

Some Lessons Learned from Construction Related Groundwater Experience

by

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Groundwater and Construction

- Nothing good happens when groundwater (or water in general) is encountered during construction.
- Contractors often take a minimalist view of groundwater control.
- When serious problems occur, big dollars become involved and **geo**technical engineers are in the spotlight...or maybe better said; are a target.
- As an industry we can do better.

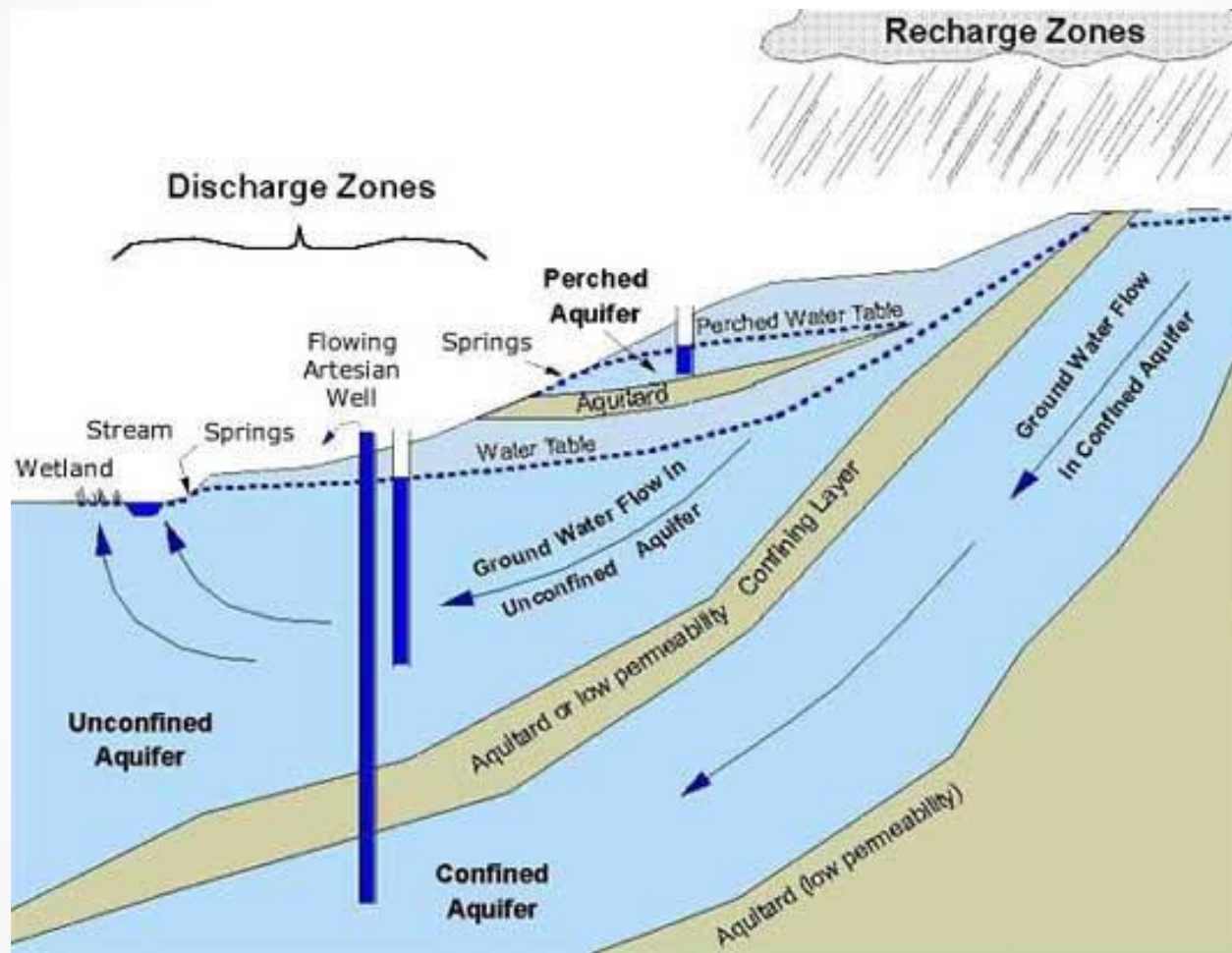
Our Goals

- Provide our clients effective advice so their projects are a success. Their success is our success!
- Help clients understand the project risks so they can make informed decisions.
- Help anticipate construction risks so that owners and contractors can be properly prepared.

