# Modeling Interfaces Involving Multiple Engineered Features

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**July 2009**

# Thesis:

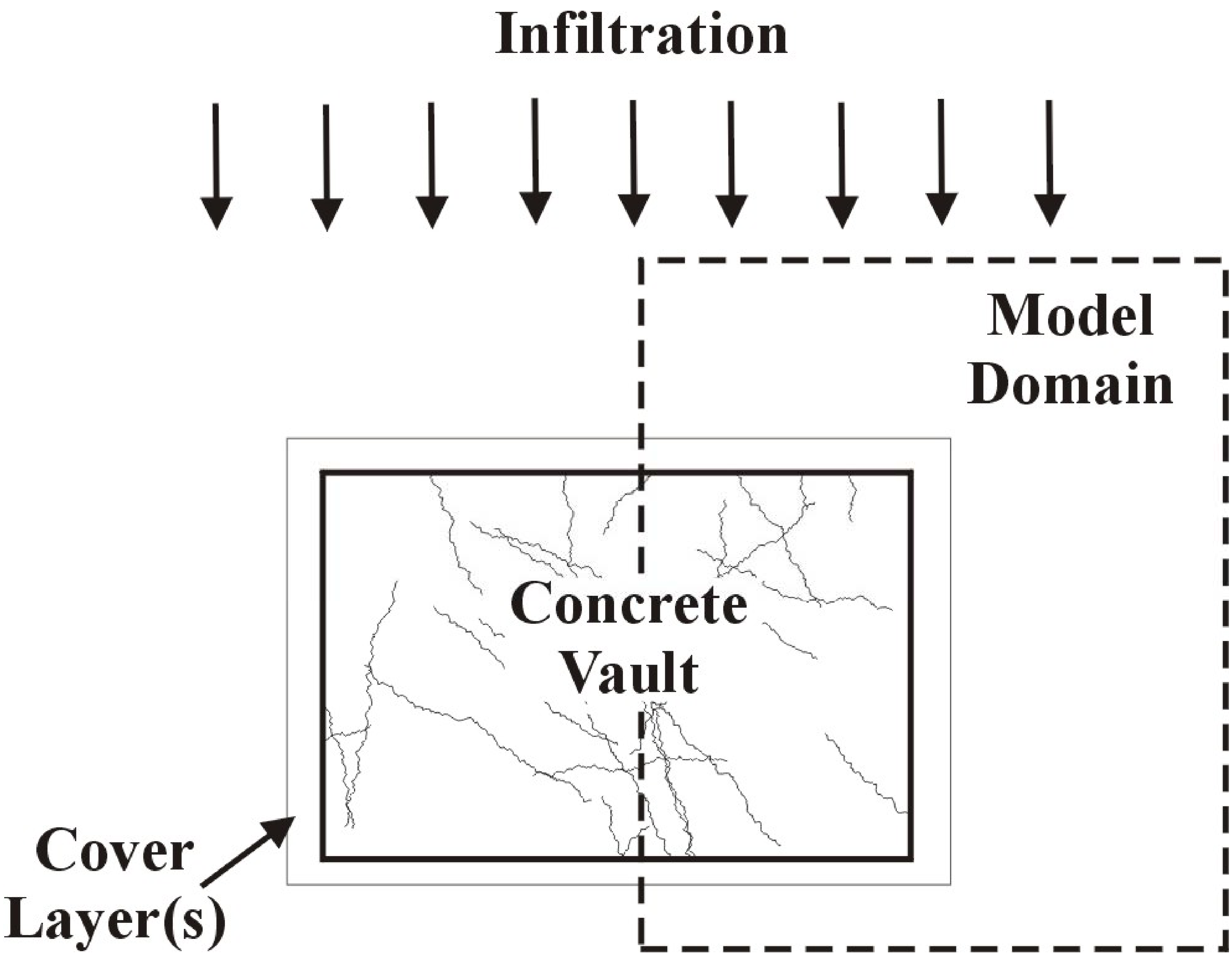
- **When one examines multiple subsystems in disposal facilities, interactions can provide surprising results. These insights should be reflected in design, but generally are not.**
- **Lower cost w/better performance is available now, better design is the low hanging fruit.**
- **Intuition and compartmentalized knowledge have served as poor guides.**

