THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) MODEL
ENGINEERING DOCUMENTATION FOR VERSION 3

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includes the references:

Giroud, J. P., and Bonaparte, R. (1989). "Leakage through liners constructed with geomembrane liners--parts I and II and technical note," *Geotextiles and Geomembranes* 8(1), 27-67, 8(2), 71-111, 8(4), 337-340.

Giroud, J. P., Badu-Tweneboah, K., and Bonaparte, R. (1992). "Rate of leakage through a composite liner due to geomembrane defects," *Geotextiles and Geomembranes* 11(1), 1-28.

from G & B Part I:

"A liner is a low-permeability barrier used to impede liquid or gas flow. …

If there was (*sic*) such a thing as an impermeable barrier, it would be possible to prevent leakage, …

... none of the materials presently used in civil engineering to line large areas is impermeable.

Thus, the Commission should recognize that all liners leak, to varying extents. That's why many hazardous waste landfills have a double liner--the second liner to capture the leak from the first liner, and to conduct the leaked liquid to a container for treatment.

OCD has performed a straightforward modeling exercise, apparently with one unique set of reasonable but not fully illustrative parameters. In their single model, representing a "good" installation the trench burial leaks approximately 2.2mm of water per year. That sounds small. How much is it?

If the trench bottom is 160 square meters, then:

The leak is 2.2 barrels/year, a reportable release in less than 2.5 years.

OCD Ex. 8, pg 13 suggests the 3,000 mg/l standard is equivalent to 240,000 mg/kg in the initial pit sample. That's right, but what does this imply?

Start: 1/4 liter pit sample. Add clean soil to make 1 liter.

Leach with 20 liters of water, yielding 3,000 mg/liter in water.

Total chloride extracted: 3,000 x 20 = 60,000 mg.

If trench material were, 25% porous & saturated, the pore water would have 60,000 mg in 0.25 liter of pore water. That's what drains through. Thus, it is possible for the leaked water to have concentration greater than 20 times that of the extract.

But the saturation limit of water is ~ 212,000 mg/liter chloride.

OCD modeling has predicted that wastes with the proposed concentration of salt will contaminate the aquifer beyond use in approximately 140 years if buried without a liner, and in approximately 2,000 years if buried with a liner.

The question then,
is not *whether* such burial will contaminate the aquifer.

The questions are:

1) *when* contamination of the aquifer will occur, and

2) whether or when the ground surface will be contaminated

For 1) the model is unrealistic; for 2) OCD gives no answer.

FAULTS OF THE OCD MODELS

Upward transport toward ground surface was neglected. This may be the most immediate, and most damaging effect of multiple burial units scattered across the landscape.

The modeled downward release from a trench neglected the variability of soils, and did not use realistic estimates of installation defects in the trench liner. It neglected the effect of multiple burial units above the same aquifer.

The modeled propagation of the release neglected the dominant dynamics of moisture diffusion into the plume due to the reduction of vapor pressure by salt. The model thereby artificially increased the delay of contamination arrival at the aquifer.

LANDFILL LINERS

There is a large, and scientifically significant, literature on the calculation of leakage from landfill liners, and on the hydraulic properties of liner materials. I uncovered this literature, starting with the short list of references on page 18 of OCD's Exhibit 8.

This extensive literature documents that the release from burial units of varying quality in various situations cannot be predicted by one simplistic calculation of one unique set of conditions. for example, the "leak" rate varies greatly with the contact between liner and underlying soil.

VARIATION OF SOIL PARAMETERS

Modeling should cover the range of parameters to reveal the breadth of effects, not choose one unique example to establish a case.

Porosity. Reasonable range 0.25-0.5.

Hydraulic conductivity. Varies by factors of ten.