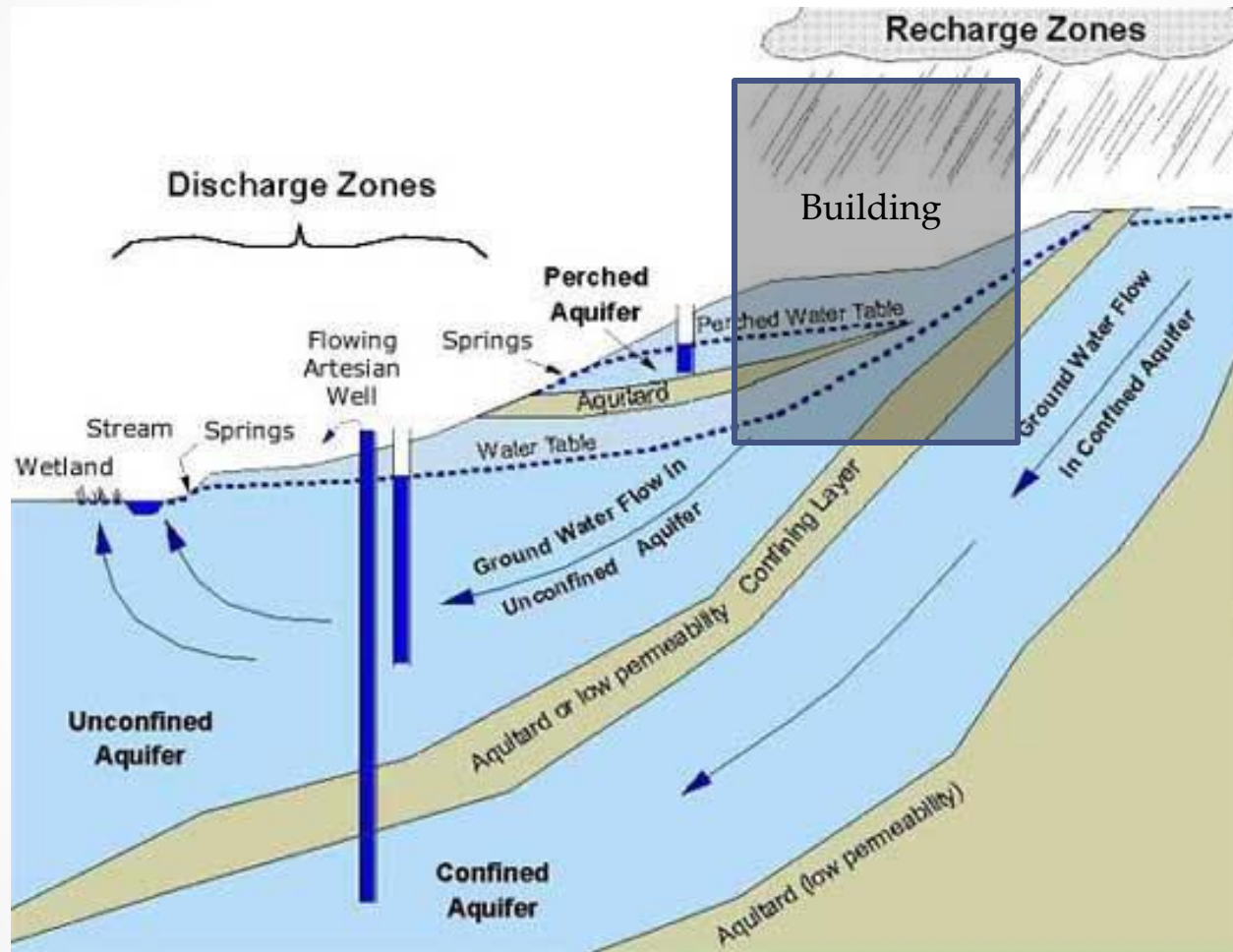
Aquifers

- **Perched** – very common in sediments and in the transition zone between soil and PWR. Typically not large flows – more nuisance flows
- **Unconfined** – most common to encounter that provides sustained flows. Upward vertical gradients are common near streams.
- **Confined or Partially Confined** – less common in shallow construction (less than 30 feet) and common in deep construction (greater than 30 feet). When encountered can provide vertical gradients that can cause significant problems.

