/y} \quad S_e = .7278$$

$$S_e = .7229$$

$$\text{van Genuchten} \quad \alpha = 5.676 \times 10^{-4} \text{ Pa}^{-1} \quad n = 2.7 \quad K = 10^{-15} \text{ m}^2$$

9

seep

$$3.9 \times 10^{-6} \text{ kg/m}^2/\text{s} = 123.2 \text{ mm/y}$$

$$4.0 \times 10^{-6} \text{ kg/m}^2/\text{s} = 126.4 \text{ mm/y}$$

$$4.1 \times 10^{-6} \text{ kg/m}^2/\text{s} = 129.56 \text{ mm/y}$$

$$\alpha = 5.886e-4 \text{ Pa}^{-1} \quad \text{Dec 2/98}$$

$$4.1 \times 10^{-6} \text{ kg/m}^2/\text{s} = 129.56 \text{ mm/y}$$

$$4.2 \times 10^{-6} \text{ kg/m}^2/\text{s} = 132.7 \text{ mm/y}$$

$$4.3e-6 \text{ kg/m}^2/\text{s} = 135.9 \text{ mm/y}$$

$$5.0e-6 \text{ kg/m}^2/\text{s} = 157 \text{ mm/y}$$

$$6.0e-6 \text{ kg/m}^2/\text{s} = 189.6 \text{ mm/y}$$

$$7.0e-6 \text{ kg/m}^2/\text{s} = 221 \text{ mm/y}$$

$$6.5e-6 \text{ kg/m}^2/\text{s} = 205.4 \text{ mm/y}$$

$$6.2e-6 \text{ kg/m}^2/\text{s} = 195.9 \text{ mm/y}$$

$$\text{Avg} = 19.5$$

$$8.2$$

$$1.46$$

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

Gardner-Russo

$$K_s = .04239 \text{ cm/min}$$

$$\alpha = 0.15544 / \text{cm}$$

van Genuchten

$$K_s = .04348 \text{ cm/min}$$

$$\alpha = .05791 / \text{cm}$$

$$n = 1.82323$$

$$K_s = 8.083 \times 10^{-13} \text{ m}^2$$

$$K_s = 8.291 \times 10^{-13} \text{ m}^2$$

$$\alpha = 1.5893 \times 10^{-3} \text{ Pa}^{-1}$$

$$\alpha = 5.921 \times 10^{-4} \text{ Pa}^{-1}$$

$$m = .4515$$

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numerical model with van Genuchten parameters

α	$K_0/m^2/s$	seep
$3.35e-5$	1058.6 mm/y	0
$3.39e-5$	1071.2 mm/y	2.1 mm/y
$3.37e-5$	1064.9 mm/y	0
$3.38e-5$	1068.1 mm/y	0

Refined grid $\alpha = 5.921e-4/Pa$ $m = .4575$ $K = 8.291E-13 \text{ m}^2$

α	$K_0/m^2/s$	seep	note
$5.0e-6$	158 mm/y	0	
$5.0e-5$	1580 mm/y	0	280 mm/y none on top
$4.0e-5$	1264 mm/y	0	
$4.3e-5$	1359 mm/y	0	
$4.6e-5$	1453.6 mm/y	0	
$4.7e-5$	1485 mm/y	0	
$4.8e-5$	1517 mm/y	0	
$4.9e-5$	1548 mm/y	0	6.5 mm/y 58.762 cu Se = 1869

look for seepage along top strip

$1.0e-4 = 3156 \text{ mm/y}$	2 center blocks 1733.6 mm/y each
$8.0e-5 = 2528 \text{ mm/y}$	825.34 mm/y each
$7.0e-5 = 2212 \text{ mm/y}$	2 center blocks 341.7 mm/y each
$6.0e-5 = 1896 \text{ mm/y}$	0
$5.5e-5 = 6.5e-5 = 2054 \text{ mm/y}$	89.0 mm/y each
$6.4e-5 K_0/m^2/s = 2022 \text{ mm/y}$	38.37 mm/y each
$6.3e-5 K_0/m^2/s = 1991 \text{ mm/y}$	0
$6.2e-5 K_0/m^2/s = 1959 \text{ mm/y}$	0

Save

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Sensitivity for 2m wide strip

$\alpha = 9.7e-4 \text{ Pa}^{-1}$	$m = 0.63$	$K = 10^{-13} \text{ m}^2$	
$1.2e-6 K_0/m^2/s = 37.9 \text{ mm/y}$			Avg 2.2 mm/y
$1.1e-6 K_0/m^2/s = 34.8 \text{ mm/y}$			Avg = 0
Find the Gardner α which produces the same result			
$\alpha = 3.3e-4 \text{ Pa}^{-1}$	$m = 0.63$	$K = 10^{-13} \text{ m}^2$	on 12/4/98
Gardner $\alpha = 2.8e-3 \text{ Pa}^{-1}$	$K = 10^{-13} \text{ m}^2$	$q^* = 36.3 \text{ mm/y}$	

$\alpha = 3.3e-4 \text{ Pa}^{-1}$	$m = 0.63$	$K = 10^{-13} \text{ m}^2$	
$1.2e-6 K_0/m^2/s = 37.9 \text{ mm/y}$			0
$5.0e-6 K_0/m^2/s = 158 \text{ mm/y}$			0
$9.0e-6 K_0/m^2/s = 284.4 \text{ mm/y}$			0
$1.0e-5 K_0/m^2/s = 316 \text{ mm/y}$			0
$1.5e-5 K_0/m^2/s = 474 \text{ mm/y}$			0
$2.0e-5 K_0/m^2/s = 632 \text{ mm/y}$			0
$3.0e-5 K_0/m^2/s = 948 \text{ mm/y}$			Avg 116.67 mm/y
$2.1e-5 K_0/m^2/s = 663.6 \text{ mm/y}$			0
$2.5e-5 K_0/m^2/s = 790 \text{ mm/y}$			Avg 1.2 mm/y
$2.2e-5 K_0/m^2/s = 695.2 \text{ mm/y}$			0
$2.4e-5 K_0/m^2/s = 758.4 \text{ mm/y}$			0
$2.45e-5 K_0/m^2/s = 774.2 \text{ mm/y}$			0
$2.49e-5 K_0/m^2/s = 786.8 \text{ mm/y}$			0
Gardner $\alpha = 9.526e-4 \text{ Pa}^{-1}$	$K = 10^{-13} \text{ m}^2$	$q^* = 293.7 \text{ mm/y}$	
Gardner $\alpha = 6.39e-4 \text{ Pa}^{-1}$	$K = 10^{-13} \text{ m}^2$	$q^* = 787.4 \text{ mm/y}$	

$\alpha = 3.3e-3 \text{ Pa}^{-1}$	$m = .63$	$K = 10^{-13} \text{ m}^2$	
$1.0e-6 K_0/m^2/s = 31.6 \text{ mm/y}$			Avg = 31.3 mm/y
$1.0e-7 K_0/m^2/s = 3.16 \text{ mm/y}$			Avg = 3.0 mm/y
$1.0e-8 K_0/m^2/s = 0.316 \text{ mm/y}$			Avg = 0.22 mm/y
$1.0e-9 K_0/m^2/s = 0.316 \text{ mm/y}$			0
$5.0e-9 K_0/m^2/s = 0.158 \text{ mm/y}$			.07
$4.0e-9 K_0/m^2/s = 0.126 \text{ mm/y}$			.05
$3.0e-9 K_0/m^2/s = 0.095 \text{ mm/y}$			.03
$2.0e-9 K_0/m^2/s = 0.063 \text{ mm/y}$			.011

Gardner $\alpha = 9.526e-3 \text{ Pa}^{-1}$	$K = 10^{-13} \text{ m}^2$	$q^* = 3.2 \text{ mm/y}$
Gardner $\alpha = 8.0e-2 \text{ Pa}^{-1}$	$K = 10^{-13} \text{ m}^2$	$q^* = 0.045 \text{ mm/y}$

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$$\alpha = 3.3e-3 \text{ Pa}^{-1} \quad m = 0.63 \quad K = 10^{-14} \text{ m}^2$$

$$1e-9 \text{ kg/m}^2/\text{s} = 0.0316 \text{ mm/y} \quad \text{Avg} = 0.022 \text{ mm/y}$$

$$1e-10 \text{ kg/m}^2/\text{s} = 0.00316 \text{ mm/y} \quad 0$$

$$5e-10 \text{ kg/m}^2/\text{s} = 0.0158 \text{ mm/y} \quad \text{Avg} = 0.00726 \text{ mm/y}$$

$$4e-10 \text{ kg/m}^2/\text{s} = 0.0126 \text{ mm/y} \quad \text{Avg} = 0.00528 \text{ mm/y}$$

$$3e-10 \text{ kg/m}^2/\text{s} = 0.00948 \text{ mm/y} \quad \text{Avg} = 0.00324 \text{ mm/y}$$

$$2e-10 \text{ kg/m}^2/\text{s} = 0.00632 \text{ mm/y} \quad \text{Avg} = 0.00115 \text{ mm/y}$$

$$\text{Gardner } \alpha = 9.526e-3 \text{ Pa}^{-1} \quad K = 10^{-14} \text{ m}^2 \quad q^* = 0.336 \text{ mm/y}$$

$$\text{Gardner } \alpha = 8.0e-2 \text{ Pa}^{-1} \quad K = 10^{-14} \text{ m}^2 \quad q^* = 0.0045 \text{ mm/y}$$

$$\alpha = 9.7e-4 \text{ Pa}^{-1} \quad m = 0.63 \quad K = 10^{-14} \text{ m}^2$$

$$1.0e-6 \text{ kg/m}^2/\text{s} = 31.6 \text{ mm/y} \quad \text{Avg} = 25.2 \text{ mm/y}$$

$$1.0e-7 \text{ kg/m}^2/\text{s} = 3.16 \text{ mm/y} \quad 0$$

$$5.0e-7 \text{ kg/m}^2/\text{s} = 15.8 \text{ mm/y} \quad 9.33 \text{ mm/y}$$

$$2.0e-7 \text{ kg/m}^2/\text{s} = 6.32 \text{ mm/y} \quad 1.96 \text{ mm/y}$$

$$\text{Gardner } \alpha = 2.8e-3 \text{ Pa}^{-1} \quad K = 10^{-14} \text{ m}^2 \quad q^* = 3.63 \text{ mm/y}$$

$$\alpha = 3.3e-4 \text{ Pa}^{-1} \quad m = 0.63 \quad K = 10^{-14} \text{ m}^2$$

$$2.43e-6 = 76.8 \text{ mm/y} \quad \text{Avg} = 0$$

$$2.5e-6 = 79.0 \text{ mm/y} \quad \text{Avg} = 0.12 \text{ mm/y}$$

$$\text{Gardner } \alpha = 9.526e-4 \text{ Pa}^{-1} \quad K = 10^{-14} \text{ m}^2 \quad q^* = 29.37 \text{ mm/y}$$

$$\text{Gardner } \alpha = 6.39e-4 \text{ Pa}^{-1} \quad K = 10^{-14} \text{ m}^2 \quad q^* = 78.7 \text{ mm/y}$$

$$\alpha = 3.3e-4 \text{ Pa}^{-1} \quad m = 0.63 \quad K = 10^{-12} \text{ m}^2$$

$$2.43e-4 = 7679 \text{ mm/y} \quad 0$$

$$2.5e-4 = 7900 \text{ mm/y} \quad 12.05 \text{ mm/y}$$

$$\text{Gardner } \alpha = 9.526e-4 \text{ Pa}^{-1} \quad K = 10^{-12} \text{ m}^2 \quad q^* = 2937.4 \text{ mm/y}$$

$$\text{Gardner } \alpha = 6.39e-4 \text{ Pa}^{-1} \quad K = 10^{-12} \text{ m}^2 \quad q^* = 7873.8 \text{ mm/y}$$

$$\alpha = 9.7e-4 \quad m = 0.63 \quad K = 10^{-12} \text{ m}^2$$

$$1.0e-5 \text{ kg/m}^2/\text{s} = 316 \text{ mm/y} \quad 0$$

$$2.0e-5 \text{ kg/m}^2/\text{s} = 632 \text{ mm/y} \quad 195.6 \text{ mm/y}$$

$$\text{Gardner } \alpha = 9.526e-4 \text{ Pa}^{-1} \quad K = 10^{-12} \text{ m}^2 \quad q^* = 216198$$

$$\text{Gardner } \alpha = 6.39e-4 \text{ Pa}^{-1} \quad K = 10^{-12} \text{ m}^2 \quad q^* = 363.3 \text{ mm/y}$$