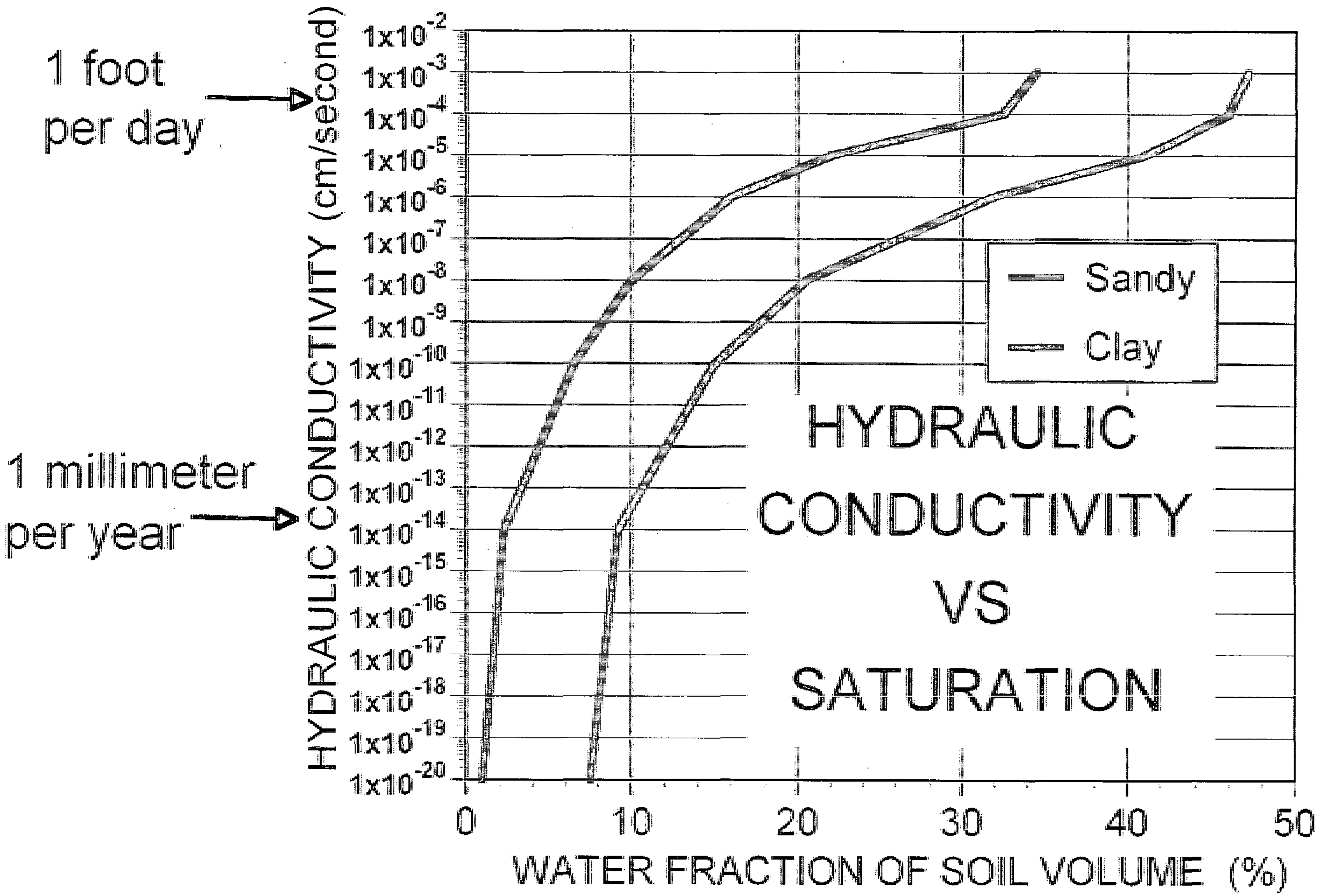
TABLE 1. DEFAULT LOW DENSITY SOIL CHARACTERISTICS

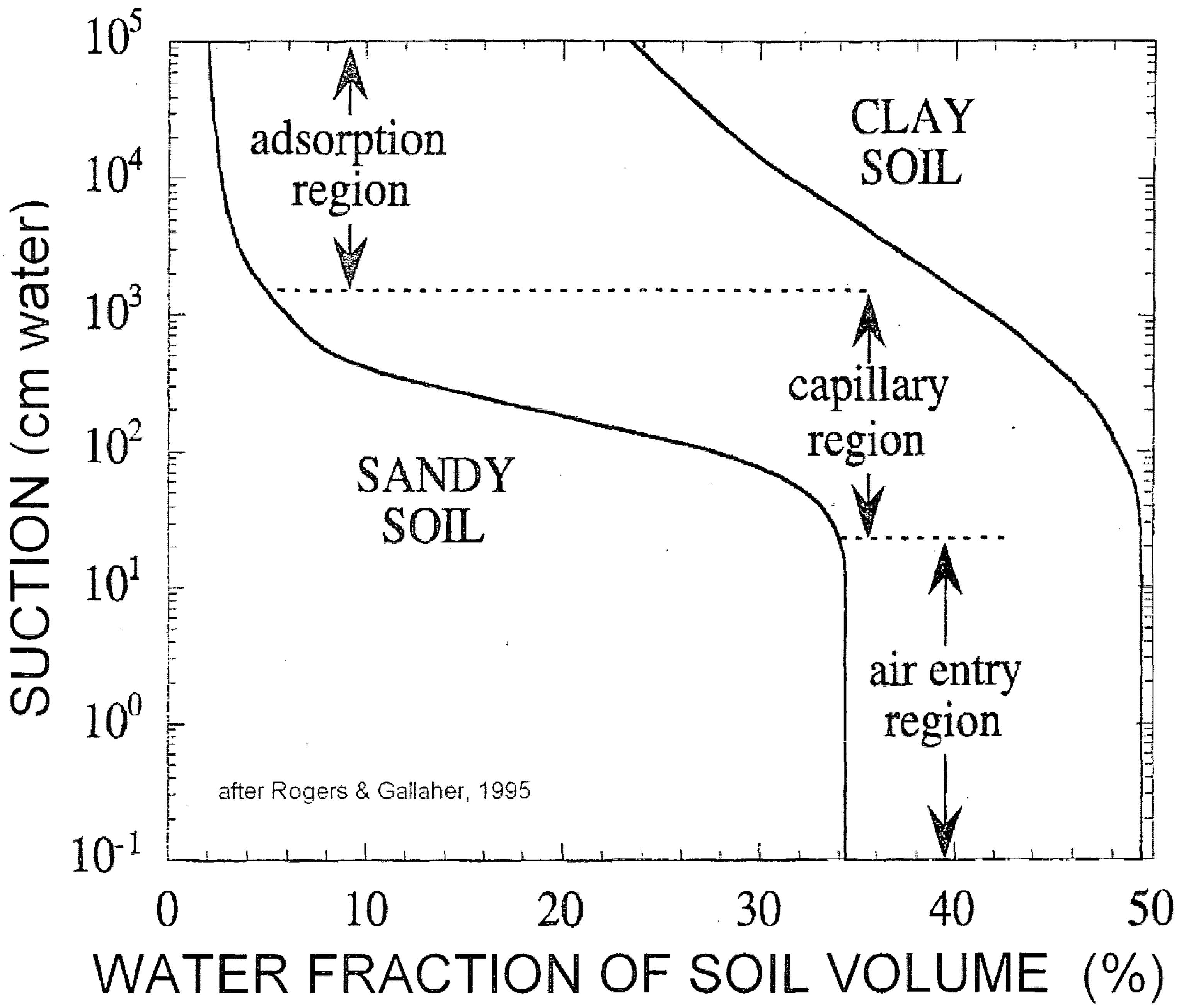
Soil Texture Class			Total Porosity vol/vol	Field Capacity vol/vol	Wilting Point vol/vol	Saturated Hydraulic Conductivity cm/sec
HELP	USDA	USCS				
1	CoS	SP	0.417	0.045	0.018	$1.0x10^{-2}$
2	S	SW	0.437	0.062	0.024	$5.8x10^{-3}$
3	FS	SW	0.457	0.083	0.033	$3.1x10^{-3}$
4	LS	SM	0.437	0.105	0.047	$1.7x10^{-3}$
5	LFS	SM	0.457	0.131	0.058	$1.0x10^{-3}$
6	SL	SM	0.453	0.190	0.085	$7.2x10^{-4}$
7	FSL	SM	0.473	0.222	0.104	$5.2x10^{-4}$
8	L	ML	0.463	0.232	0.116	$3.7x10^{-4}$
9	SiL	ML	0.501	0.284	0.135	$1.9x10^{-4}$
10	SCL	SC	0.398	0.244	0.136	$1.2x10^{-4}$
11	CL	CL	0.464	0.310	0.187	$6.4x10^{-5}$
12	SiCL	CL	0.471	0.342	0.210	$4.2x10^{-5}$
13	SC	SC	0.430	0.321	0.221	$3.3x10^{-5}$
14	SiC	CH	0.479	0.371	0.251	$2.5x10^{-5}$
15	C	CH	0.475	0.378	0.251	$2.5x10^{-5}$
21	G	GP	0.397	0.032	0.013	$3.0x10^{-1}$