Types of Aquifers



Types of Aquifers



Areas for Improvement

- Hydraulic properties are assumed based on handbook, textbook type values, or small scale laboratory tests.
- Overly simple geologic conceptual models.
- The potential for vertical gradients is not recognized.
- We don't consider the impact of water chemistry.
- Most geo-professionals don't take anisotropy into account.

Hydraulic Property Development

- Common methods
 - Textbook or handbook based on soil description
 - Grain size distribution curves
 - Permeameter or Consolidometer
 - Slug testing (primarily for environmental projects)
- Less common methods
 - Packer testing
 - Short term pump testing (less than 8 hrs)
 - Long term pump testing (24 hrs or greater)

Hydraulic Properties

Flow:

Permeability = Hydraulic conductivity = K (units of velocity but **not** velocity)

Transmissivity = T (units of volume/time/length of flow zone thickness) $T = Kb$ where b is flow zone thickness

Storage

Storativity = **Specific Yield** = Storage Coefficient = S (unitless)

Specific Storage = $S_s = S/b$ (1/length)

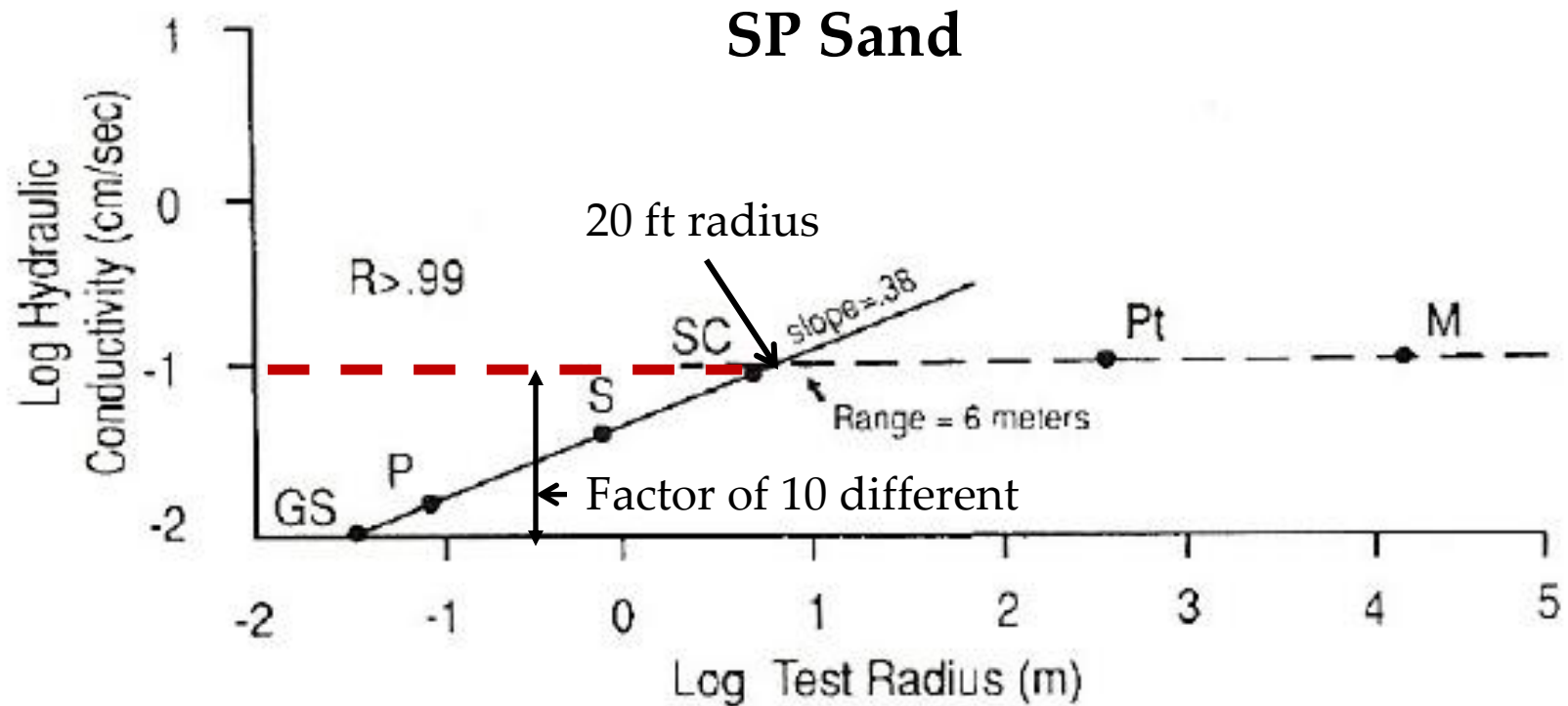
m_w = from SeepW – slope of volumetric moisture content curve = S_s/γ_w