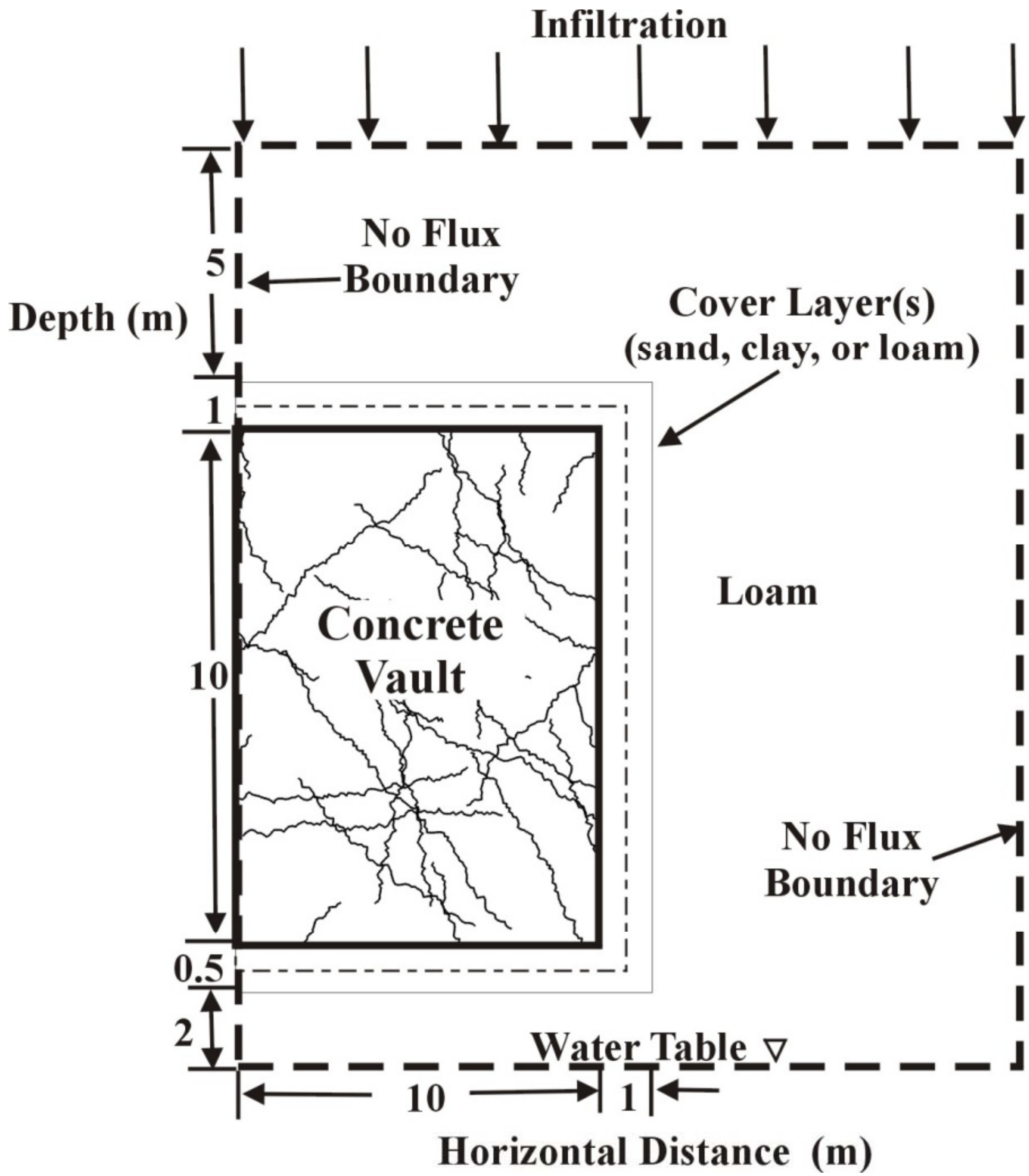
# Examples:

- Scale effects on percolation
- Scale effects on mixing
- Hydraulic gradient effects
- Slowing barrier degradation

# Scale Effects on Percolation

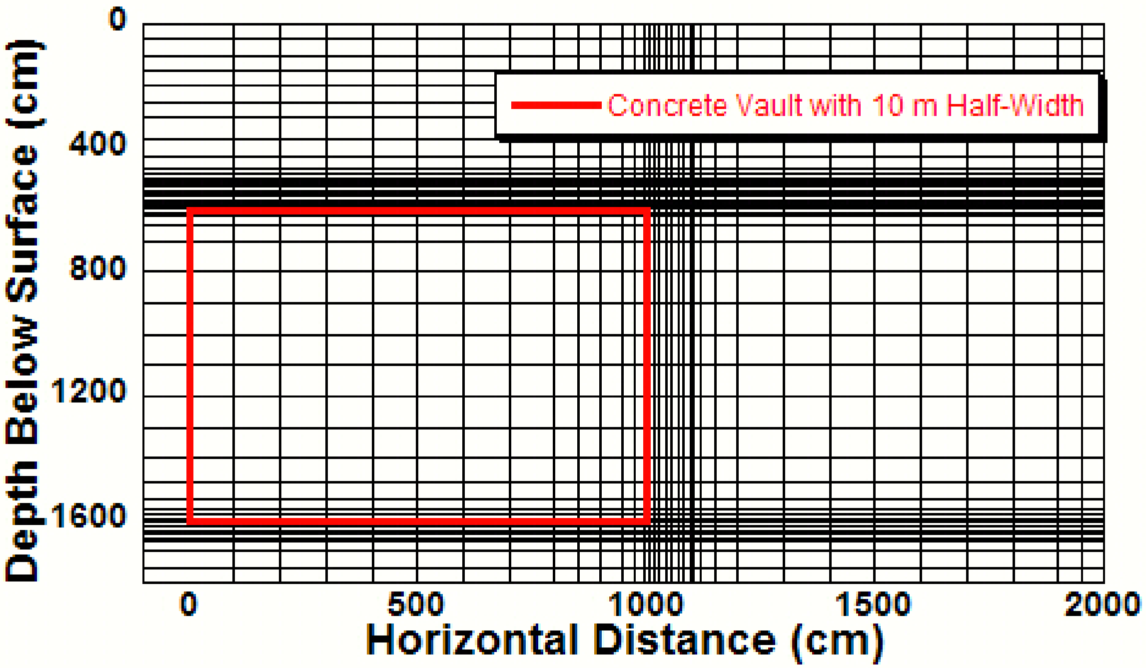
- **Below ground rectangular vault assumed**
- **Modify roof slope, size, soil type around vault, leakage through cover**
- **Cover included implicitly**
- **Estimate water flowing through vault ($cm^3/cm^2$/year)**
- **Rob Rice dissertation:**
- **Design Factors Affecting the Flow of Water through Below-Ground Concrete Vaults, J. Envir. Engrg. Volume 132, Issue 10, pp. 1346-1354 (October 2006)**


Infiltration
Model
Domain
Concrete
Vault
Cover
Layer(s)