Table of saturated hydraulic conductivity (*K*) values found in nature

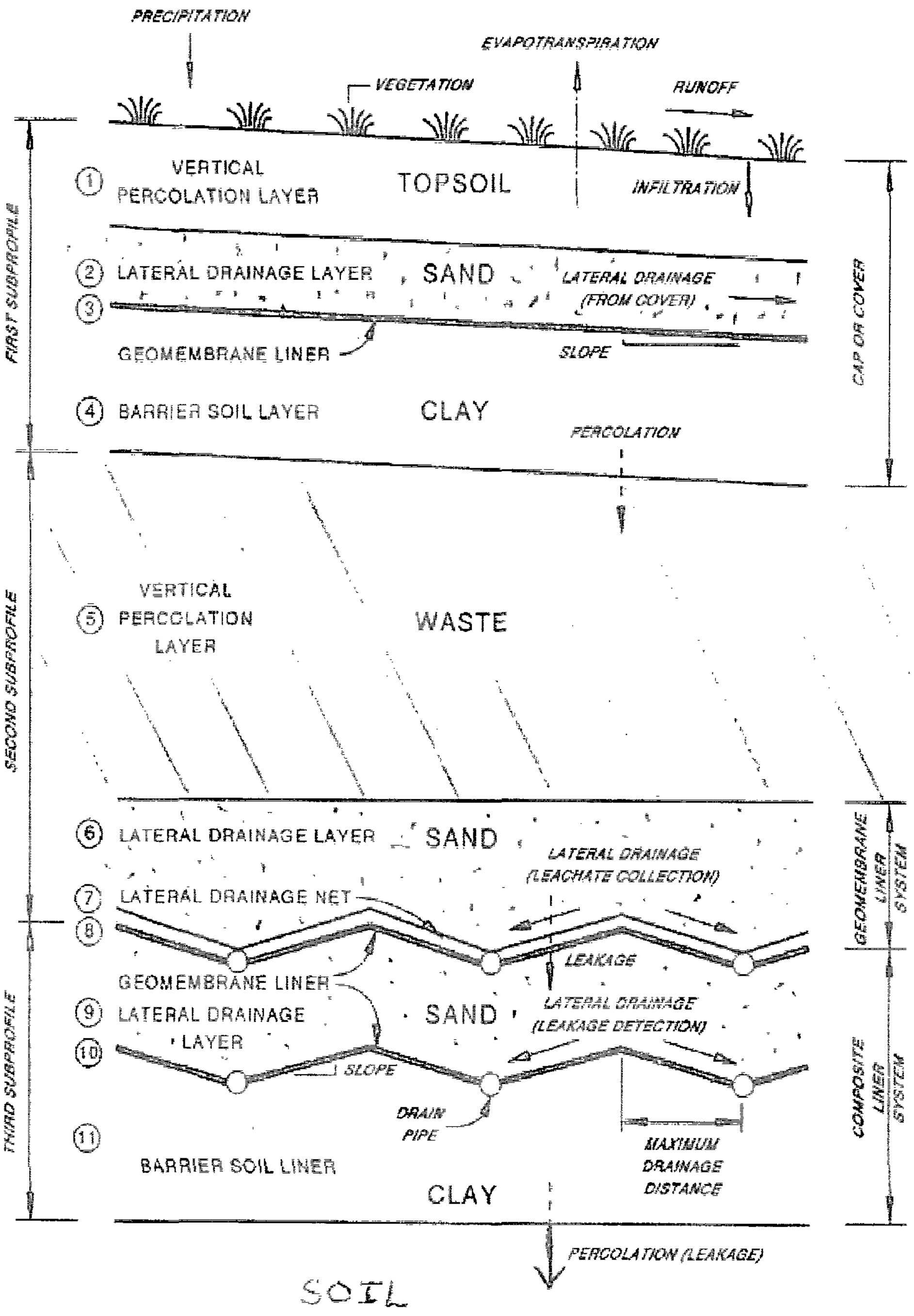
Values are for typical fresh groundwater conditions — using standard values of viscosity and specific gravity for water at 20°C and 1 atm. See the similar table derived from the same source for intrinsic permeability values.[5]