Problems

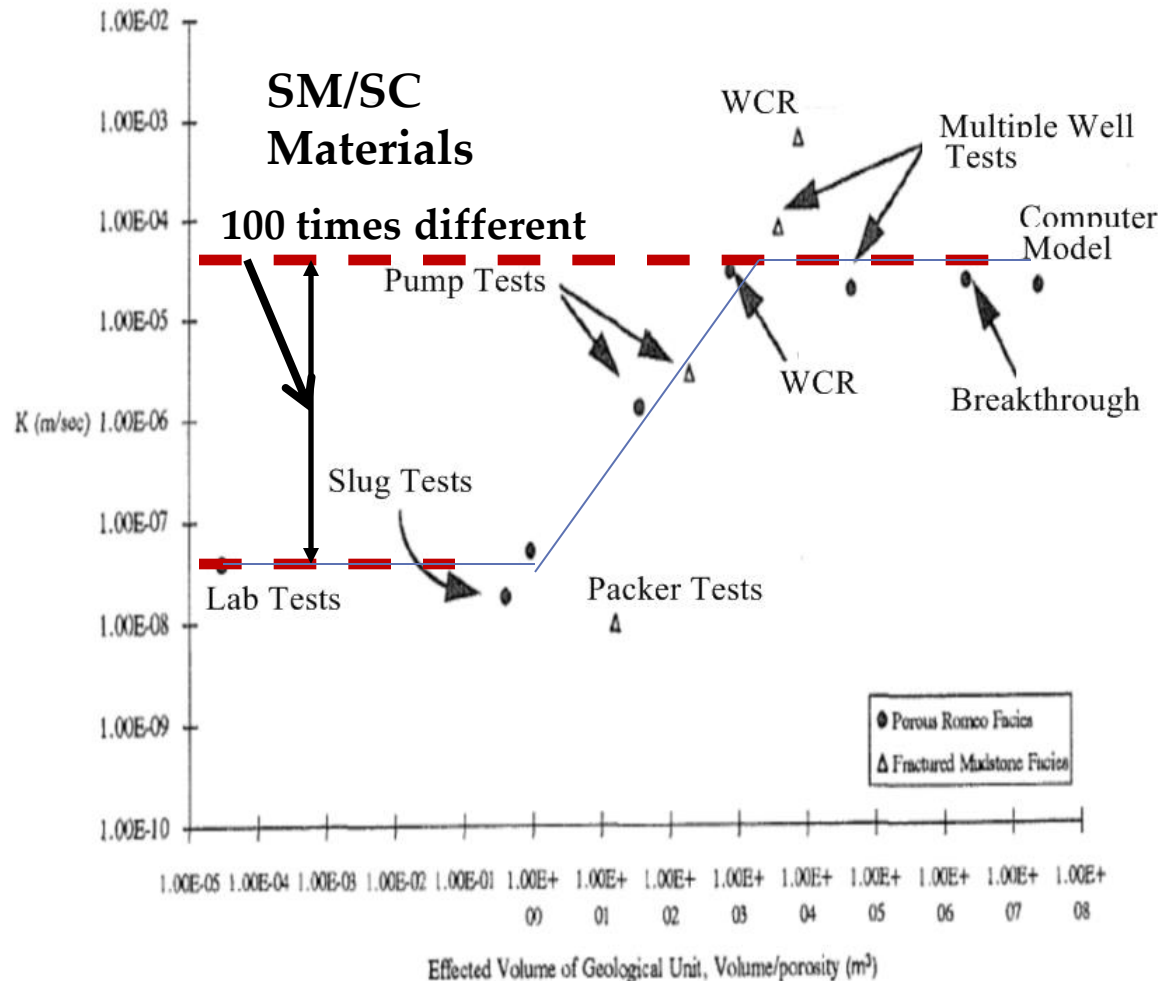
- Our sampling typically only “touches” about 30% of the soil in widely spaced borings.
- Although we complexly layer our conceptual models, we tend to think of the properties in those layers as isotropic and homogeneous.
- We rely heavily on limited testing to assign properties to our model layers.