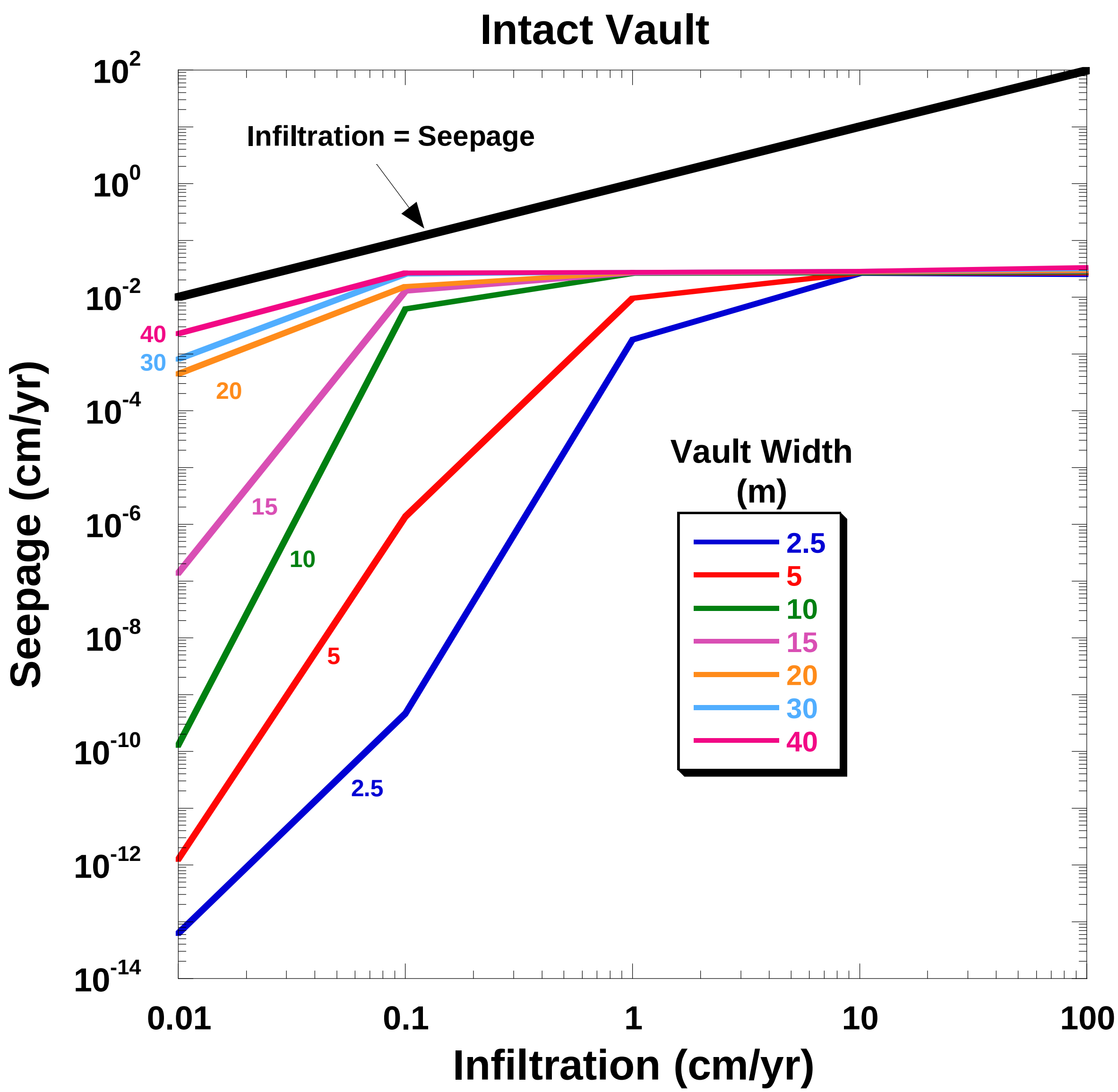



Design Factors Affecting the Flow of Water through Below-Ground Concrete Vaults
J. Envir. Engrg. Volume 132, Issue 10, pp. 1346-1354 (October 2006)

# Gridding



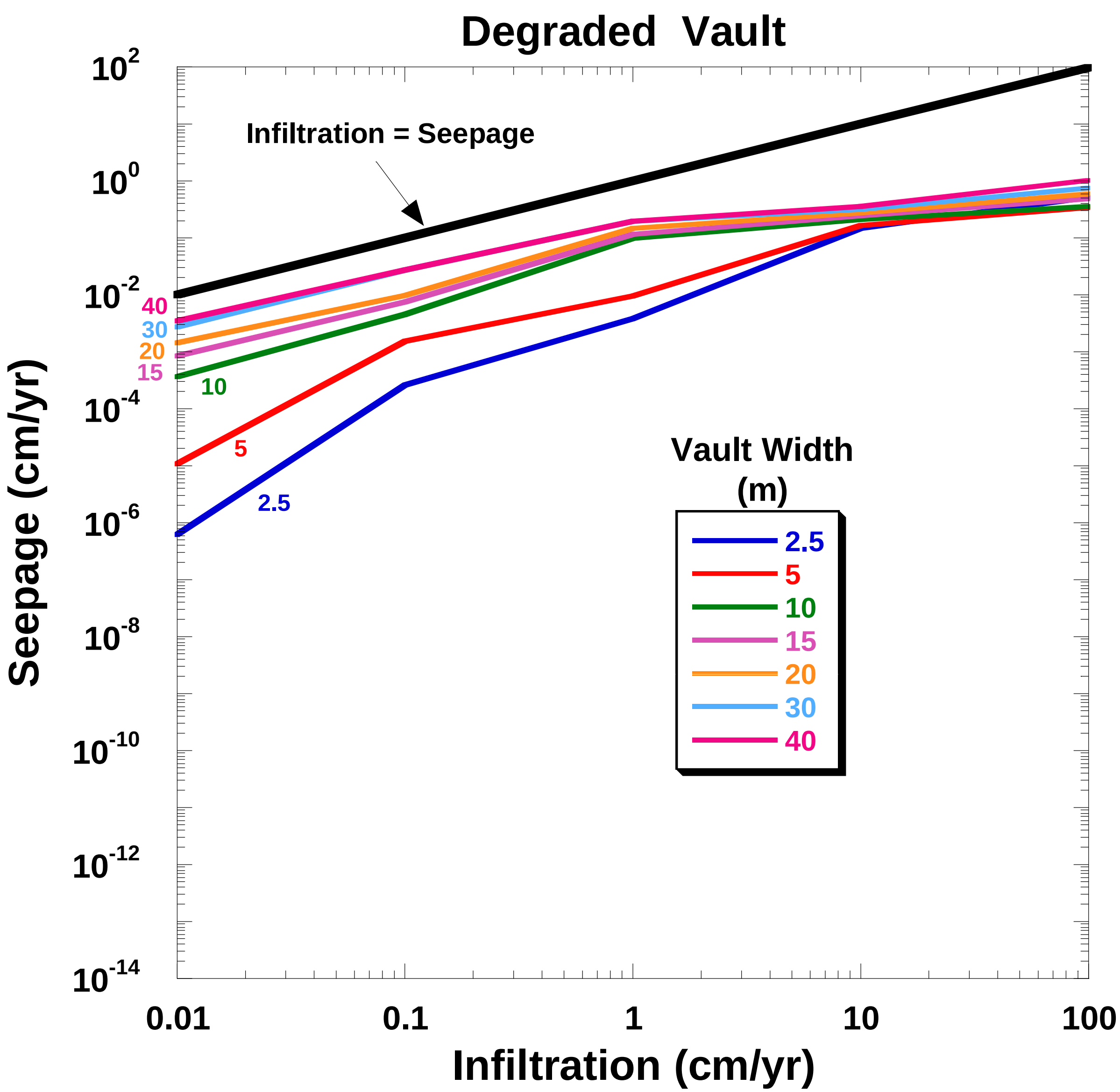
Concrete Vault with 10 m Half-Width
Depth Below Surface (cm)
0
400
800
1200
1600
0
500
1000
1500
2000
Horizontal Distance (cm)