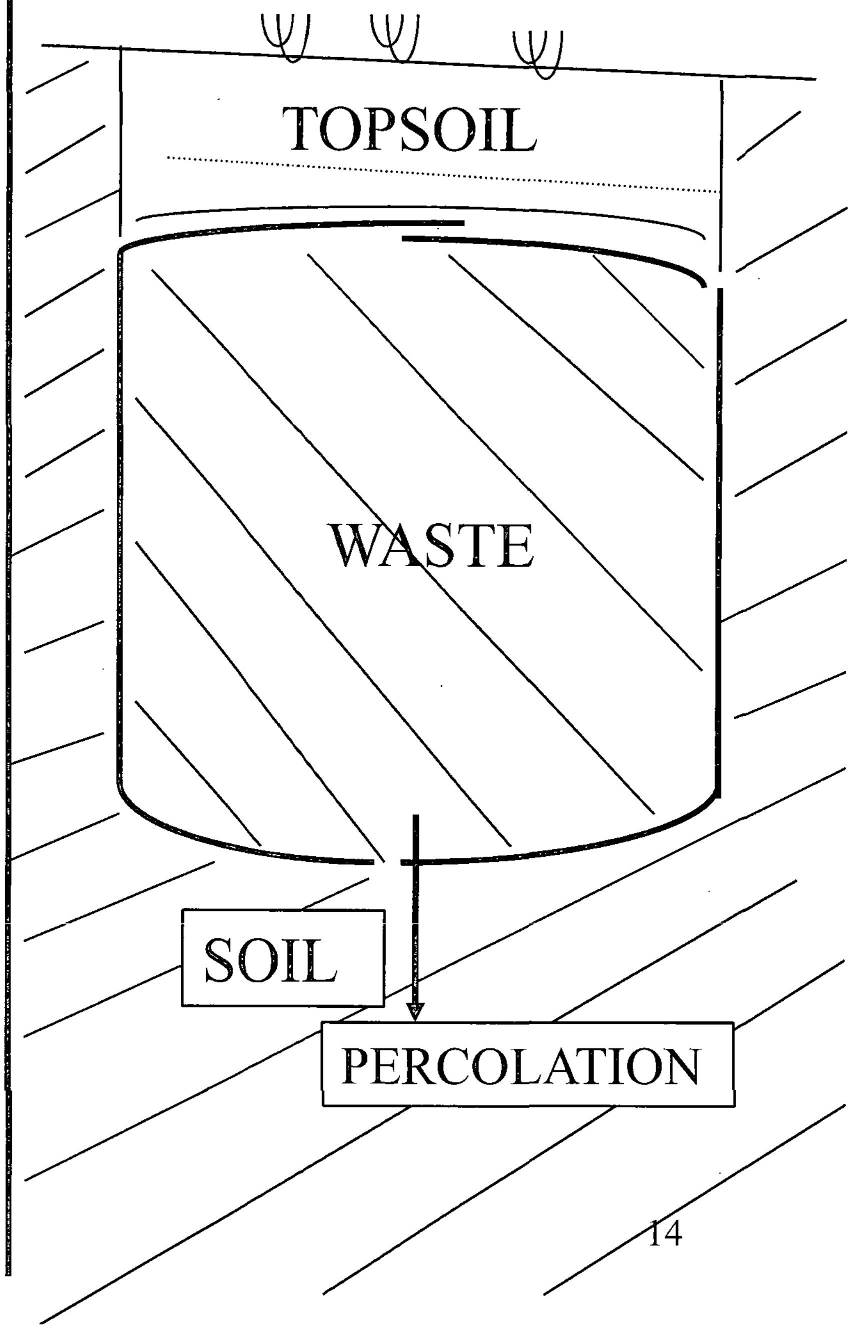
K (cm/s)	10^2	10^1	$10^0=1$	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
K (ft/day)	10^5	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}
Relative Permeability	Pervious				Semi-Pervious				Impervious				
Aquifer	Good					Poor				None			
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							
Unconsolidated Clay & Organic					Peat		Layered Clay			Fat / Unweathered Clay			
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoir Rocks			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite	