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1998

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$$\alpha = 3.3e-3 \text{ Pa}^{-1} \quad m = 0.63 \quad K = 10^{-12} \text{ m}^2$$

$$1e-8 \text{ kg/m}^2/\text{s} = 0.316 \text{ mm/y} \quad 0$$

$$2e-8 \text{ kg/m}^2/\text{s} = 0.632 \text{ mm/y} \quad \text{Avg} = 0.115 \text{ mm/y}$$

$$\text{Gardner } \alpha = 9.526e-3 \text{ Pa}^{-1} \quad K = 10^{-12} \text{ m}^2 \quad q^* = 31.7 \text{ mm/y}$$

$$\text{Gardner } \alpha = 8.0e-2 \text{ Pa}^{-1} \quad K = 10^{-12} \text{ m}^2 \quad q^* = 0.45 \text{ mm/y}$$

Sensitivity Analysis With TPA 3.2

Take tpa.inp file from /tpa/7a20KSOy-1kr-oso

This is the nominal case of the 1000 vector runs

Charge # of simulations to 1 remove
 Charge Fow to constant = 1.0 correlation
 Charge Fmult to constant = 0.01 0.13 between
 Ks and Fow

dose50y-1.dat dose10y-1.dat

Charge Fmult to constant = 0.2

dose50y-2.dat dose10y-2.dat

Charge Fmult to constant = 0.5

dose50y-3.dat dose10y-3.dat

Charge Fmult to constant = 1.0

dose50y-4.dat dose10y-4.dat

To Page No.

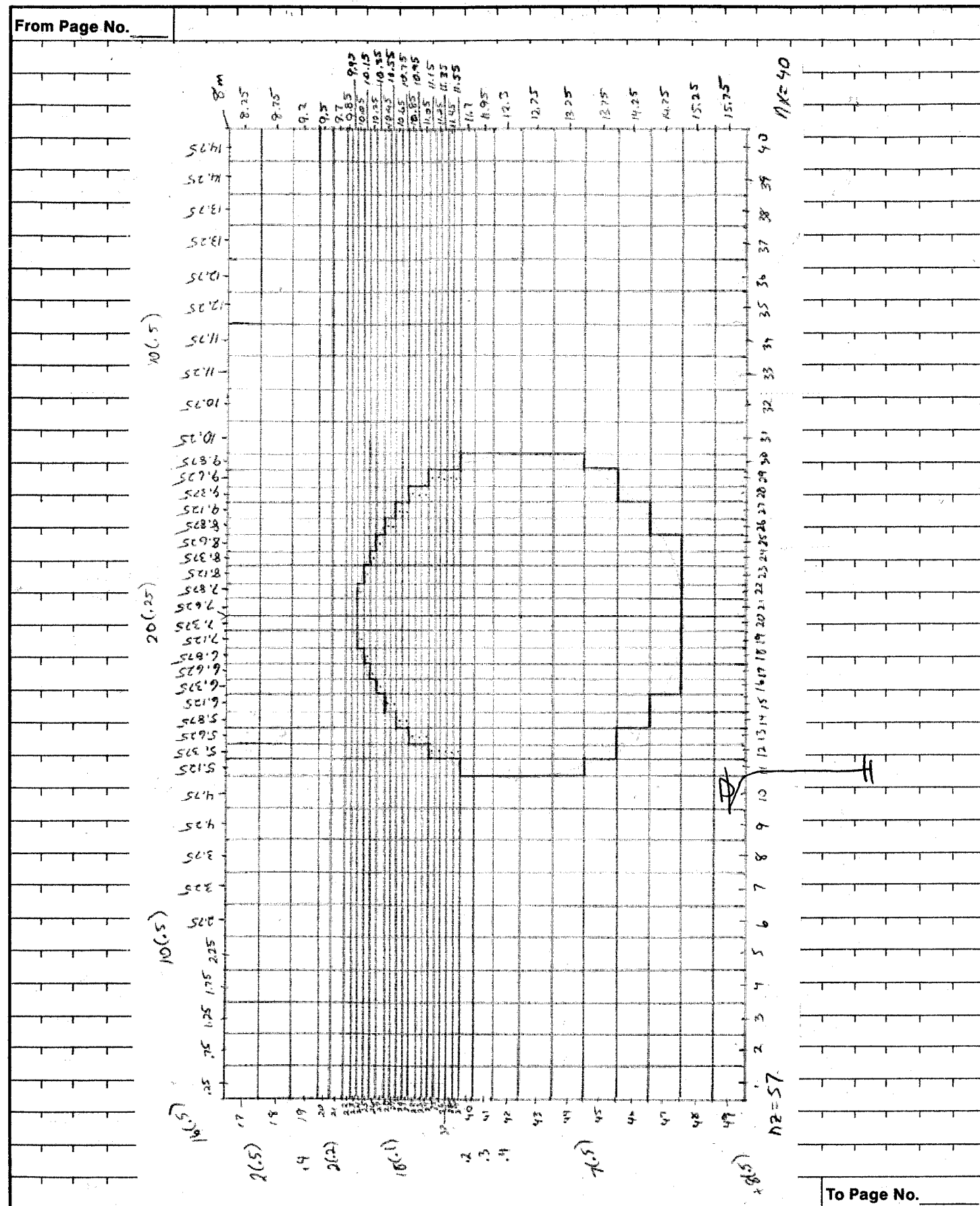
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$$\alpha = \frac{bpg}{20 \cos \theta}$$

b = aperture

$$\rho = 998 \text{ Kg/m}^3$$

$$g = 9.8 \text{ m/s}^2$$

$$\gamma = 0.072 \text{ N/m}$$

 θ = contact angle

$$\frac{\text{m}^3/\text{m}^3}{(\text{Kg m/s}^2)/\text{m}} = \frac{1}{\text{m}}$$

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

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

$$\text{If } b \approx 200 \mu\text{m} \quad 2s \approx 28 \text{ cm}$$

$$b \approx 100 \mu\text{m} \quad 2s \approx 14 \text{ cm}$$

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

3rd refinement Shown on Page 68

$$1.2 \times 10^{-6} \text{ Kg/m}^2/\text{s} = 37.92 \text{ mm/y}$$

$$4.0 \times 10^{-6} \text{ Kg/m}^2/\text{s} = 126.4 \text{ mm/y}$$

$$3.0 \times 10^{-6} \text{ Kg/m}^2/\text{s} = 94.8 \text{ mm/y}$$

$$2.5 \times 10^{-6} \text{ Kg/m}^2/\text{s} = 79 \text{ mm/y}$$

$$2.9 \times 10^{-6} \text{ Kg/m}^2/\text{s} = 91.64 \text{ mm/y}$$

$$2.8 \times 10^{-6} \text{ Kg/m}^2/\text{s} = 88.48 \text{ mm/y}$$

seap

O

83.5 Avg mm/y

8.664 at top Avg 46.6 mm/y

O at top Avg 26.8 mm/y

4.13 at top Avg 42.26 mm/y

O at top Avg 38.48 mm/y

3rd grid refinement file archive

~ dhughson/multi flo/inputbak/multi.24

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12/10/98

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

seep

$1.2e-6 \text{ kg/m}^2/\text{s} = 37.92 \text{ mm/y}$	0 on top	Aug = 42.85 mm/y
$1.3e-6 \text{ kg/m}^2/\text{s} = 41.08 \text{ mm/y}$	0 on top	Aug = 46.85 mm/y
$1.4e-6 \text{ kg/m}^2/\text{s} = 44.24 \text{ mm/y}$	0 on top	Aug = 50.85 mm/y
$1.5e-6 \text{ kg/m}^2/\text{s} = 47.4 \text{ mm/y}$	0 on top	Aug = 54.85 mm/y
$1.6e-6 \text{ kg/m}^2/\text{s} = 50.56 \text{ mm/y}$	0 on top	Aug = 58.84 mm/y
$1.7e-6 \text{ kg/m}^2/\text{s} = 53.72 \text{ mm/y}$	0 on top	Aug = 62.82 mm/y
$1.8e-6 \text{ kg/m}^2/\text{s} = 56.88 \text{ mm/y}$	0 on top	Aug = 66.8 mm/y
$1.9e-6 \text{ kg/m}^2/\text{s} = 60.04 \text{ mm/y}$	0 on top	Aug = 70.78 mm/y
$2.0e-6 \text{ kg/m}^2/\text{s} = 63.2 \text{ mm/y}$	4.6 mm outside top	Aug = 74.5 mm/y
$2.1e-6 \text{ kg/m}^2/\text{s} = 66.36 \text{ mm/y}$	10.75 mm outside top	Aug = 78.12 mm/y
$2.2e-6 \text{ kg/m}^2/\text{s} = 69.52 \text{ mm/y}$	16.82 mm outside top	Aug = 81.74 mm/y
$2.3e-6 \text{ kg/m}^2/\text{s} = 72.68 \text{ mm/y}$	22.89 mm outside top	Aug = 85.37 mm/y
$2.4e-6 \text{ kg/m}^2/\text{s} = 75.84 \text{ mm/y}$	28.94 mm outside top	Aug = 88.99 mm/y
$2.5e-6 \text{ kg/m}^2/\text{s} = 79.0 \text{ mm/y}$	35.02 mm outside top	Aug = 92.61 mm/y
$2.6e-6 \text{ kg/m}^2/\text{s} = 82.16 \text{ mm/y}$	41.08 mm outside top	Aug = 96.23 mm/y
$2.7e-6 \text{ kg/m}^2/\text{s} = 85.32 \text{ mm/y}$	47.15 mm outside top	Aug = 99.84 mm/y
$2.8e-6 \text{ kg/m}^2/\text{s} = 88.48 \text{ mm/y}$	53.21 mm outside top	Aug = 103.45 mm/y
$2.9e-6 \text{ kg/m}^2/\text{s} = 91.64 \text{ mm/y}$	59.27 mm outside top	Aug = 107.06 mm/y
$3.0e-6 \text{ kg/m}^2/\text{s} = 94.80 \text{ mm/y}$	65.34 mm outside top	Aug = 110.67 mm/y
$3.1e-6 \text{ kg/m}^2/\text{s} = 97.96 \text{ mm/y}$	2.68 mm on top	Aug = 114.25 mm/y