perched water
"shelf"

Clay-Loam Soil
Layers

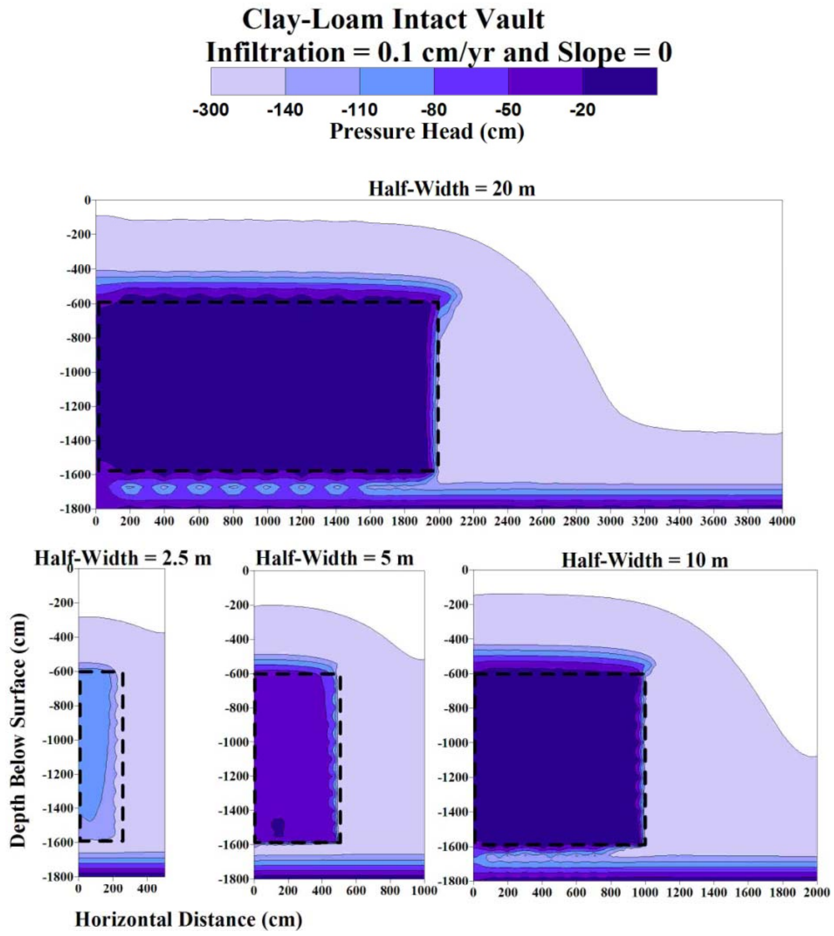
UTEP




infiltration
is
the implicit
leakage
through
cover

Clay - Loam

# Perched Water is Why

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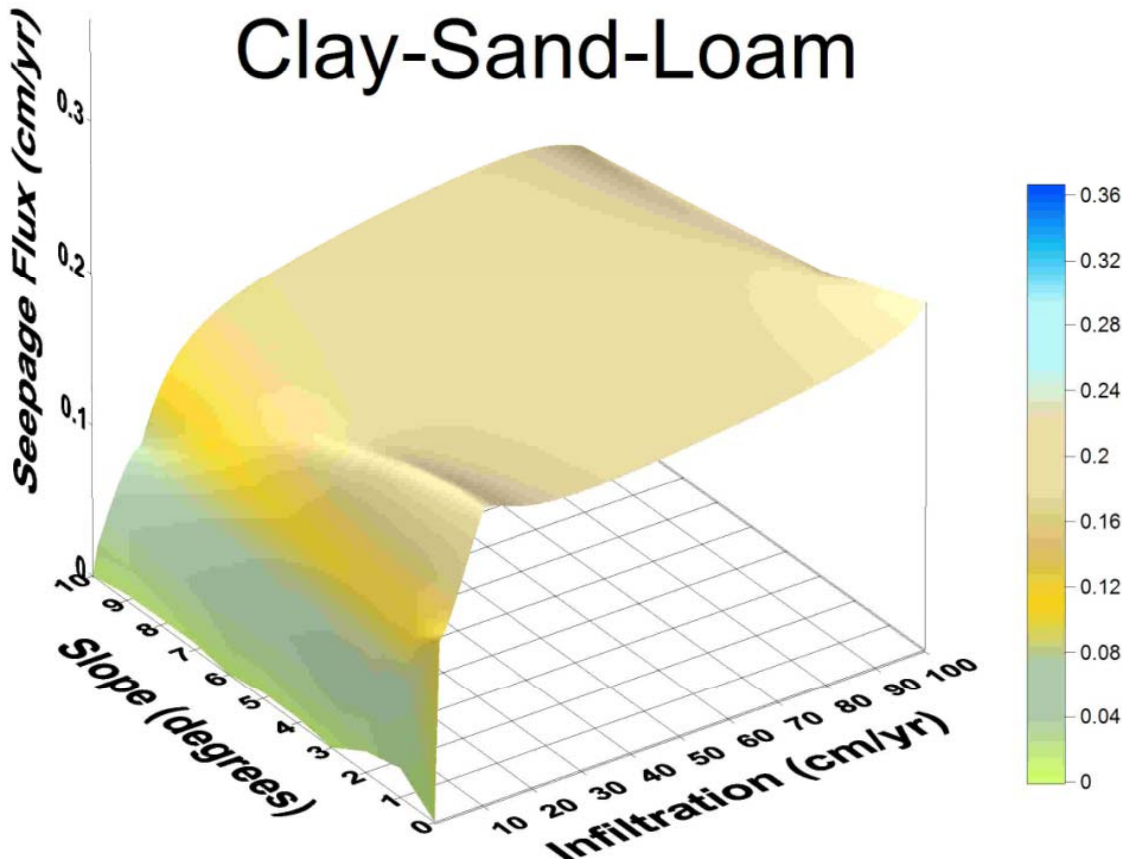
# What happens