1 foot
per day
1 millimeter
per year
HYDRAULIC CONDUCTIVITY (cm/second)
1x10-2
1x10-3
1x10-4
1x10-5
1x10-6
1x10-7
1x10-8
1x10-9
1x10-10
1x10-11
1x10-12
1x10-13
1x10-14
1x10-15
1x10-16
1x10-17
1x10-18
1x10-19
1x10-20
0
10
20
30
40
50
WATER FRACTION OF SOIL VOLUME (%)
Sandy
Clay
HYDRAULIC
CONDUCTIVITY
VS
SATURATION


SUCTION (cm water)
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
0
10
20
30
40
50
WATER FRACTION OF SOIL VOLUME (%)
adsorption region
CLAY SOIL
capillary region
SANDY SOIL
air entry region
after Rogers & Gallaher, 1995

LANDFILLS AND TRENCHES ARE NOT THE SAME


PRECIPITATION
EVAPOTRANSPIRATION
VEGETATION
RUNOFF
1 VERTICAL PERCOLATION LAYER
TOPSOIL
INFILTRATION
2 LATERAL DRAINAGE LAYER
SAND
LATERAL DRAINAGE (FROM COVER)
3
GEOMEMBRANE LINER
SLOPE
4 BARRIER SOIL LAYER
CLAY
PERCOLATION
FIRST SUBPROFILE
CAP OR COVER
5 VERTICAL PERCOLATION LAYER
WASTE
SECOND SUBPROFILE
6 LATERAL DRAINAGE LAYER
SAND
LATERAL DRAINAGE (LEACHATE COLLECTION)
7 LATERAL DRAINAGE NET
8
LEAKAGE
GEOMEMBRANE LINER
9 LATERAL DRAINAGE LAYER
SAND
LATERAL DRAINAGE (LEAKAGE DETECTION)
10
SLOPE
DRAIN PIPE
11 BARRIER SOIL LINER
CLAY
MAXIMUM DRAINAGE DISTANCE
GEOMEMBRANE LINER SYSTEM
COMPOSITE LINER SYSTEM
THIRD SUBPROFILE
PERCOLATION (LEAKAGE)
SOIL


TOPSOIL
WASTE
SOIL
PERCOLATION

ASSUMPTIONS AND PARAMETERS WITHIN THE HELP PROGRAM

Vapor diffusivity of the membrane (sidewalls neglected)

Density of pinholes

Density of defects

Installation quality

- Perfect--no gaps, “sprayed-on” seal.
- Excellent--contact typically achievable only in the lab
- Good--prepared smooth soil surface & wrinkle control
- Worst--contact between membrane & soil does not limit drainage rate

VAPOR TRANSPORT THROUGH THE SIDE WALLS OF THE TRENCH

Literature values for lldpe or ldpe, adjusted for 20 mil thickness

Rough average: 0.2 grams/m^2 day, for 100% difference of vapor pressure. (literature is unclear)

Assume trench liner 4m wide, 4m deep, 40 m long

352 m^2 wall area

Vapor infusion at 100% difference of vapor pressure: 0.2g/m^2 day

Infusion = 25 liters/year. A trivial amount.

Initial water at 28% of volume: 179 m^3 or 179,000 liters.

HOLES AND DEFECTS

"…one hole per 4000 m^2 (acre) should be considered … A hole size of 1 cm2 ($0.16 in^2$) is recommended for calculations conducted to size the components of the lining system …"

"…the above hole sizes and frequency have been selected with the assumption that intensive quality assurance monitoring will be performed. A frequency of 25 holes/ha (10 holes/acre) or more is possible when quality assurance is limited to an engineer spot-checking the work done …"

Giroud & Bonaparte, *Geotextiles and Geomembranes 8, 27-67 (1989)*

Realistic suggestion: one hole per trench. 160/4000=1/25

TABLE 6
Calculated Leakage Rates due to Pinholes and Holes in a Geomembrane

	Defect diameter	Water depth on top of the geomembrane, h_w: *0·003 m (0·01 ft)*	*0·03 m (0·1 ft)*	*0·3 m (1 ft)*	*3 m (10 ft)*	*30 m (100 ft)*
Pinholes	0·1 mm (0·004 in)	0·006 (0·0015)	0·06 (0·015)	0·6 (0·15)	6 (1·5)	60 (15)
	0·3 mm (0·012 in)	0·5 (0·1)	5 (1)	50 (13)	500 (130)	5 000 (1 300)
Holes[a]	2 mm (0·08 in)	40 (10)	130 (30)	400 (100)	1 300 (300)	4 000 (1 000)
	11·3 mm (0·445 in)	1 300 (300)	4 000 (1 000)	13 000 (3 000)	40 000 (10 000)	130 000 (30 000)

Values of leakage rate in liters/day (gallons/day)

Giroud & Bonaparte, *Geotextiles and Geomembranes 8, 27-67 (1989)*

CONTEXT OF LEAKAGE PRESENTED IN THE HELP LITERATURE

ONE 2 mm hole, 0.01 ft head
wrinkled (poor contact) installation
40 liter per day leak

For 160 sq m trench bottom, this is equivalent to 3.5 inches per year of infiltration, much larger than the 0.09 inch/year (2.2 mm) of the OCD model.