~ dhuahson/multiflo/inputbak/multi. 25

1st grid refinement shown on Page 19
base case properties $\alpha = 9.7e-4 \text{ Pa}^{-1}$ $m = 0.63$ $K = 10^{-13} \text{ m}^2$

seep

$3.1e-7 \text{ kg/m}^2/\text{s} = 9.99 \text{ mm/y}$	9.79 mm on top	Aug = 11.82 mm/y
$9.5e-10 \text{ kg/m}^2/\text{s} = 0.03 \text{ mm/y}$	0 on top	Aug = 0
$9.5e-9 \text{ kg/m}^2/\text{s} = 0.3 \text{ mm/y}$	0.24 mm on top	Aug = 0.27 mm/y
$1.9e-9 \text{ kg/m}^2/\text{s} = 0.06 \text{ mm/y}$	0.13 mm on top	Aug = 0.015 mm/y
$1.8e-9 \text{ kg/m}^2/\text{s} = 0.569 \text{ mm/y}$	0.10 mm on top	Aug = 0.012 mm/y
$1.7e-9 \text{ kg/m}^2/\text{s} = 0.537 \text{ mm/y}$	0.0674 mm on top	Aug = 0.0093 mm/y

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$1.6e-9 \text{ kg/m}^2/\text{s} = 0.0506 \text{ mm/y}$	0.0035 mm on top	Aug = 0.0068 mm/y
$1.5e-9 \text{ kg/m}^2/\text{s} = 0.0474 \text{ mm/y}$	2.25e-4 mm on top	Aug = 4.4e-3 mm/y
$1.4e-9 \text{ kg/m}^2/\text{s} = 0.0442 \text{ mm/y}$	0 on top	Aug = 2.25e-3 mm/y

~ dhuahson/multiflo/inputbak/multi. 26

Dec 21, 1998 Drip Shop Start 8:15 AM

Run - overview

Run - 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 discussions 8:10 AM

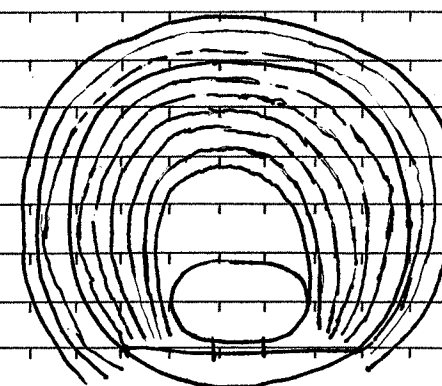
unstructured grid refinement for seepage models

100% RH same as being in water

50% RH & above important

fracture clusters - fractures through P+H

how many containers get wet how much water falls on these canisters



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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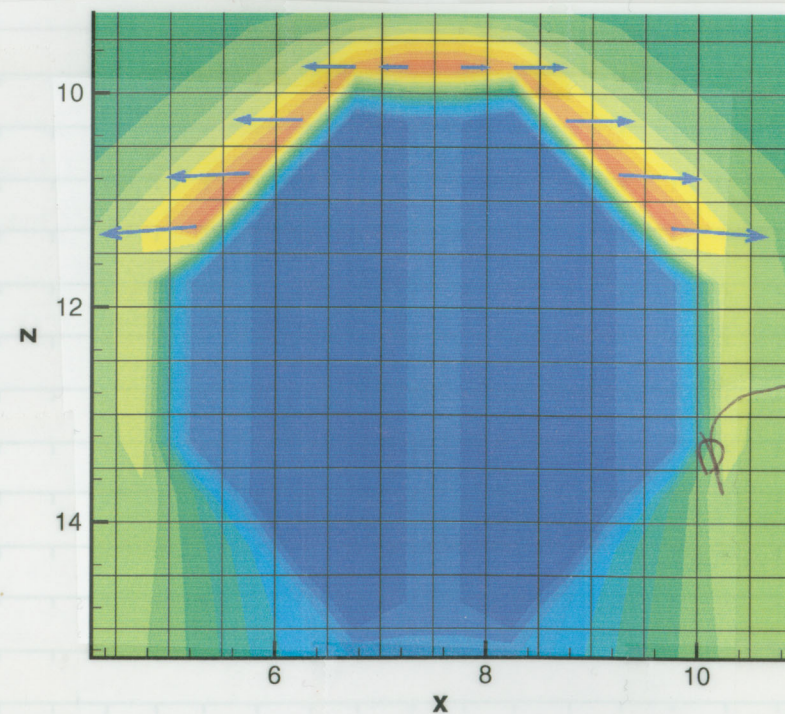
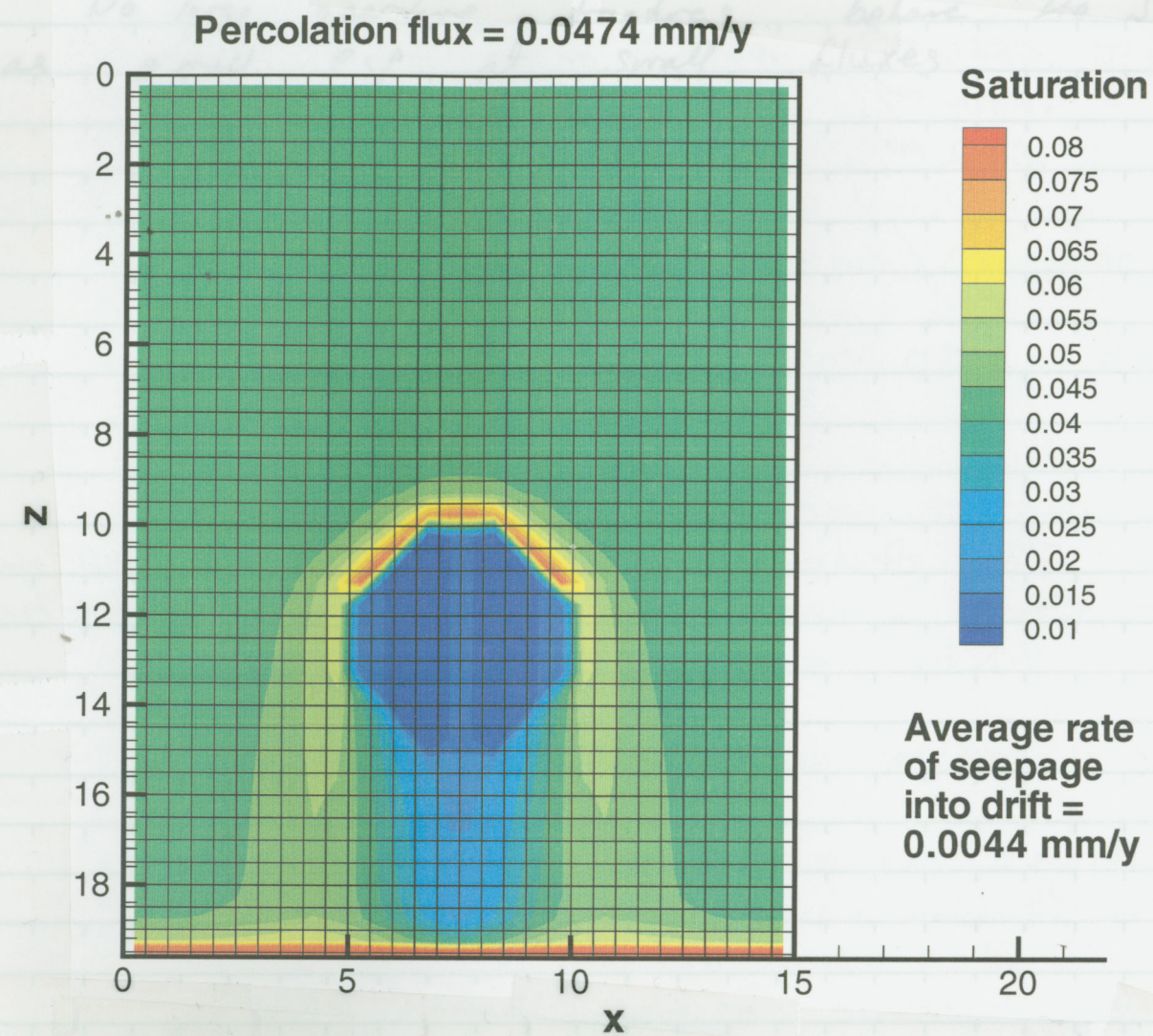
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From



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Dec 21, 1998
~ dhughson/multiflo/
seep/stucapdr

refine 1. pit
refine 1. lay
refine 1. prt
close 1. prt

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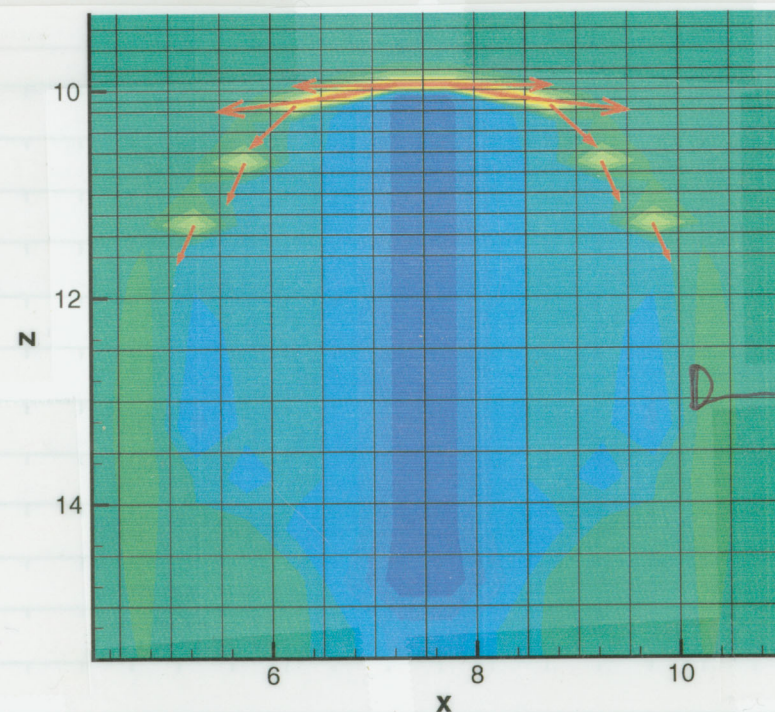
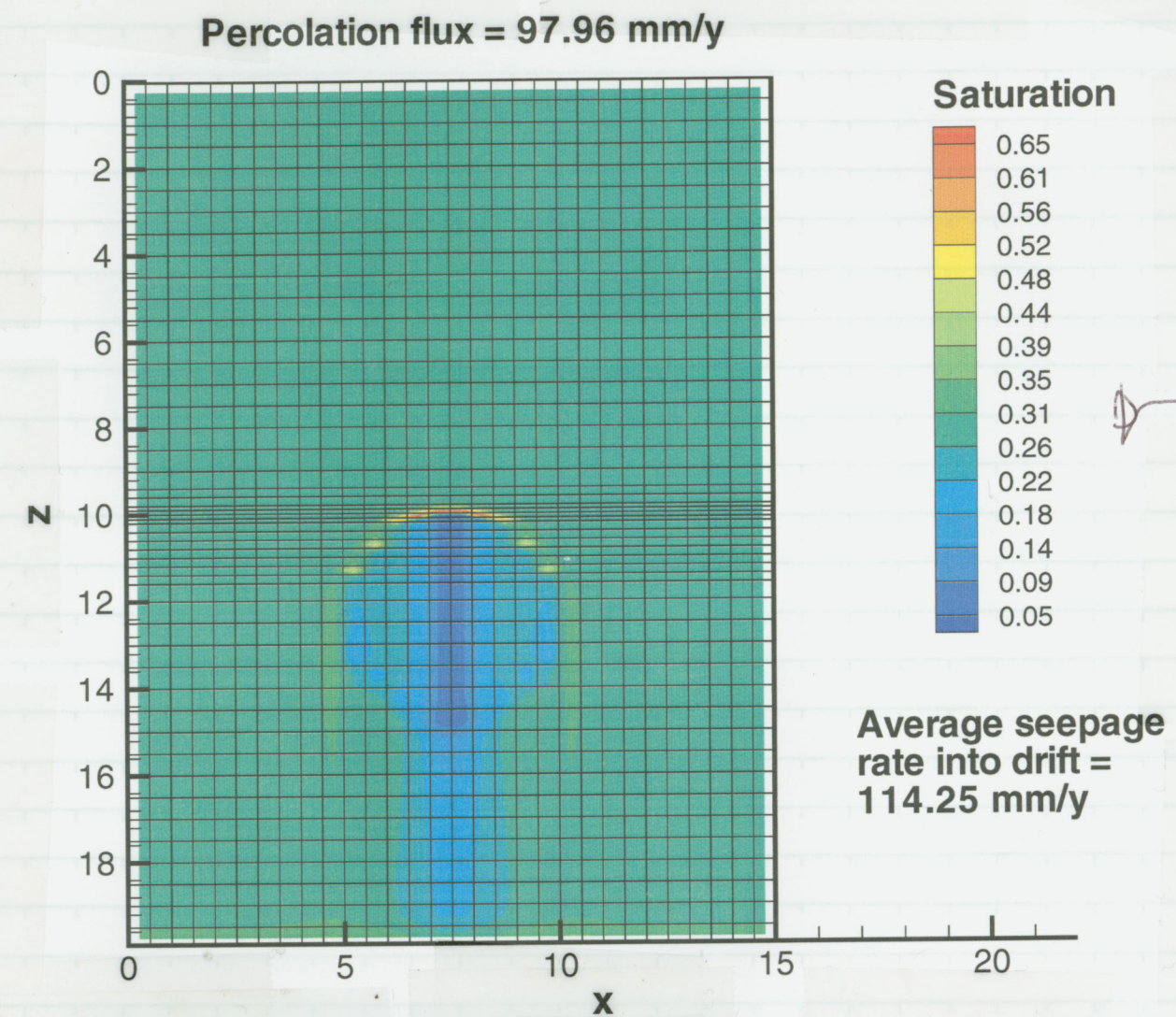
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Dec 30
1998