- Lateral diversion of water around a cover is scale dependent
- Water perches over top of large vaults even at low infiltration rates
- Once perched water forms infiltration rate through cover becomes unimportant
- In general, smaller, modular vaults with individual covers perform best
- Modular also allows nearby infiltration of mixing water




**Perched water shelf where seepage independent of cover leakage (infiltration)**

**Slope not very important**

**Drainage layer (sand) helps, but only a little**

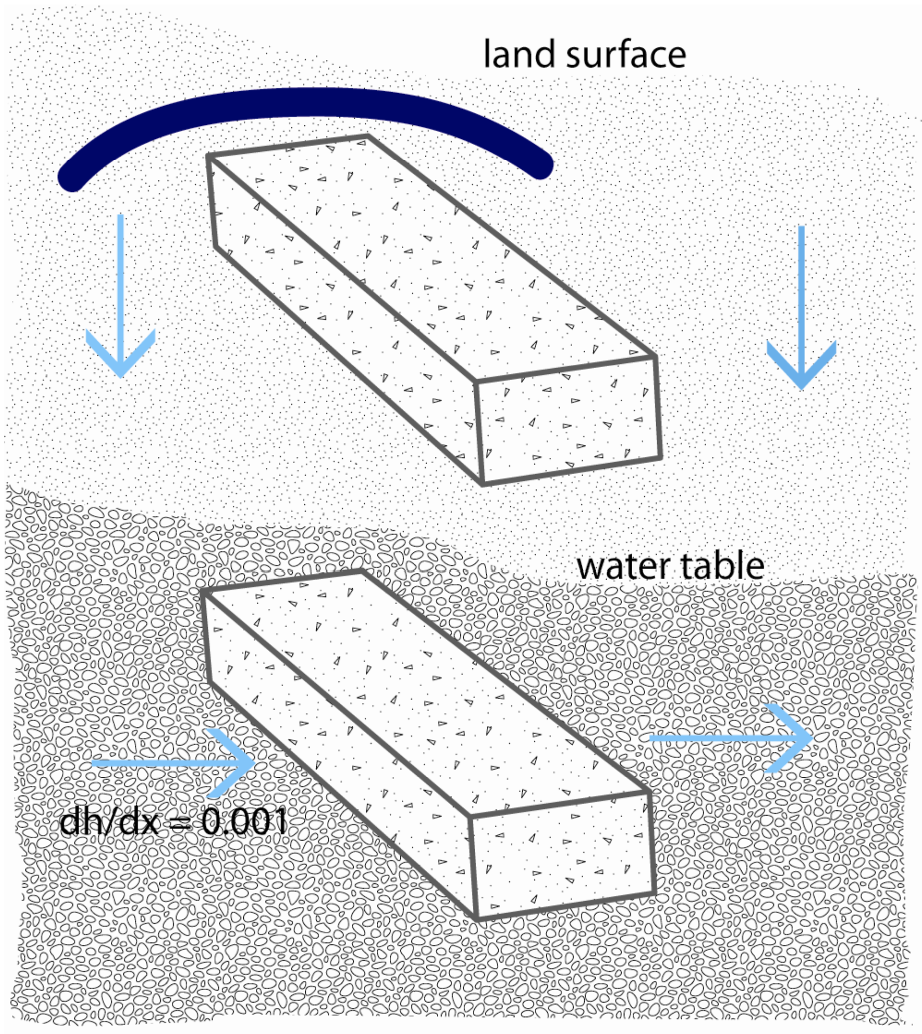
# Percolation Study Conclusions

- Clay layers placed adjacent to the concrete lower water flow through the vault, slow degradation, and enhance hydraulic performance.
- Smaller vault sizes perform better.
- Roof slope has a relatively small influence on hydraulic performance.
- Covers are generally ineffective in controlling seepage