Discussion suggested that even a decayed liner would provide some continuing protection for the aquifer.

NO

Because ONE small hole in the liner can induce a flow larger than the total leak calculated by OCD, a slightly damaged liner or a liner that has degraded in time may provide almost no protection.

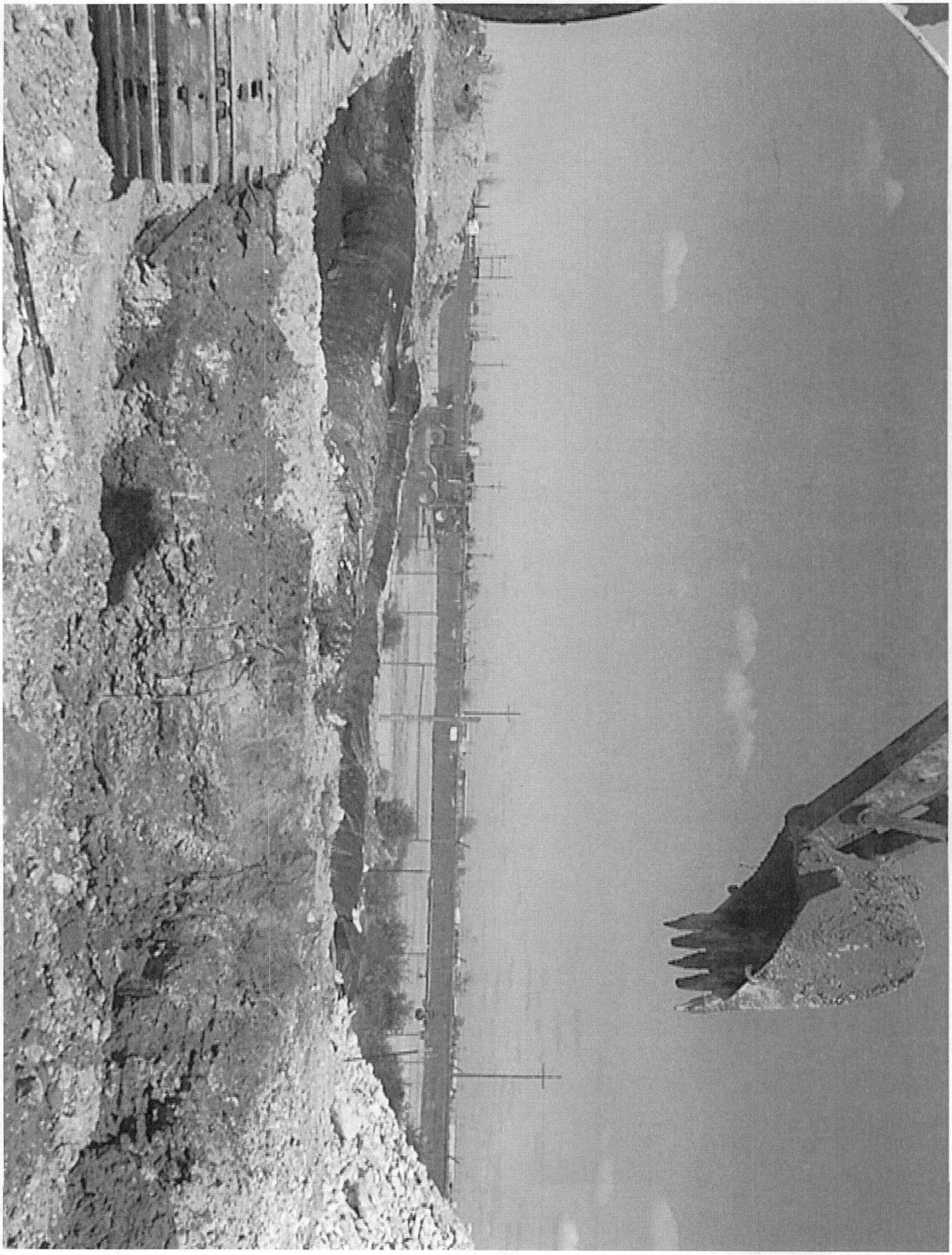
A small hole can drain a bucket if the bucket is not being filled faster than the drain.

CAN A TRENCH LINER BE INTACT?

19.15.17.11 J(3) requires a geotextile under the liner "where needed" to reduce the strain of protuberances. But a pad under the liner can increase the leak rate.

from G & B Part I, pg. 35:

"It may seem appropriate to use a geotextile cushion between the geomembrane upper component and the low-permeability soil lower component of a composite liner if the soil contains stones which may damage the geomembrane. …(but) ... lateral flow in the geotextile increases the rate of leakage …"



Why worry more about the integrity of a liner containing wastes with 3,000 mg/l leach standard than a liner containing wastes with 250 mg/l leach standard (factor of 12 difference)?

Integrity of the liner is *more* than 12 times as important when the concentration of the contents is increased by a factor of 12 because the increased salt concentration actually increases the rate of transport of chloride toward the aquifer.