From



Presented at dripshop
Dec 21, 1998
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seep/stucapdr

refine 2. pit
refine 2. lay
refine 2. prt
close 2. prt

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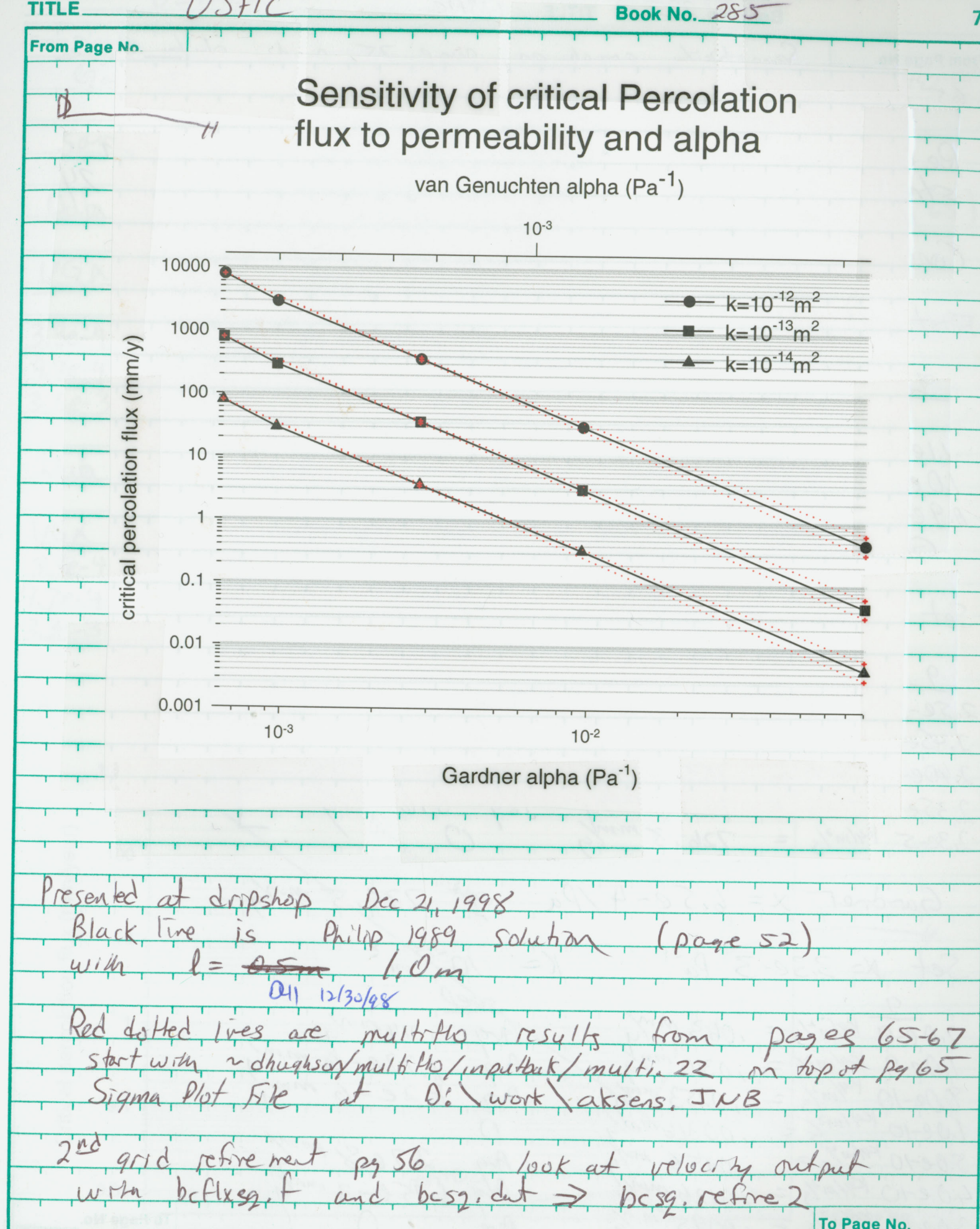
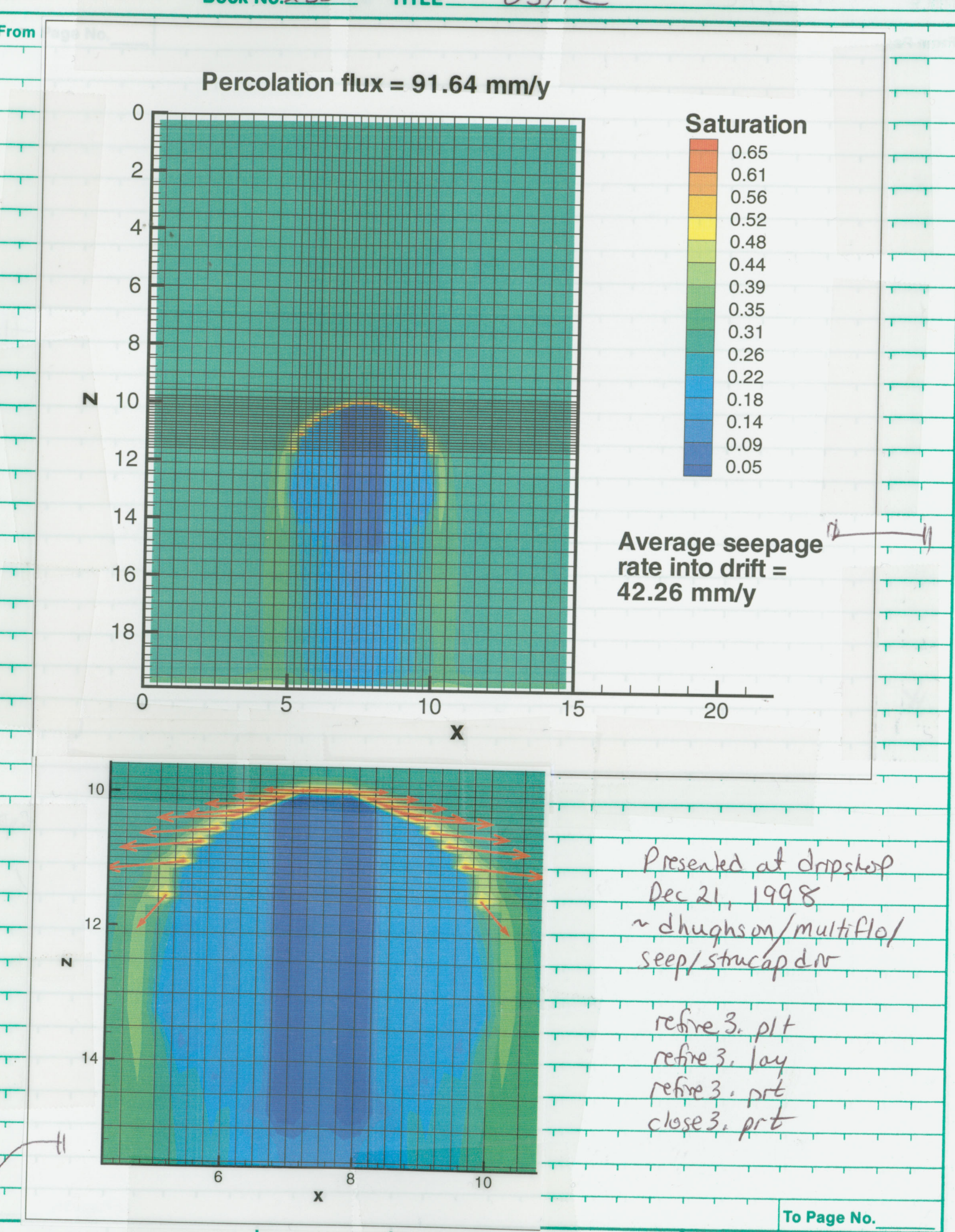
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Sensitivity graph on page 75 and data pages 65 to 67 done with grid refinement 2 pg 56

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

q DA 12/1/98

seep

$1.1e-6 \text{ kg/m}^2/\text{s} = 34.8 \text{ mm/y}$ Avg = 3.14 mm/y
 $1.0e-6 \text{ kg/m}^2/\text{s} = 31.6 \text{ mm/y}$ Avg = 1.38 mm/y
 $0.9e-6 \text{ kg/m}^2/\text{s} = 28.44 \text{ mm/y}$ 0
 Gardner $\alpha = 3.1e-3 \text{ Pa}$ $q^* = 29.7 \text{ mm/y}$

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

q

seep

$2.5e-5 \text{ kg/m}^2/\text{s} = 790 \text{ mm/y}$ Avg 33.2 mm/y
 $2.45e-5 \text{ kg/m}^2/\text{s} = 774.2 \text{ mm/y}$ Avg 24.0 mm/y
 $2.40e-5 \text{ kg/m}^2/\text{s} = 758.4 \text{ mm/y}$ Avg 14.8 mm/y
 $2.35e-5 \text{ kg/m}^2/\text{s} = 742.6 \text{ mm/y}$ Avg 5.6 mm/y
 $2.3e-5 \text{ kg/m}^2/\text{s} = 726.8 \text{ mm/y}$ 0