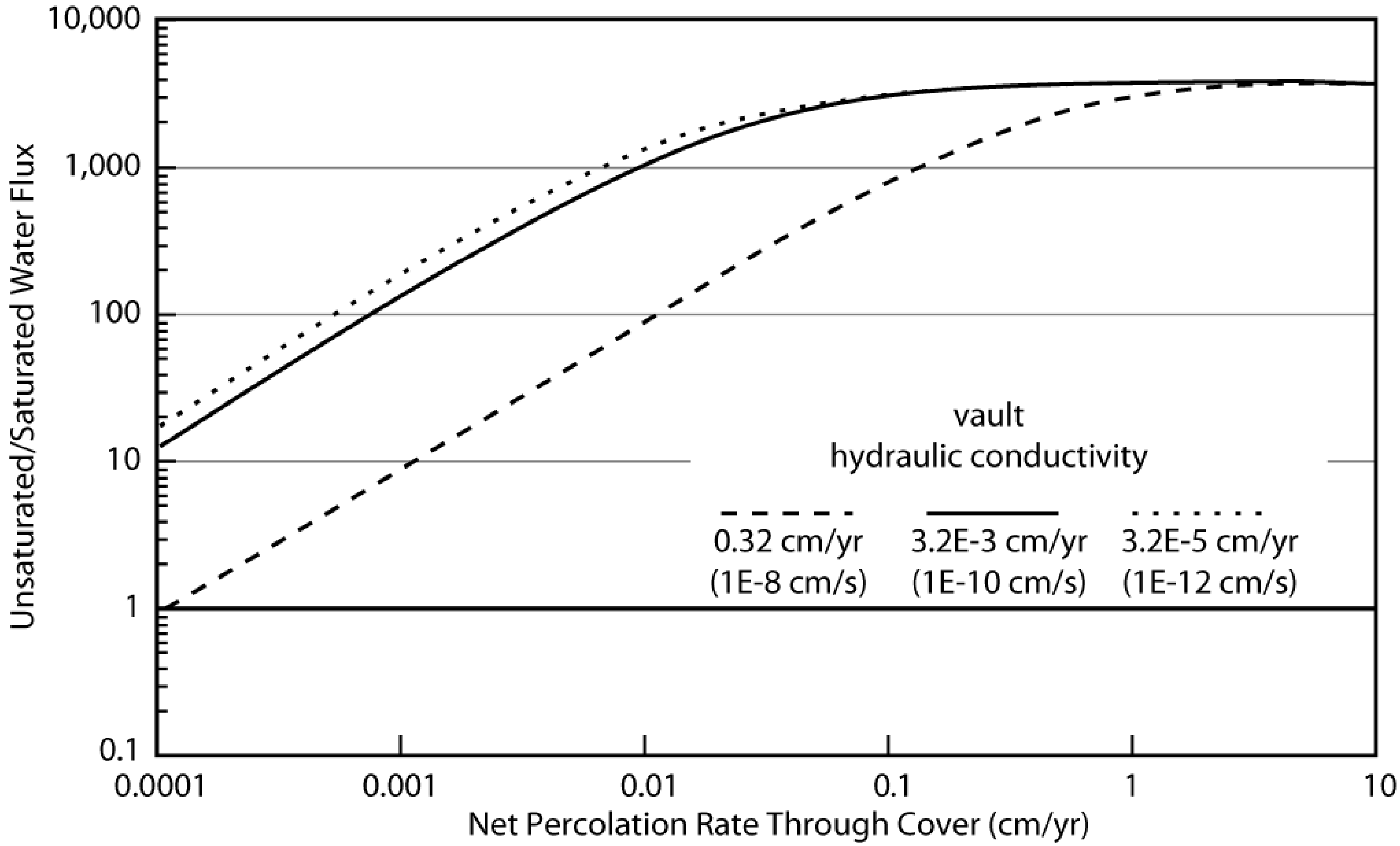
# Don’t put waste below the water table!

- This is a widely held hypothesis, clearly obvious to most analysts.
- Let’s do a simple numerical experiment to test the hypothesis and show how important it is.

# Numerical Test



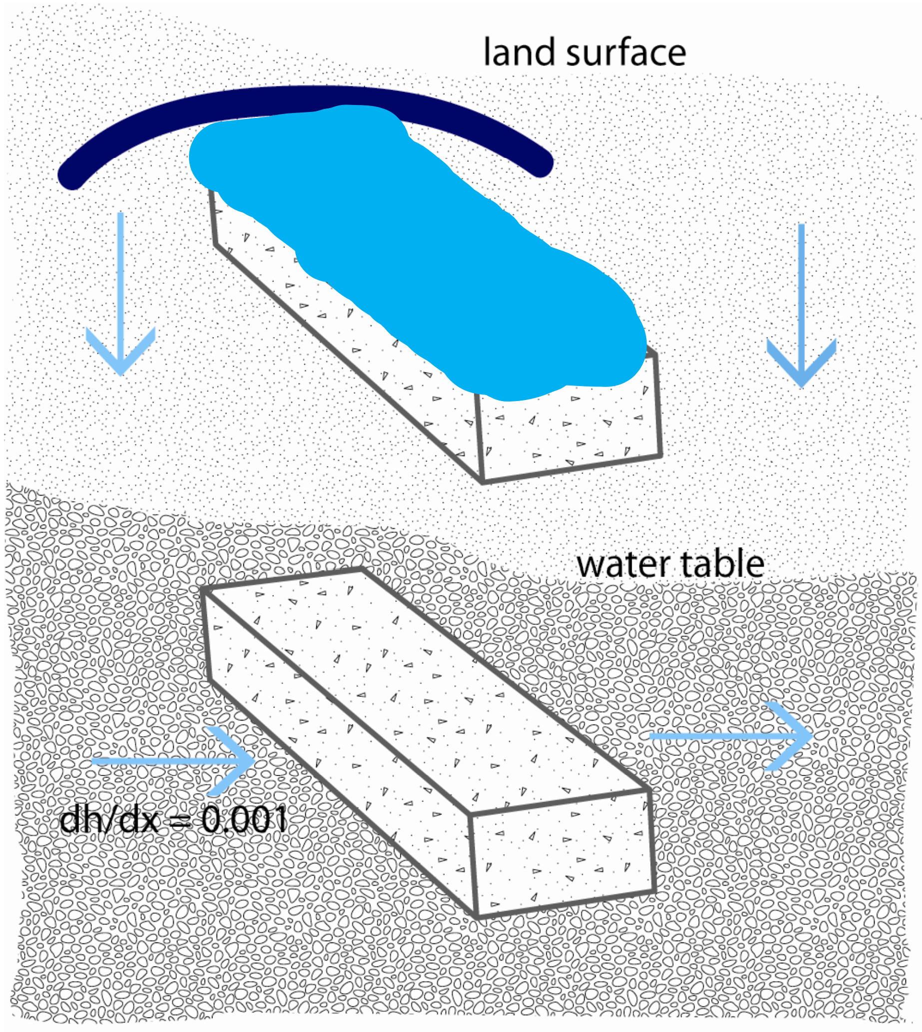
# Turns out the obvious is wrong



# Why Saturated Sites Work Better (Hydraulically)

- Perched water gives a unit gradient in unsaturated zone
- Typical groundwater has a low gradient (e.g., 1/0.001 = 1000)
- Top versus side of vault exposed to flow
- Unsaturated zone locations are easier to construct however