COLLIGATIVE EFFECTS

Fluid properties change as the concentration of a solute (salt) changes.

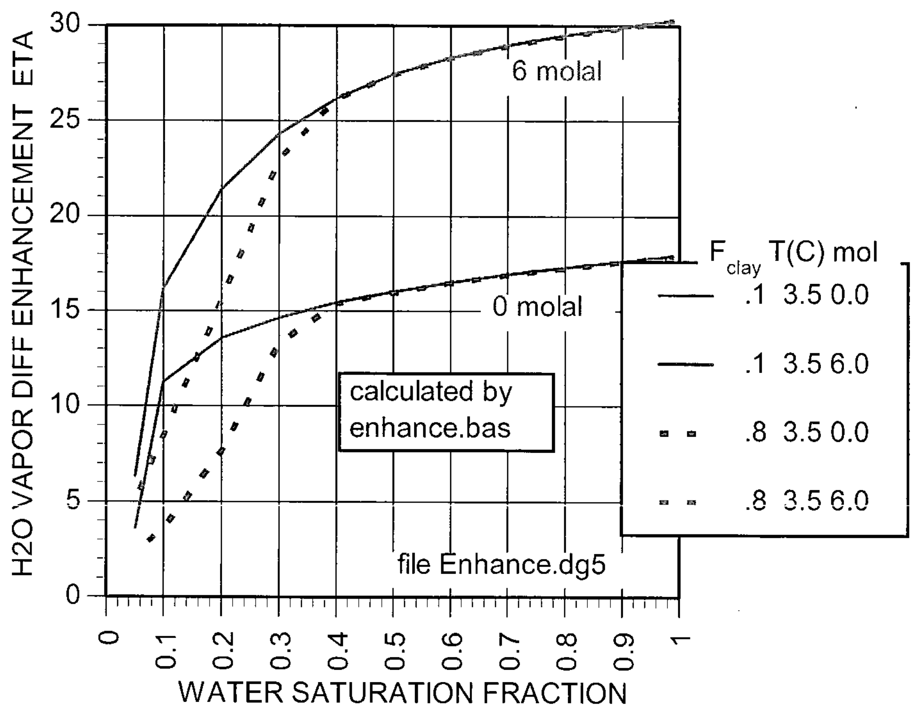
What changes as salt dissolves in the pore water?

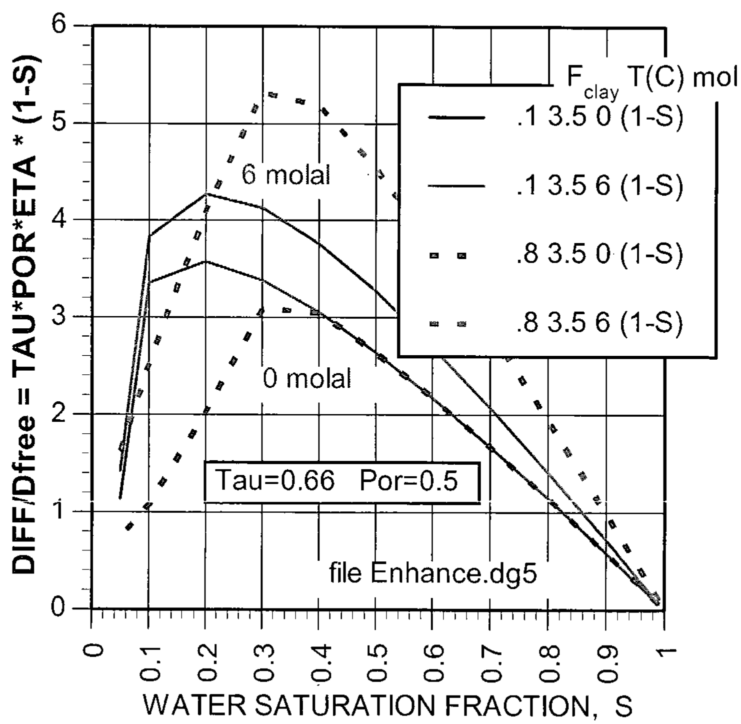
Surface tension increases, increasing the "suction" or potential. At 60,000 mg/l chloride, the potential is approximately -8.3×10^6 Pascals, equivalent to 83 bars or a head of 2778 ft pure water.

Vapor pressure decreases, viscosity and density of the liquid increase.