Gardner $\alpha = 6.5e-4 \text{ Pa}$ $q^* = 738.5 \text{ mm/y}$

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

q

seep

$2.0e-9 \text{ kg/m}^2/\text{s} = .063 \text{ mm/y}$ Avg .014 mm/y
 $1.0e-9 \text{ kg/m}^2/\text{s} = .0316 \text{ mm/y}$ Avg $1.77e-6 \text{ mm/y}$
 $8.0e-10 \text{ kg/m}^2/\text{s} = .0253 \text{ mm/y}$ Avg $8.2e-6 \text{ mm/y}$
 $1.0e-10 \text{ kg/m}^2/\text{s} = .00316 \text{ mm/y}$ 0
 $5.0e-10 \text{ kg/m}^2/\text{s} = .0158 \text{ mm/y}$ Avg $2.7e-8 \text{ mm/y}$
 $4.0e-10 \text{ kg/m}^2/\text{s} = .0126 \text{ mm/y}$ Avg $6.75e-3 \text{ mm/y}$
 $3.0e-10 \text{ kg/m}^2/\text{s} = .0095 \text{ mm/y}$ Avg 0

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Gardner $\alpha = \cancel{5 \times 10^{-1} \text{ Pa}^{-1}} q^* = 1.7e-1 \text{ Pa}$ $q^* = .00997 \text{ mm/y}$
DA 12/31/98

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

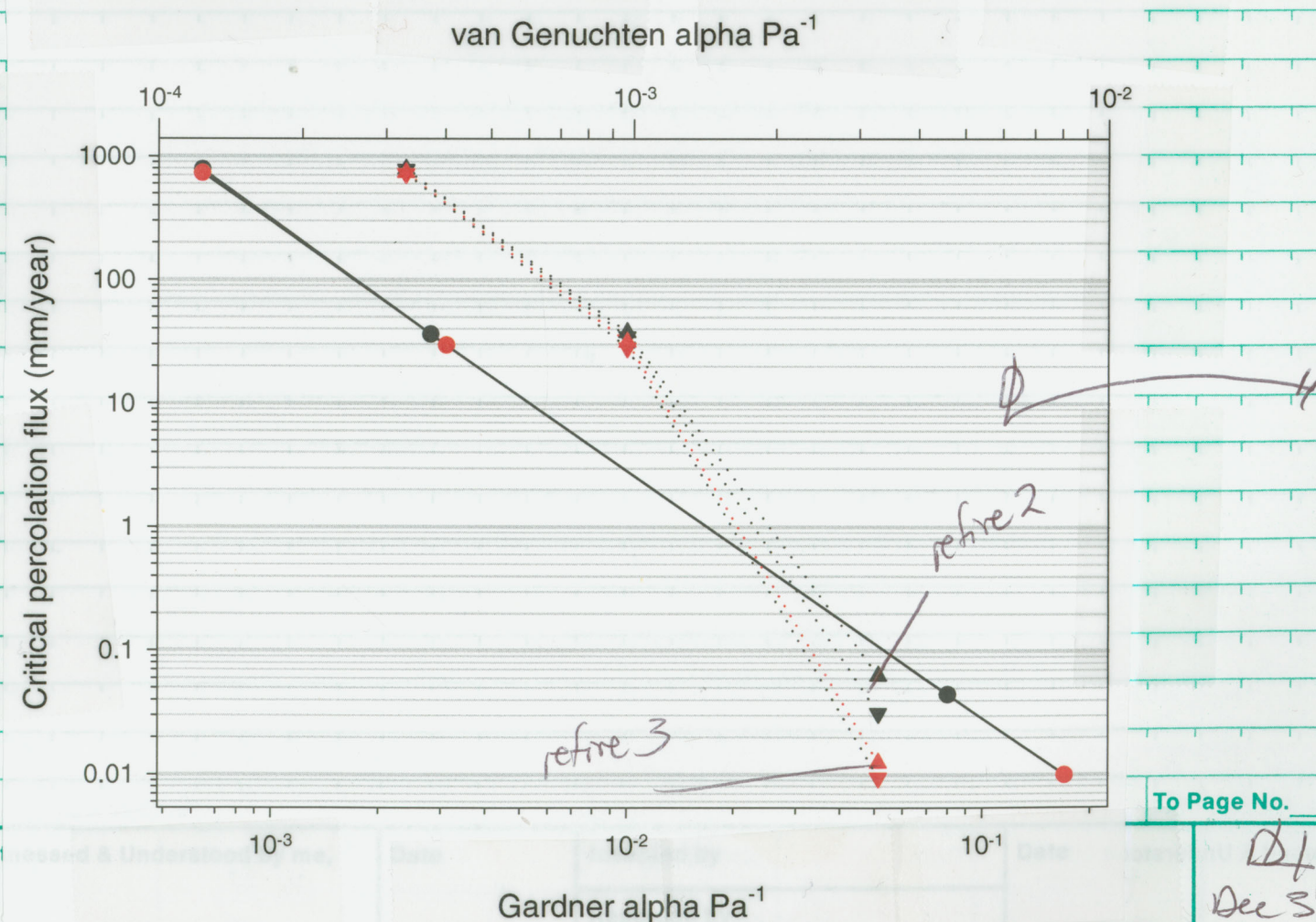
Data for refine 2 set $\alpha = 9.7e-4$ $K = 10^{-13} \text{ m}^2$ (pg 65)

DA 12/31/98

UGA	Hi	Low	GK	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 $K = 10^{-13} \text{ m}^2$ (pg 76)

UGA	Hi	Low	GK	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	1.7e-1	.00997



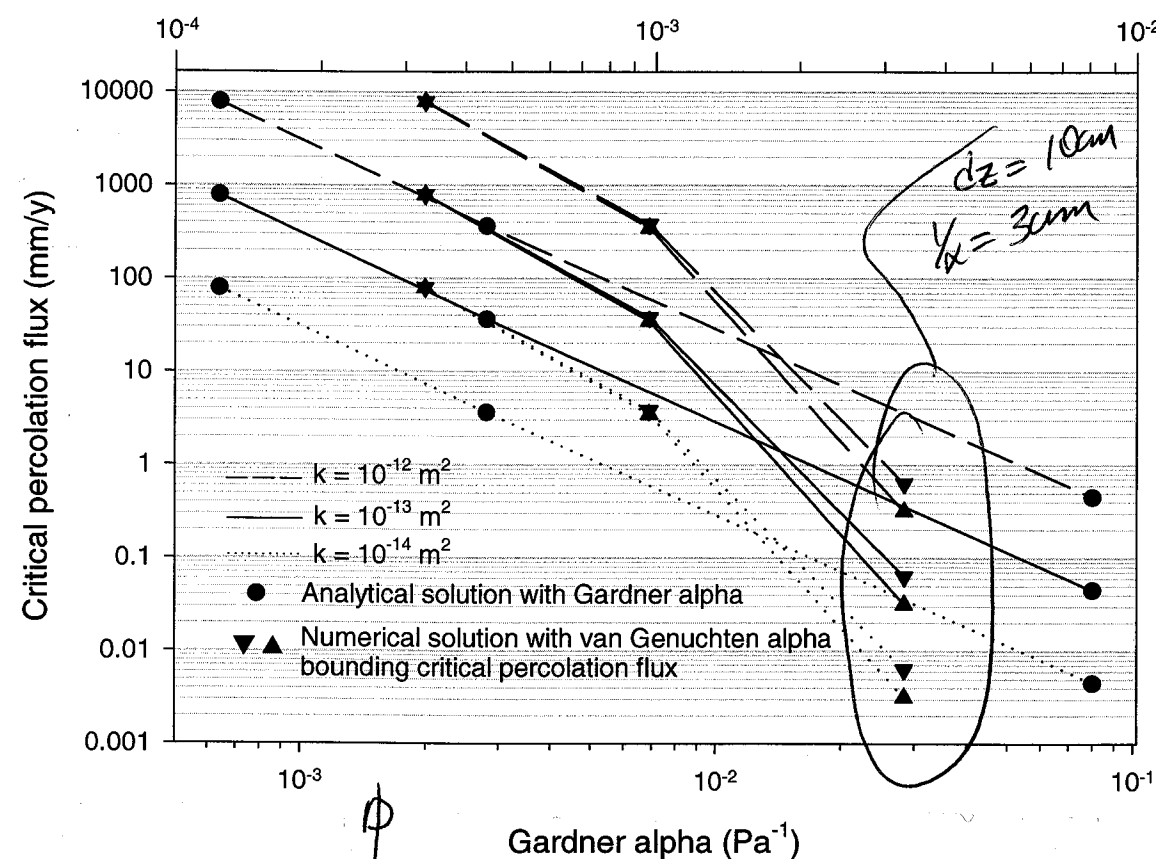
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DA
Dec 31

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Plot on page 25 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

van Genuchten alpha (Pa^{-1})

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1998

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Grid refinement #4 from refine 2 pay 56

 $\alpha = 3.3 \times 10^{-3} \text{ Pa}^{-1}$ capillary rise $\sim 3\text{cm}$

	9.9	
23	1.05	9.95 23 - 9.925
	1.025	9.975 24 - 9.9625
	1.025	10.0 25 - 9.9875
24	1.025	10.025 26 -
	1.025	10.05 27
	1.05	28
ALL 4 rows at next column	10.1	29
DH 1/4/99		

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

3.16e-8 $\text{Pa/m}^2/\text{s}$	= 1.0 mm/y	seep
6.33e-8 $\text{Pa/m}^2/\text{s}$	= 2.0 mm/y	0
9.49e-8 $\text{Pa/m}^2/\text{s}$	= 3.0 mm/y	0
1.27e-7 $\text{Pa/m}^2/\text{s}$	= 4.01 mm/y	0
3.16e-7 $\text{Pa/m}^2/\text{s}$	= 10 mm/y	Ag 2.7 mm/y
1.58e-7 $\text{Pa/m}^2/\text{s}$	= 5 mm/y	0
1.9e-7 $\text{Pa/m}^2/\text{s}$	= 6 mm/y	Ag = 5.6e-2 mm/y

 $k = 10^{-12} \text{ m}^2$ $\alpha = 3.3 \times 10^{-3} \text{ Pa}^{-1}$

1.9e-6 $\text{Pa/m}^2/\text{s}$	= 60.04 mm/y	seep
1.6e-6 $\text{Pa/m}^2/\text{s}$	= 50.56 mm/y	Aug = 0.56 mm/y
		0

 $k = 10^{-14} \text{ m}^2$ $\alpha = 3.3 \times 10^{-3} \text{ Pa}^{-1}$

1.9e-8 $\text{Pa/m}^2/\text{s}$	= 0.6 mm/y	seep
1.7e-8 $\text{Pa/m}^2/\text{s}$	= 0.537 mm/y	5.6e-3 mm/y
		0

 $\sim \text{dhughson/multiFlo/inputbak/multi.29}$

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1999

From Page No. Grid refine 4

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

$$\begin{aligned} \frac{q}{K} &= 2.0e-7 \text{ m/s} = 6.3 \text{ mm/y} \\ \frac{q}{K} &= 3.0e-7 \text{ m/s} = 9.48 \text{ mm/y} \\ \frac{q}{K} &= 4.0e-7 \text{ m/s} = 12.64 \text{ mm/y} \\ \frac{q}{K} &= 5.0e-7 \text{ m/s} = 15.8 \text{ mm/y} \end{aligned} \quad \left. \begin{array}{l} \text{seep} \\ 0 \\ 0 \\ 0 \end{array} \right\} \text{Avg. } 8.26 \text{ mm/y}$$