# Why




perched water gives dh/dx ~1

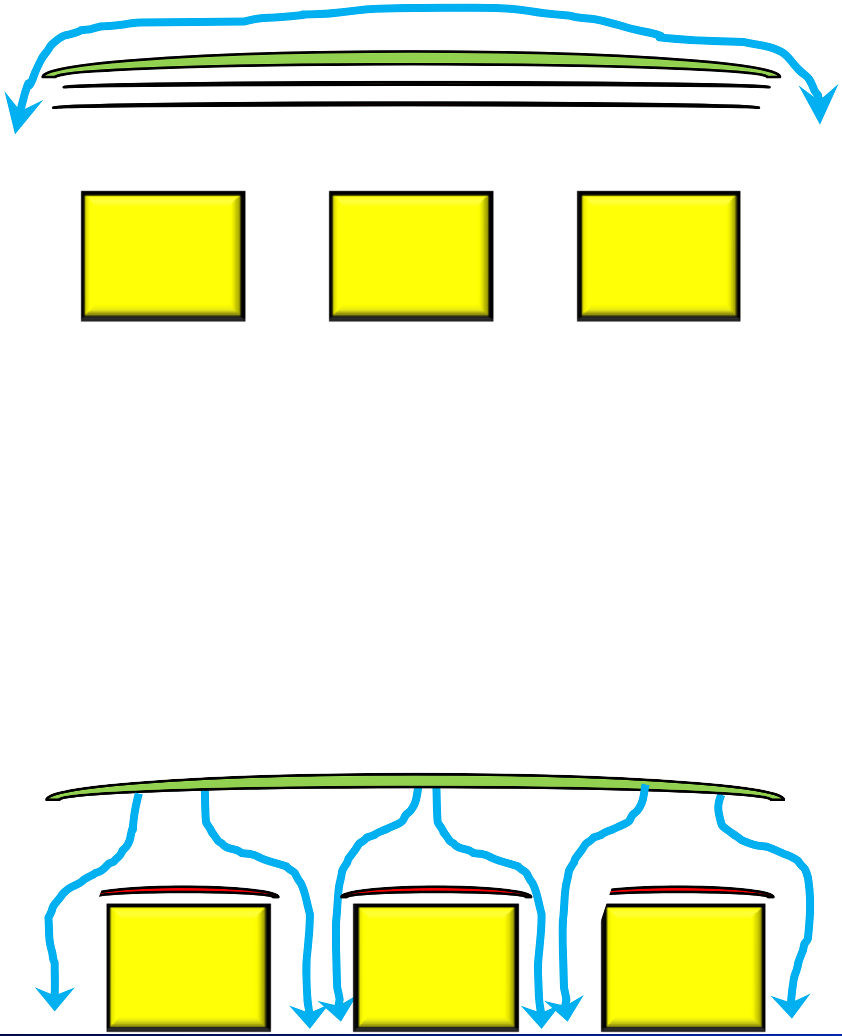
fine pores in cementitious materials mean essentially saturated flow at both locations

relation of vault to flow direction also decreases performance of unsaturated location

# Mixing – Peak Dose is Risk Driver

- For long lived contaminants, peak dose
  - ~ (release rate)/(mixing flow).
- Peak dose should be controlled by management of both release and mixing
- Minimize spikes in release, maximize mixing
- Remember D. Esh slide of rain giving infiltration peaks

# Mixing



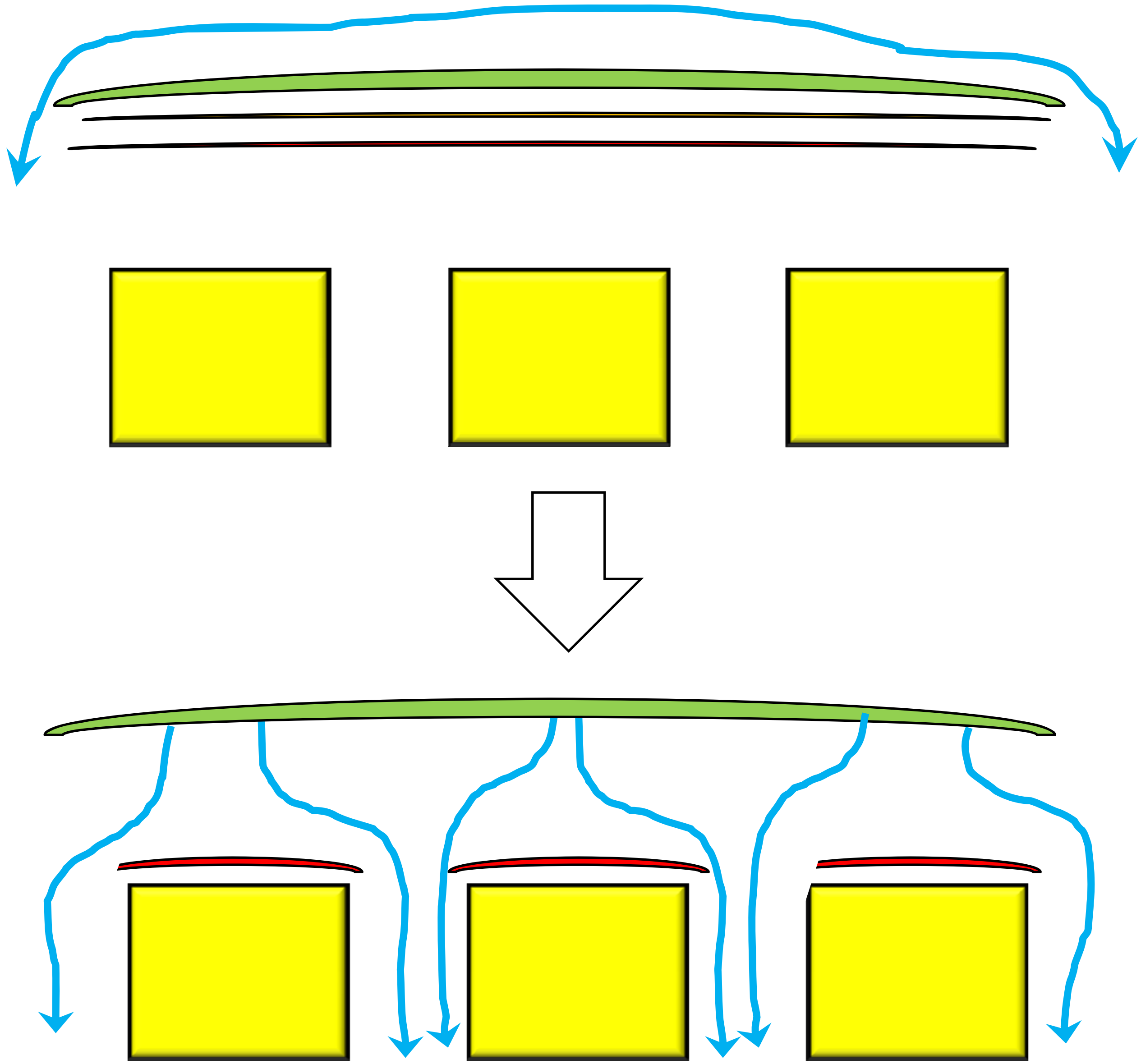
- Consider two different cover options:
  a) large over over entire facility or
- b) smaller modular covers and smaller vaults