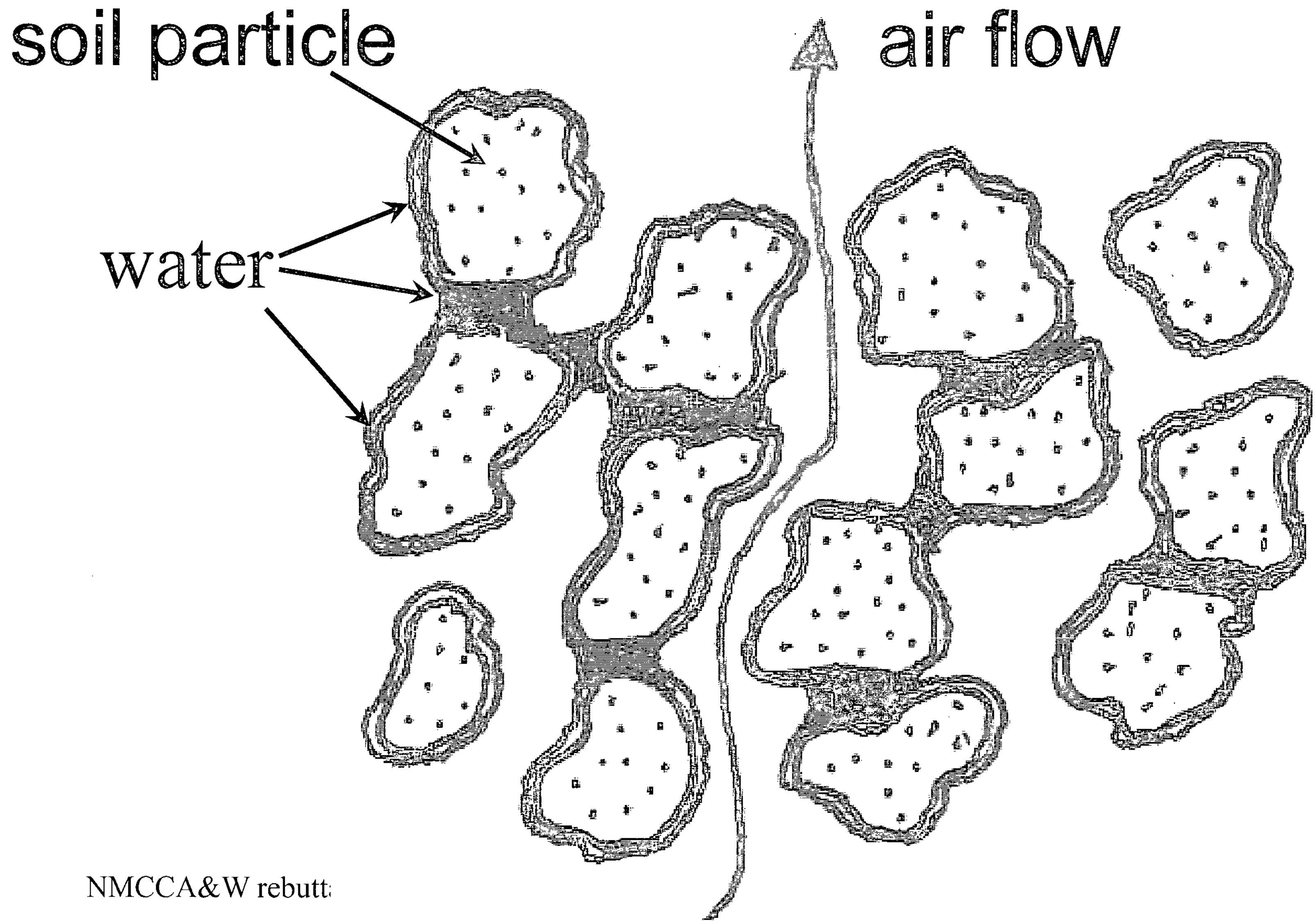
All of these effects alter unsaturated flow.

This is a complicated problem. Increasing density increases the flow rate, increasing viscosity slows the flow rate, the increased surface tension alters the lenses of fluid between soil particles, altering the Philip-deVries enhancement of water vapor diffusion.

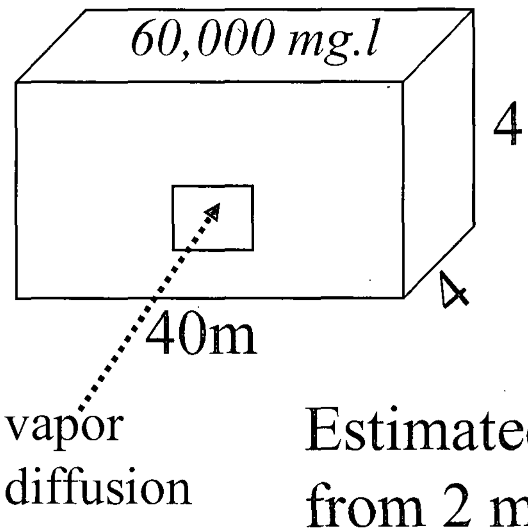




POROUS STRUCTURE OF THE SOIL



CONSIDER A SLUG OF SALT WATER MOVING DOWNWARD FROM THE TRENCH, 2.2mm/yr



OCD downward flux 0.352 m^3/year

(352 kg/year)

Estimated flux to the face of the plume, diffusing from 2 m outside the plume: 1.43 kg/m2-yr.

Addition to plume from two faces, each 40x4 m^2:

458 kg/year

Conclusions regarding vapor diffusion:

Diffusion through the membrane is negligible.

Diffusion into the plume below the trench will have a dominant effect on the motion of the plume, adding liquid, diluting the concentration, and greatly increasing the speed of movement toward the aquifer.

The MULTIMED model neglected the major dynamic of chloride transport beneath the trench.

FAULTS OF THE OCD MODELS

Upward transport toward ground surface was neglected. This may be the most immediate, and most damaging effect of multiple burial units scattered across the landscape.

The modeled downward release from a trench neglected the variability of soils, and did not use realistic estimates of installation defects in the trench liner. It neglected the effect of multiple burial units above the same aquifer.

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