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

$$\begin{aligned} \frac{q}{K} &= 4.0e-6 \text{ m/s} = 126.4 \text{ mm/y} \\ \frac{q}{K} &= 5.0e-6 \text{ m/s} = 158.0 \text{ mm/y} \end{aligned} \quad \left. \begin{array}{l} \text{seep} \\ 0 \\ 8.26 \text{ mm/y} \end{array} \right\}$$

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

$$\begin{aligned} \frac{q}{K} &= 4.0e-5 \text{ m/s} = 1264 \text{ mm/y} \\ \frac{q}{K} &= 4.5e-5 \text{ m/s} = 1422 \text{ mm/y} \\ \frac{q}{K} &= 4.7e-5 \text{ m/s} = 1485 \text{ mm/y} \end{aligned} \quad \left. \begin{array}{l} \text{seep} \\ 0 \\ 0 \\ 14.56 \text{ mm/y} \end{array} \right\}$$

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

$$\begin{aligned} \frac{q}{K} &= 3.1e-4 \text{ m/s} = 9985 \text{ mm/y} \\ \frac{q}{K} &= 4.0e-4 \text{ m/s} = 12640 \text{ mm/y} \\ \frac{q}{K} &= 3.5e-4 \text{ m/s} = 11060 \text{ mm/y} \\ \frac{q}{K} &= 3.4e-4 \text{ m/s} = 10744 \text{ mm/y} \end{aligned} \quad \left. \begin{array}{l} \text{seep} \\ 0 \\ \text{Avg} = 1263 \text{ mm/y} \\ \text{Avg} = 80 \text{ mm/y} \\ 0 \end{array} \right\}$$

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

$$\begin{aligned} \frac{q}{K} &= 3.4e-5 \text{ m/s} = 1074.4 \text{ mm/y} \\ \frac{q}{K} &= 3.5e-5 \text{ m/s} = 1106 \text{ mm/y} \end{aligned} \quad \left. \begin{array}{l} \text{seep} \\ 0 \text{ all } 11/6/99 \\ \text{Avg } 8.04 \text{ mm/y} \end{array} \right\}$$

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

$$\begin{aligned} \frac{q}{K} &= 3.5e-6 \text{ m/s} = 110.6 \text{ mm/y} \\ \frac{q}{K} &= 3.4e-6 \text{ m/s} = 107.4 \text{ mm/y} \end{aligned} \quad \left. \begin{array}{l} \text{seep} \\ 8.04 \text{ mm/y} \\ 0 \end{array} \right\}$$

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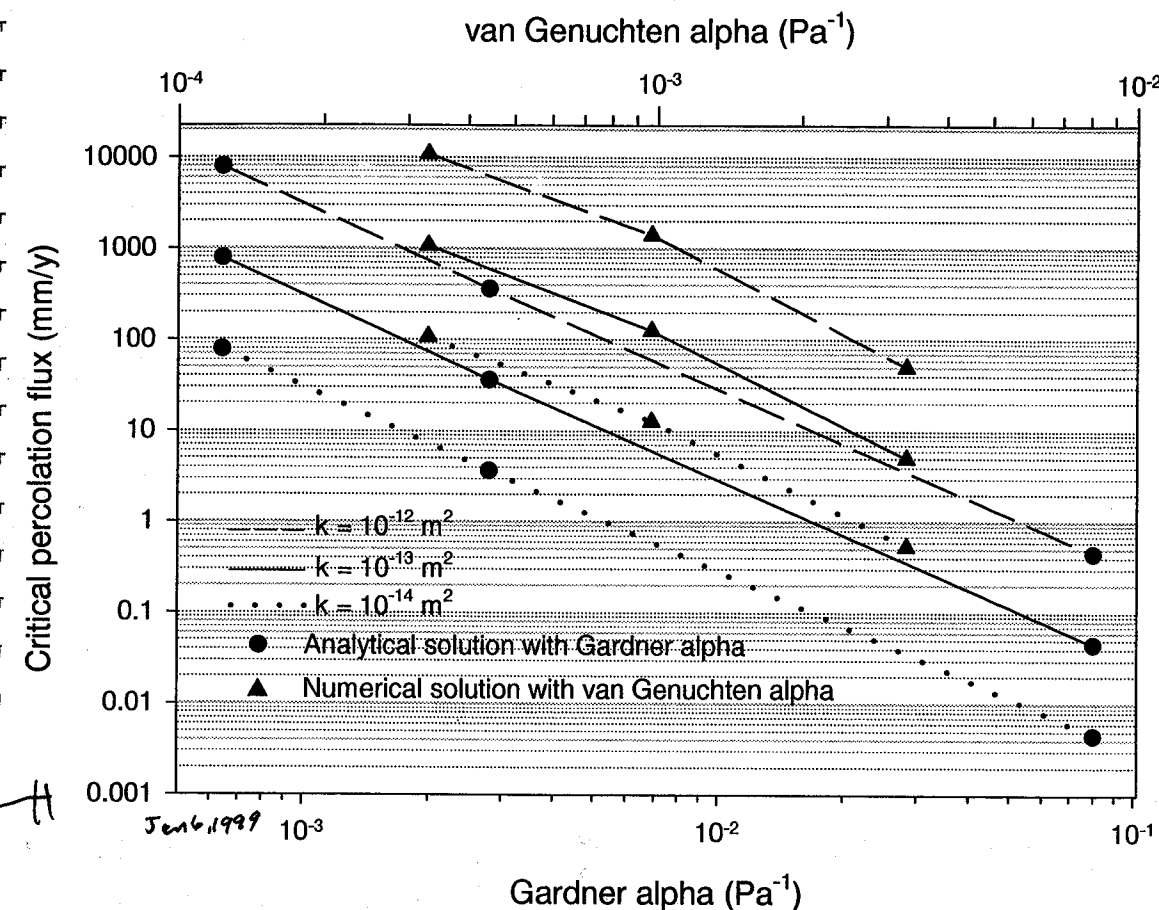
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Grid Refine 4

Sensitivity of critical percolation flux to permeability and alpha



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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 Richards Eq. transformed to Helmholtz in polar coord. and find solution for perturbation in boundary shape.

Approach 2 Use multiblock with structured and unstructured grid.

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Approach 2A - Multiblock with unstructured grid shown on following pages

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

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	0
2.1e-5	0
2.2e-5	0
2.3e-5	0
2.4e-5	0
2.5e-5	0
2.6e-5	0

632 mm/y
790 mm/y
822 mm/y
top 2 blocks 3.82e-3 each

7.91e-6 250 mm/y

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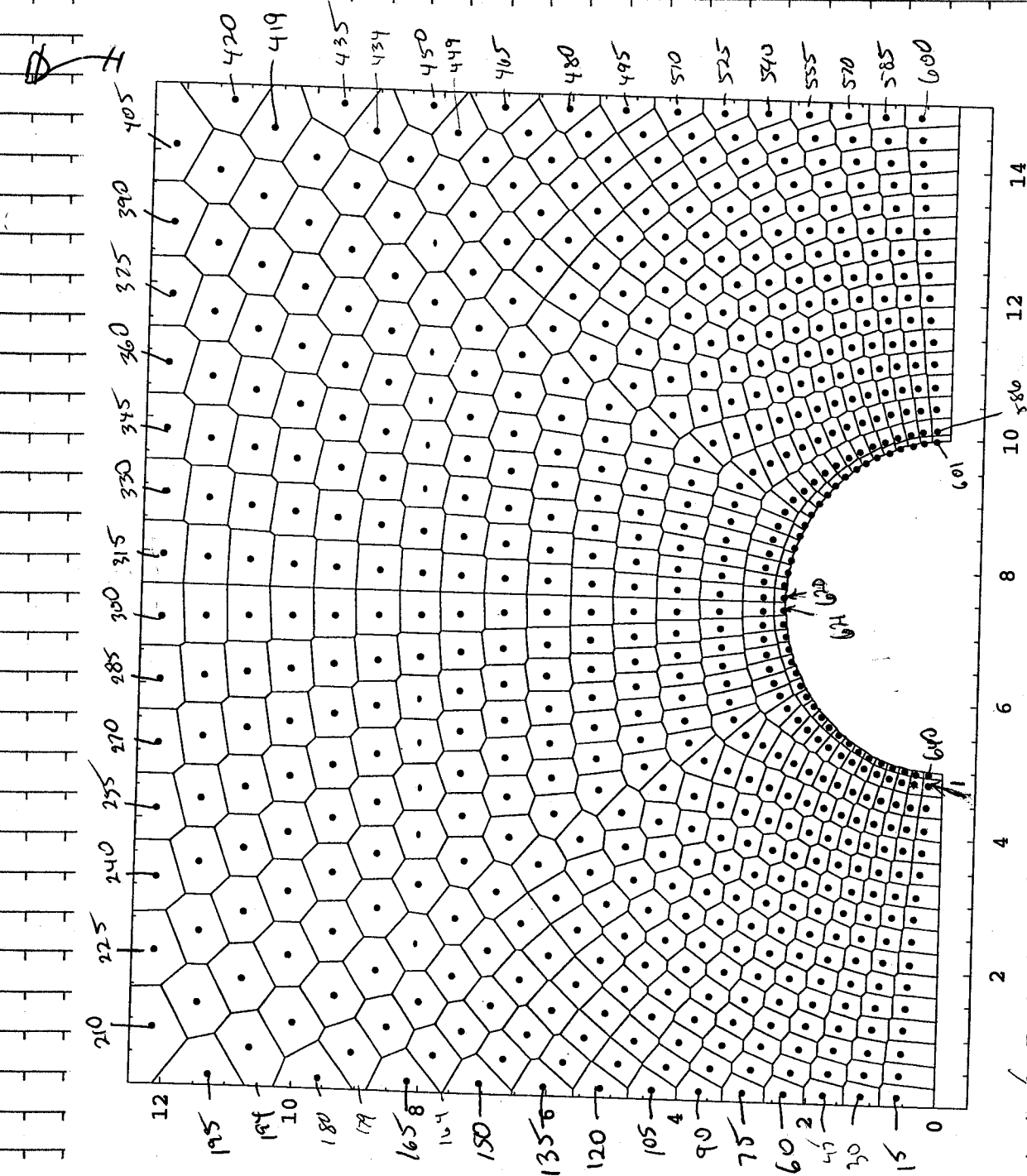
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For the unstructured grid, look for flux which results in $S_p \approx 1$ $P_c \approx 0$ at nodes 620, 621
BC at TOP type 3 liquid vel in m/year

Q_{BC}	S_p	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_p at bottom boundary from 0.5 to 0.8
 $3.5e-1$ 0.9995 76.27

Change S_p at bottom bndr from 0.8 to 0.9
 $3.5e-1$ 0.9992 89.32

Change S_p 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_q on the boundary, not S_p

S_p on bottom bndry = 0.9 $S_q = 0.1$
 $3.5e-1$ 1.0 0
 $3.0e-1$ 1.0 0
 $2.5e-1$ 0.9998 50.80

$0.25 \text{ m/year} = 250 \text{ mm/year}$

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 Multfho) to compare with Philip's solution