This works fine most of the time but can be unconservative when dealing with groundwater.

Testing Size Effects



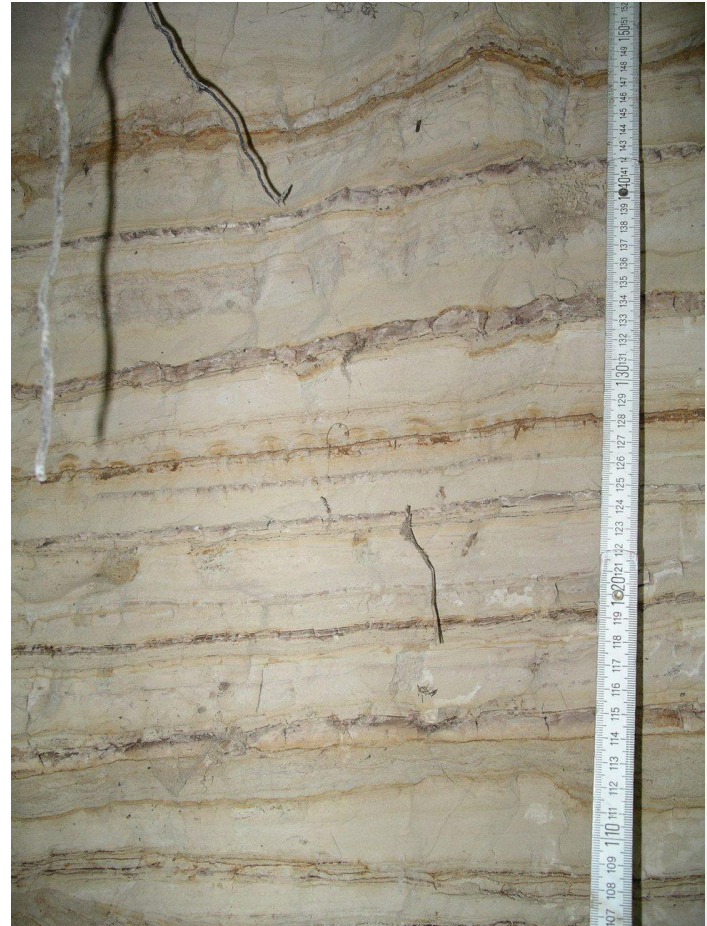
Another Example



What is the Cause?

- It is all about **volume**...the larger the volume the more anisotropy that is included.
- Permeability can easily change by orders of magnitude over short distances so inclusion of these “defects” will change mass properties.
- Small volume lab tests measure average disturbed properties (GS analysis) or vertical properties (Permeameter).
- Due to macro and micro stratification, in **sediments** the K_h is typically 10 to 100 times K_v .