# Lowering Peak Dose

- Smaller vaults with clay against the vault will perform better and more reliably than the typical cover – (lower release)
- Mixing of leachate with diverted water takes place when  vault size<(distance to boundary)/10
- Buried (clay over structure) covers degrade more slowly – further from the surface
- Combination of plastic and brittle materials naturally resists subsidence and seals cracks
- Modular design is usually cheaper since expensive, mostly useless, cover is eliminated

# Improved Design

- Replace monolithic landfill type covers with modular designs
- Conceptually cover begins at top of buried structure, NOT land surface
- Clay layers, geomembranes, capillary barriers go as close to structure as possible (blanket the structure not the site)
- Vault width < (distance to boundary/10) to ensure proper mixing
- French drains to infiltrate water between vaults
- Modular design means less surface runoff to cause erosion
- Important barriers further beneath land surface – more robust
- Compatible with new buildings/ parking lots, etc above buried structure(s)
- Generally >10X lowering of dose while lowering costs and improving reliability



expensive,
unreliable
high risk

lower cost
reliable
lower risk
(vaults should also
be smaller if possible)

# Other Important PA Issues

- Probabilistic analysis: Peak of the mean analysis has methodological problems that cause systematic under estimates of risk
- Transients
  - In nature transient events almost always cause peaks
  - in PA we mostly scale up steady state processes and ignore transients
  - more or earlier seepage is not always conservative
  - e.g., tank failure; leaky dam
  - storage by a barrier followed by failure of the barrier is critical (e.g., aging of iron corrosion products (Kd declines with time -> storage followed by release)
- Management of preferential flow paths and stagnant regions within structures over time – backup drains
- Avoidance of “infallible barrier” proofs
  - nearly impossible to prove
  - decrease public confidence
- Managing how materials property changes over time interact with waste isolation performance

# Conclusion

- Traditional covers and designs are poor ideas that belong with landfills not buried structures
- Better engineering design is the low hanging fruit
  - available today
  - lowers cost
  - improves performance
  - often counterintuitive
- PA concepts have not filtered back to design
- PA analysts spend too much time analyzing poor designs and too little looking at new concepts

# BACKUP SLIDES

# Ideal Design

- Low cost
- Robust relative to materials degradation
- Does not unduly limit future land use
- Predictable performance bounds
- Low peak dose for all significant transport pathways
- Resistant to intrusion
- Avoids peaks or spikes in release rate
- Provides reliable mixing for any released contaminants
- Wherever practicable, delays release sufficiently long for maximization of decay

# Why?

## Standard Cover

- barriers close to surface decreases reliability and longevity
- runoff causes erosion requiring expensive erosion barriers
- improper consideration of mixing
- leakage not low enough to reduce release

## Modular Buried Cover

- structural support for cover layers
- deeper burial of barriers increases longevity and reliability
- adjacent use of brittle and plastic barriers is optimal for reliability and low seepage
- mixing part of design ($x<L/10$)
- lower leakage, lower cost

The error function for a step function release for dispersion only (appropriate for transverse mixing of plumes) is:

$$\frac{C}{C_o} = \frac{1}{2} Erfc(x/\sqrt{4Dt})$$

Solving for C/Co = 0.25, 25% mixing of plumes gives:

$$\frac{x}{\sqrt{4Dt}} = 0.477$$

Where x is the size of the facility and D is the dispersion coefficient. The transverse dispersivity of a groundwater plume is approximately 0.01*scale, where the scale is the distance to the compliance boundary (L).

$$\alpha = 0.01L$$

The ground water travel time to the boundary is:

$$t = L/v$$

The dispersion coefficient (D) is given as:

$$D = \alpha v = 0.01Lv$$

Substitution gives:

$$\frac{x}{\sqrt{4Dt}} = 0.477 = \frac{x}{\sqrt{0.04L^2}}$$

$$x = 0.0954L \cong \frac{L}{10}$$

This gives the design constraint that the largest region of impermeable surface transverse the direction of groundwater flow should, as a criterion of engineering design, be less than 1/10 of the distance to the compliance boundary.

$$x < L/10$$

Elimination of the concept of the landfill cover and replacing it with the above scaling relationship with mini covers that begin at the top of the decommissioned structure rather than at the surface of the earth will lower costs and improve performance and reliability.