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

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

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

$$UG \quad \frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{S - S_r}{1 - S_r} = \left[1 + (\alpha|P_c|)^m\right]^{\frac{1}{m}-1} = S_e \quad \text{confusion up to } m=5$$

$$K(\psi) = K_s \sqrt{S_e} \left(1 - (1 - S_e)^{\frac{1}{m}}\right)^2$$

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

Plotting K vs P_c for UG and GR (von Genuchten & Gardner-Russell). I find that

$\alpha_0 = 4.85e-4 / Pa$ gives approximately similar behavior near $P_c = 0$ $S_e = 1$ as does $UG = 9.7e-4 Pa^{-1}$

$$Pa = \frac{M}{m^2} = \frac{kg \cdot m/s^2}{m^2} = \frac{kg}{m \cdot s^2} \quad \left(4.85e-4 \frac{ms^2}{kg}\right) \left(\frac{998 kg}{m^3}\right) \left(\frac{9.8 m}{s^2}\right) = 4.74 m^{-1}$$

$$1e-13 m^2 \left(\frac{998 kg}{m^3}\right) \frac{9.8 m/s^2}{1.19e-3 \frac{kg}{m \cdot s}} \frac{1000 mm}{m} (60 \cdot 60 \cdot 24 \cdot 365)^{\frac{2}{3}} = 2.756e4 \frac{mm}{yr}$$

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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
$1.0e-2 m/yr = 10 mm/yr$		1.5131e4 Pa	0.3554
$1.0e-1 m/yr = 100 mm/yr$		4565	0.6025
$1.0 m/yr = 1000 mm/yr$		0	1.0
$0.5 m/yr = 500 mm/yr$		0	1.0
$0.2 m/yr = 200 mm/yr$		2054	0.8405
$0.3 m/yr = 300 mm/yr$		1019	0.9323
$0.4 m/yr = 400 mm/yr$		345.6	0.9808
$0.44 m/yr = 440 mm/yr$		132.1	0.9932
$0.46 = 460 mm/yr$		0	1.0
$4.85e-4 \frac{ms^2}{kg} \frac{998 kg}{m^3} \frac{9.8 m}{s^2} = 4.74 m^{-1} = \alpha_0$			

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

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

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

$$0.45 m/yr \quad 450 mm/yr \quad 0 \quad 1.0$$

- 3) Saturation - Pressure relationship for Gardner model

First, change top BC from type 3 to type 5

Units $kg/m^2/s$ Top area $(15m)(10m) = 150 m^2$

$$(0.4 m/yr) \left(\frac{998 kg}{m^3}\right) \frac{1}{60 \cdot 60 \cdot 24 \cdot 365 s} = 1.266e-5 kg/m^2/s$$

$$1.266e-5 \frac{kg}{m^2/s} = 400 mm/yr \quad P_c \quad S_e \quad \text{Type 5 BC}$$

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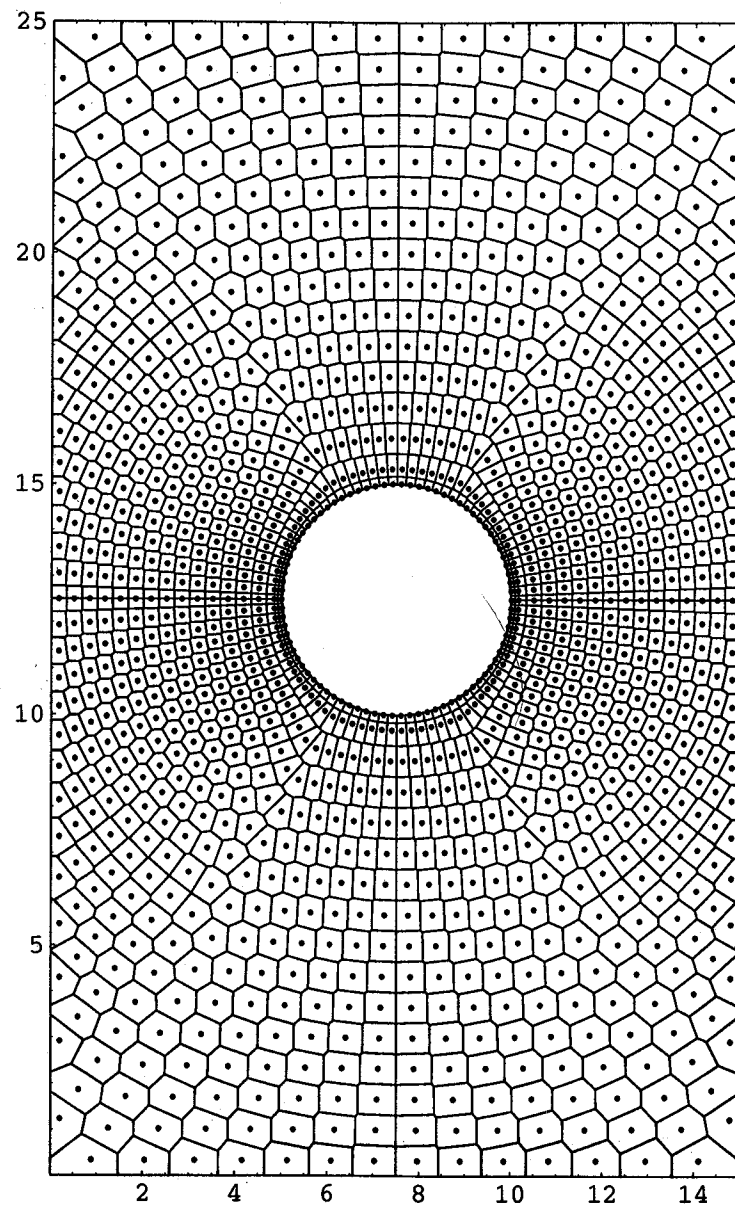
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From Page No. April 5, 1999

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

Plus P_c S_0
 $1.2662-5 \text{ kg/m}^2/\text{s} = 400 \text{ mm/yr}$ 565.4 1.9664
change bottom BC from $S_g = 0.6$ to $S_g = 0.05$
 $1.2662-5 \text{ kg/m}^2/\text{s} = 400 \text{ mm/yr}$ 0 1.0



Input file using this grid
 $R = 25\text{m}$
~dhughson/multiFlo/inputbak/multi.30

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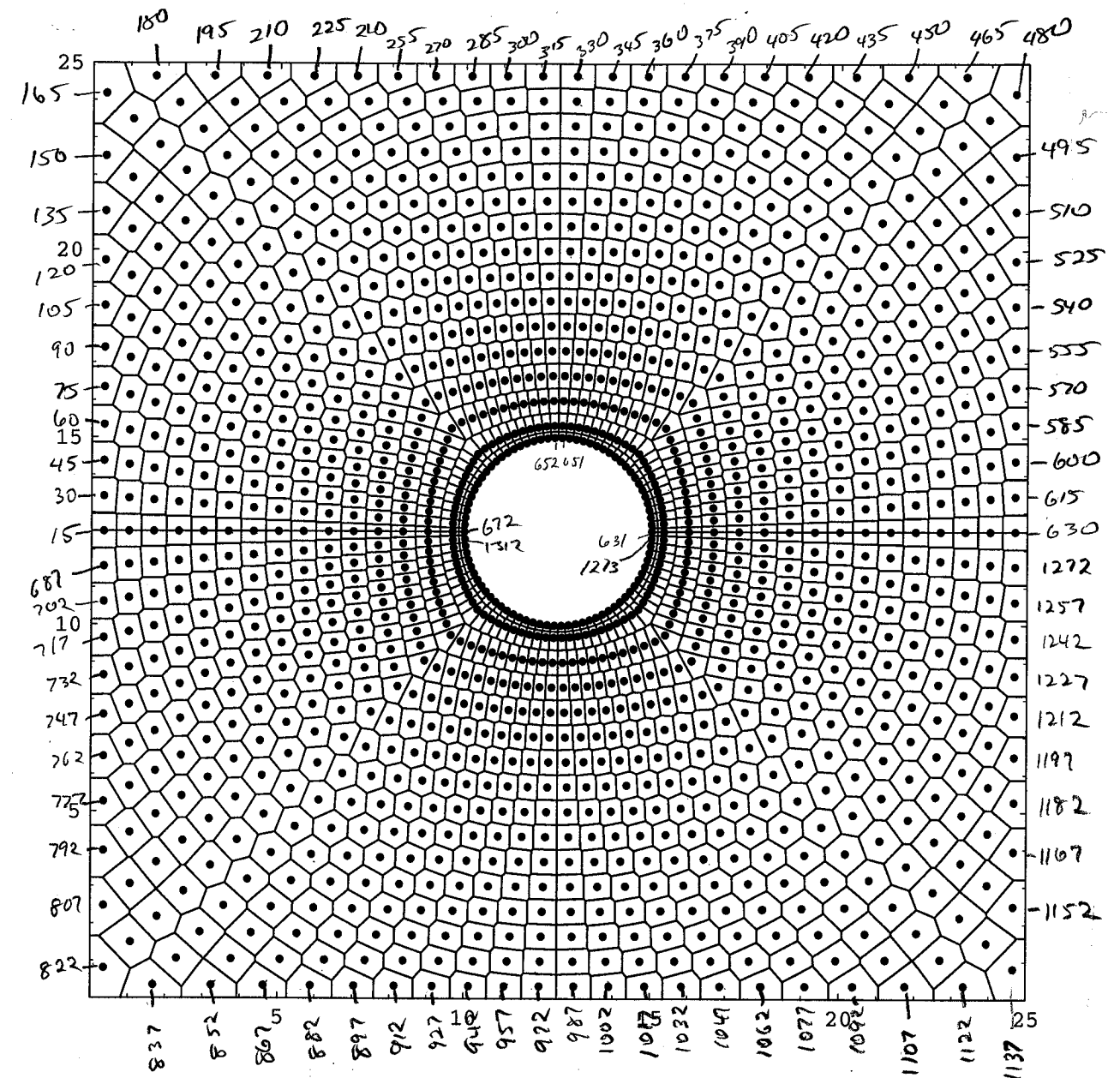
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threshold on page 93-94

~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	S_e
$1.266e-6 \text{ kg/m}^2/\text{s}$		705.8	.8260

Mohan has corrected some errors in metra. The $25\text{m} \times 5\text{m}$ test case I created to compare structured & unstructured grid results shows identical results.

~ dhughan/multiflo/kest test-str. dat
test-uns. dat

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

Flux	at node 651, 652	P_c	S_e
$1.266e-6 \text{ kg/m}^2/\text{s} = 40 \text{ mm/yr}$		1534	.4282
$1.266e-5 \text{ kg/m}^2/\text{s} = 400 \text{ mm/yr}$		846	.7504
$4.0e-5 \text{ kg/m}^2/\text{s} = 1264 \text{ mm/yr}$		440.9	.9417
$4.2e-5 \text{ kg/m}^2/\text{s} = 1327 \text{ mm/yr}$		418.6	.949
$4.5e-5 \text{ kg/m}^2/\text{s} = 1422 \text{ mm/yr}$		385.4	.9587
$4.9e-5 \text{ kg/m}^2/\text{s} = 1548 \text{ mm/yr}$		341.3	.9698
$5.5e-5 \text{ kg/m}^2/\text{s} = 1740 \text{ mm/yr}$		273.8	.983
$5.7e-5 \text{ kg/m}^2/\text{s} = 1801 \text{ mm/yr}$		250.5	.9866
$6.1e-5 \text{ kg/m}^2/\text{s} = 1927.6 \text{ mm/yr}$		201.6	.9925
$6.2e-5 \text{ kg/m}^2/\text{s} = 1959 \text{ mm/yr}$		188.8	.9937
$6.4e-5 \text{ kg/m}^2/\text{s} = 2022 \text{ mm/yr}$		162.1	.9958
$6.6e-5 \text{ kg/m}^2/\text{s} = 2085.5 \text{ mm/yr}$		133.7	.9975
$6.8e-5 \text{ kg/m}^2/\text{s} = 2149 \text{ mm/yr}$		103.0	.9988
$7.0e-5 \text{ kg/m}^2/\text{s} = 2212 \text{ mm/yr}$		68.97	.9996

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Flux	at node 651, 652	P_c	S_e
$7.1e-5 \text{ kg/m}^2/\text{s} = 2243.5 \text{ mm/yr}$		50.25	.9998
$7.2e-5 \text{ kg/m}^2/\text{s} = 2275 \text{ mm/yr}$		49.92	.9999
$7.3e-5 \text{ kg/m}^2/\text{s} = 2307 \text{ mm/yr}$		very slow to	

Flux entered as $\text{kg/m}^2/\text{s}$ & converted to mm/yr
 by $\frac{\text{m}^3}{998 \text{ kg}} \cdot \frac{60 \text{ s}}{\text{min}} \cdot \frac{60 \text{ min}}{\text{hr}} \cdot \frac{24 \text{ hr}}{\text{day}} \cdot \frac{365 \text{ day}}{\text{yr}}$

Using Table Lookup for Gardner-Russo model model
 Density 998.3 kg/m^3

Flux	P_c	S_e
$6.4e-5 \text{ kg/m}^2/\text{s}$	2022 mm/yr	108.5
$7.5e-5 \text{ kg/m}^2/\text{s}$	2369 mm/yr	755.9
$8.5e-5 \text{ kg/m}^2/\text{s}$	2685 mm/yr	496.2
$9.5e-5 \text{ kg/m}^2/\text{s}$	3000 mm/yr	264.8
$1.05e-4 \text{ kg/m}^2/\text{s}$	3317 mm/yr	58.65
$1.10e-4 \text{ kg/m}^2/\text{s}$	3475 mm/yr	0
$1.07e-4 \text{ kg/m}^2/\text{s}$	3380 mm/yr	9.6
$1.08e-4 \text{ kg/m}^2/\text{s}$	3412 mm/yr	0
$1.075e-4 \text{ kg/m}^2/\text{s}$	3396 mm/yr	9.982
$1.079e-4 \text{ kg/m}^2/\text{s}$	3408.5 mm/yr	stuck in convergence
$1.078e-4 \text{ kg/m}^2/\text{s}$	3405 mm/yr	4.226

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

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

$$K = \frac{K_{rg}}{\mu} = \frac{(1 \times 10^{-13} \text{ m}^2) (998.21 \frac{\text{kg}}{\text{m}^3}) (9.8 \text{ m/s}^2)}{1002 \times 10^{-6} \frac{\text{kg}\cdot\text{m}}{\text{s}^2}} = 9.763 \times 10^{-9} \frac{\text{m}}{\text{s}}$$

$60 \cdot 60 \cdot 24 \cdot 365 \cdot 1000$

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

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

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

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

Philip threshold = 2257.6 mm/yr

From MF 3408 mm/yr

archive
~ dhuughson/
multi flo / input bak /
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 $1e-14 \text{ m}^2$
Philip threshold = 225.76 mm/yr

Flux	P	Se
$9.0e-6 \text{ kg/m}^2/\text{s} = 284.3 \frac{\text{mm}}{\text{yr}}$	376.4	9790
$1.0e-5 \text{ kg/m}^2/\text{s} = 315.9 \frac{\text{mm}}{\text{yr}}$	159.3	9918
$1.07e-5 \text{ kg/m}^2/\text{s} = 338.0 \frac{\text{mm}}{\text{yr}}$	19.61	990
$1.078e-5 \text{ kg/m}^2/\text{s} = 340.6 \frac{\text{mm}}{\text{yr}}$	4.235	9998

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

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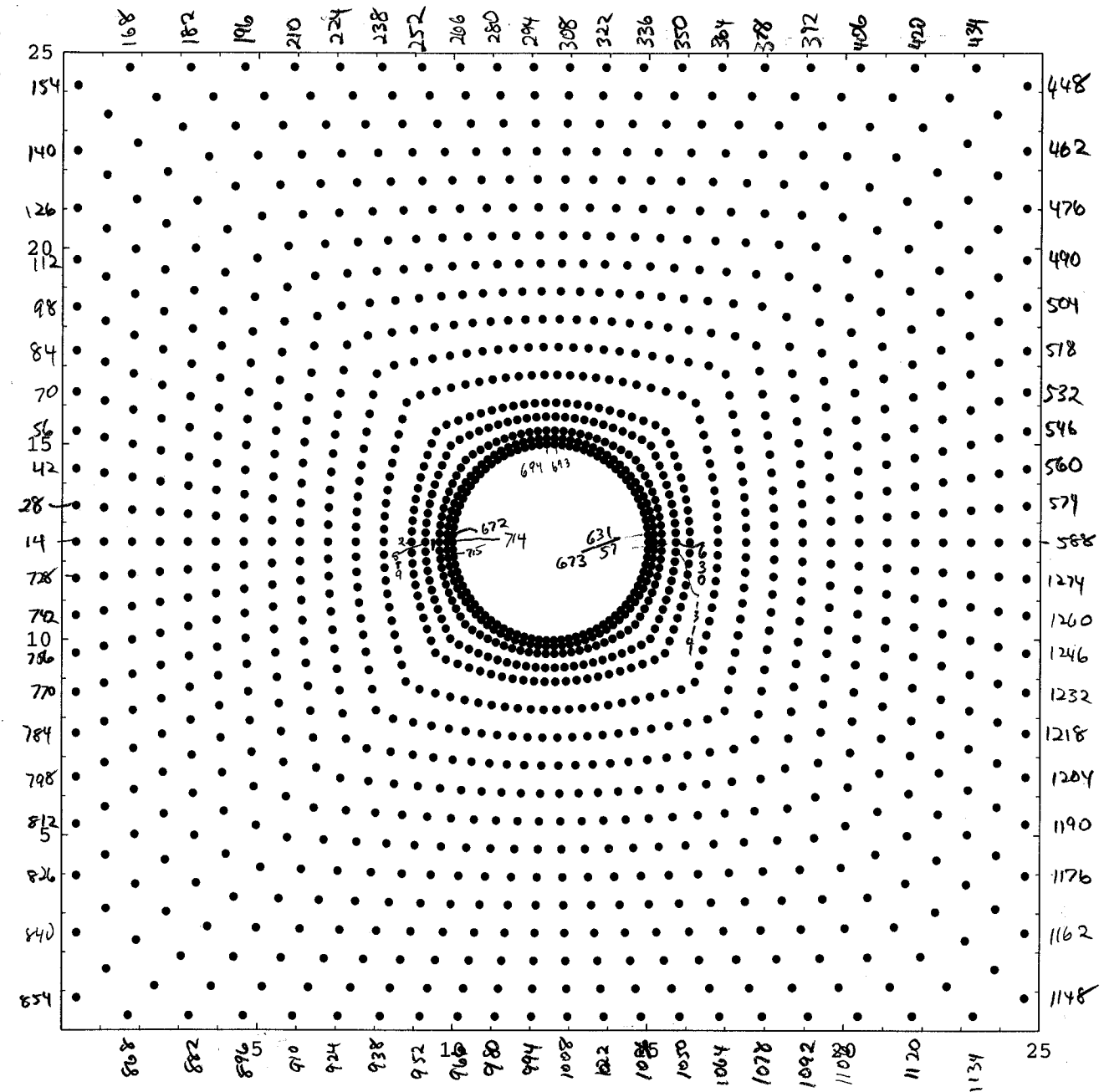
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NOTE: The pencil entries above were cited and pointed out to the Principal Investigator. Due to the size of the print it was agreed to leave this page as is.

~ dhuughson / multi flo / input bak / multi. 32

8/11/2000

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CHANDRA RA

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Flux	at nodes 693, 694	Pc	Sl
$1.078e-5 = 340.6 \text{ mm/y}$		4546	.6058
$3.0e-5 \text{ kg/m}^2/\text{s} = 947.8 \text{ mm/y}$		2291	.8189
$5.0e-5 \text{ kg/m}^2/\text{s} = 1579.6 \text{ mm/y}$		1171	.9202
$6.0e-5 \text{ kg/m}^2/\text{s} = 1895.6 \text{ mm/y}$		790.3	.9504
$7.0e-5 \text{ kg/m}^2/\text{s} = 2211.5 \text{ mm/y}$		472.4	.9728
$8.0e-5 \text{ kg/m}^2/\text{s} = 2527.4 \text{ mm/y}$		194.6	.9898
$9.0e-5 \text{ kg/m}^2/\text{s} = 2843.4 \text{ mm/y}$		0	1.0
$8.5e-5 \text{ kg/m}^2/\text{s} = 2685.4 \text{ mm/y}$		68.74	.9966
$8.6e-5 \text{ kg/m}^2/\text{s} = 2717 \text{ mm/y}$		44.44	.9978
$8.7e-5 \text{ kg/m}^2/\text{s} = 2748.6 \text{ mm/y}$		20.45	.9990
$8.8e-5 \text{ kg/m}^2/\text{s} = 2774 \text{ mm/y}$		1.636	.9999
Philip solution = 2257.6 mm/y threshold			
changing (refining) grid from pg 91 to pg 95			
changed MF threshold from 3408 mm/y			
to 2774 mm/y			
ONE MORE GRID REFINEMENT			
node 693 - 15.008	OK		
node 651 - 15.158	move to 16 cm		
node 609 - 15.7126	new @ 16 cm		
2 d hughson/multiplier/inputback/multiplier 32			
$6.0e-5 \text{ kg/m}^2/\text{s}$	750.4		.9534
$7.0e-5 \text{ kg/m}^2/\text{s}$	432.7		.9754
$8.0e-5 \text{ kg/m}^2/\text{s}$	154.6		.9920
$8.4e-5 \text{ kg/m}^2/\text{s}$	53.59		.9974
$8.45e-5 \text{ kg/m}^2/\text{s} = 2670 \text{ mm/y}$	41.04		.9980
$8.5e-5 \text{ kg/m}^2/\text{s} = 2685.4 \text{ mm/y}$	28.76		.9986
$8.6e-5 \text{ kg/m}^2/\text{s} = 2717 \text{ mm/y}$	4.5		.9998

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Book # 285

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change Russo m parameter from 0.5 to 0.9

Flux	Pc	Sl
$8.0e-5 \text{ kg/m}^2/\text{s}$	154.6	.988

Try Russo m parameter at 0.1

Flux	Pc	Sl
$8.0e-5 \text{ kg/m}^2/\text{s}$	154.6	.9975

Try Russo m parameter at 0.0

Flux	Pc	Sl
$8.0e-5 \text{ kg/m}^2/\text{s}$	154.6	.9993
$8.1e-5 \text{ kg/m}^2/\text{s}$	128.8	.9995
$8.2e-5 \text{ kg/m}^2/\text{s}$	103.4	.9997
$8.3e-5 \text{ kg/m}^2/\text{s}$	78.35	.9998
$8.4e-5 \text{ kg/m}^2/\text{s}$	53.5	.9999
$8.5e-5 \text{ kg/m}^2/\text{s}$	28.76	1.0
$8.6e-5 \text{ kg/m}^2/\text{s} = 2717 \text{ mm/y}$	4.5	1.0

Grid

pg 91

pg 95

Threshold Flux
3408 mm/y
2774 mm/y

another row
around drift
no room in this
notebook

change
Russo m

2720 mm/y

2717 mm/y

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