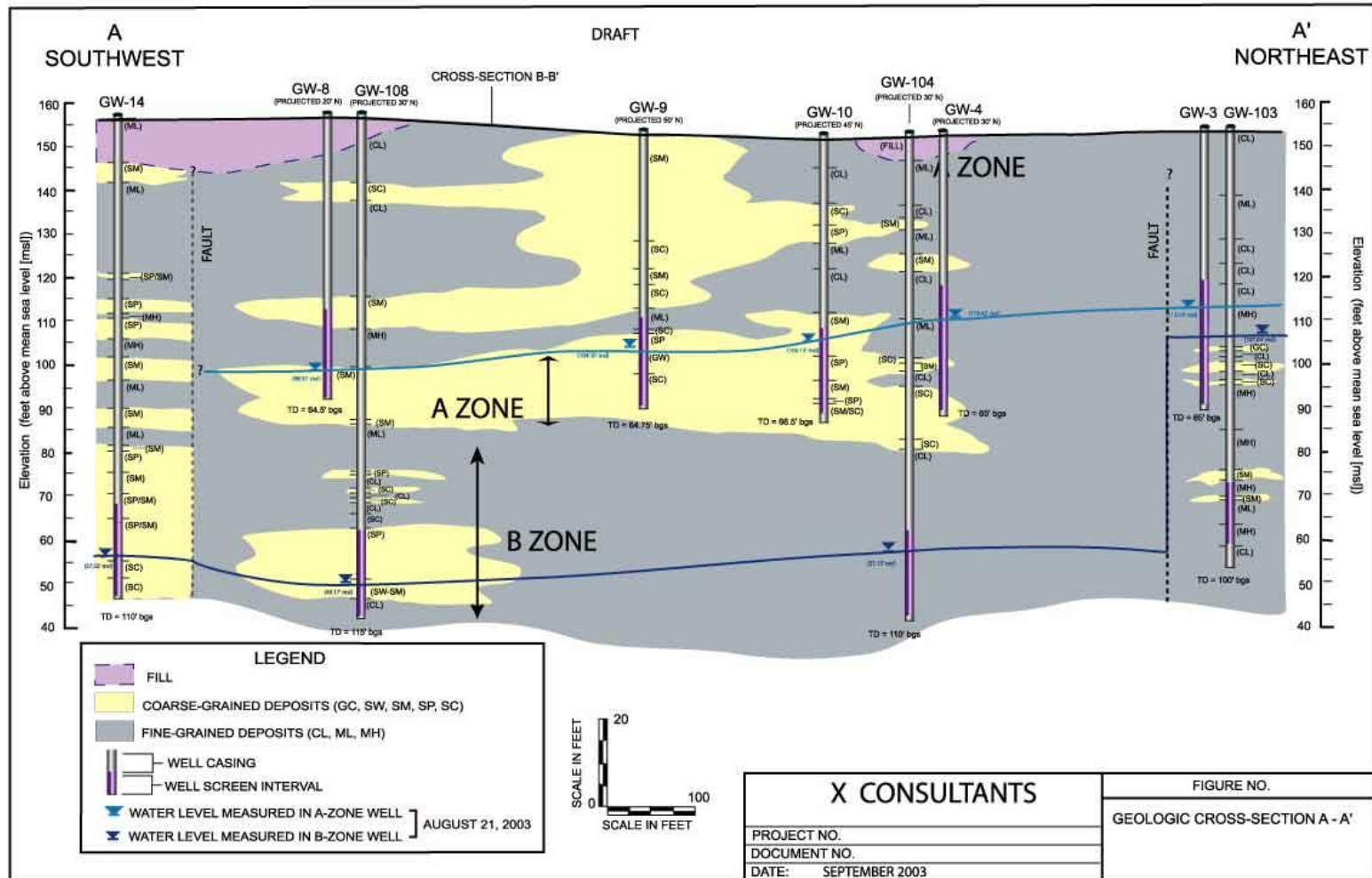
Vertical Anisotropy



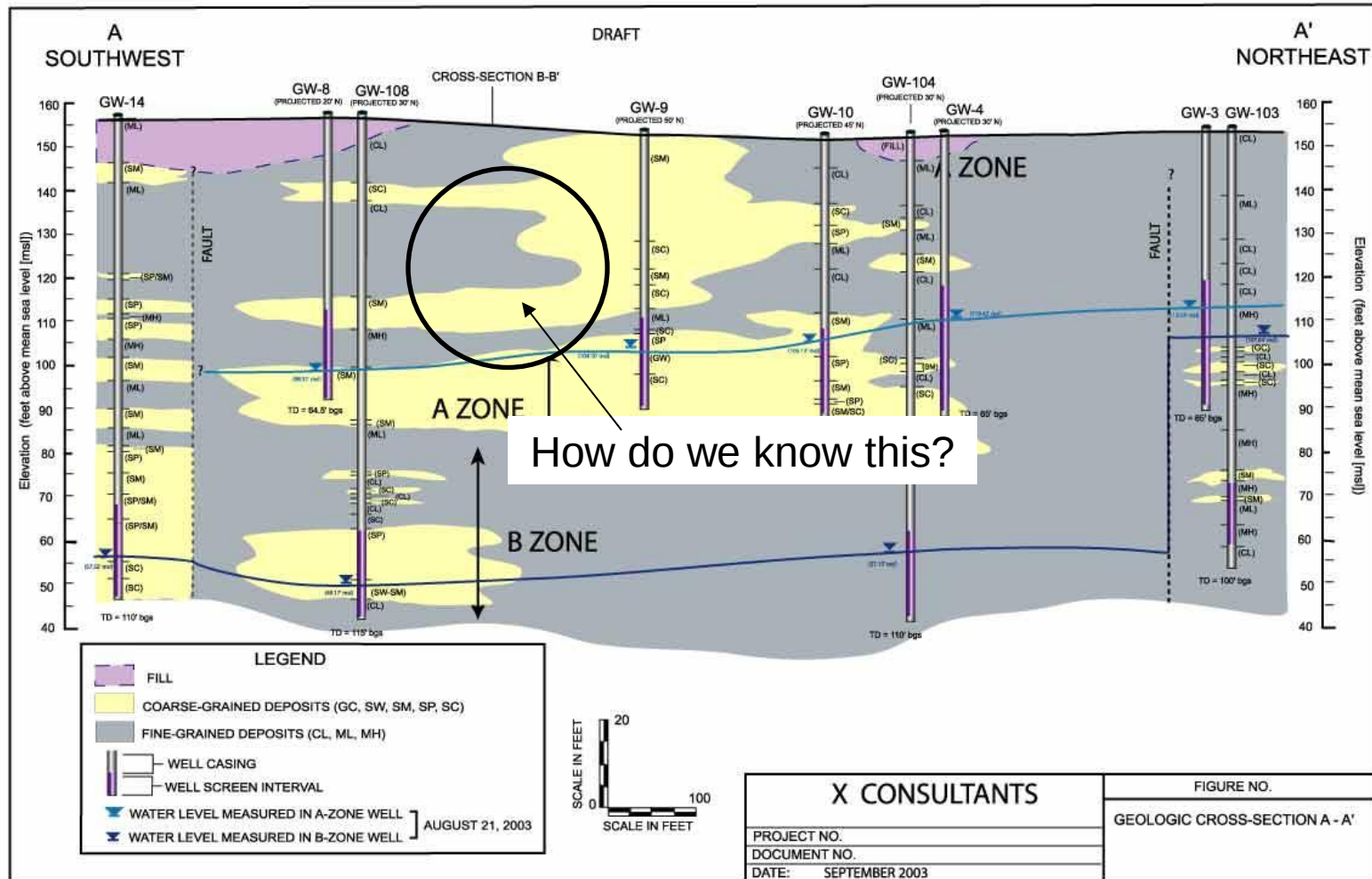
Conceptual Model

- We often oversimplify properties in our models by not recognizing the impacts of macro and micro anisotropy.
- We often over scrutinize our conceptual cross sections because of the desire to “connect the dots”.
- We don’t recognize conditions that will make water control more difficult. Low flow can be more of a problem than high flow!
- We understand the limitations of our data.

Typical Conceptual Model



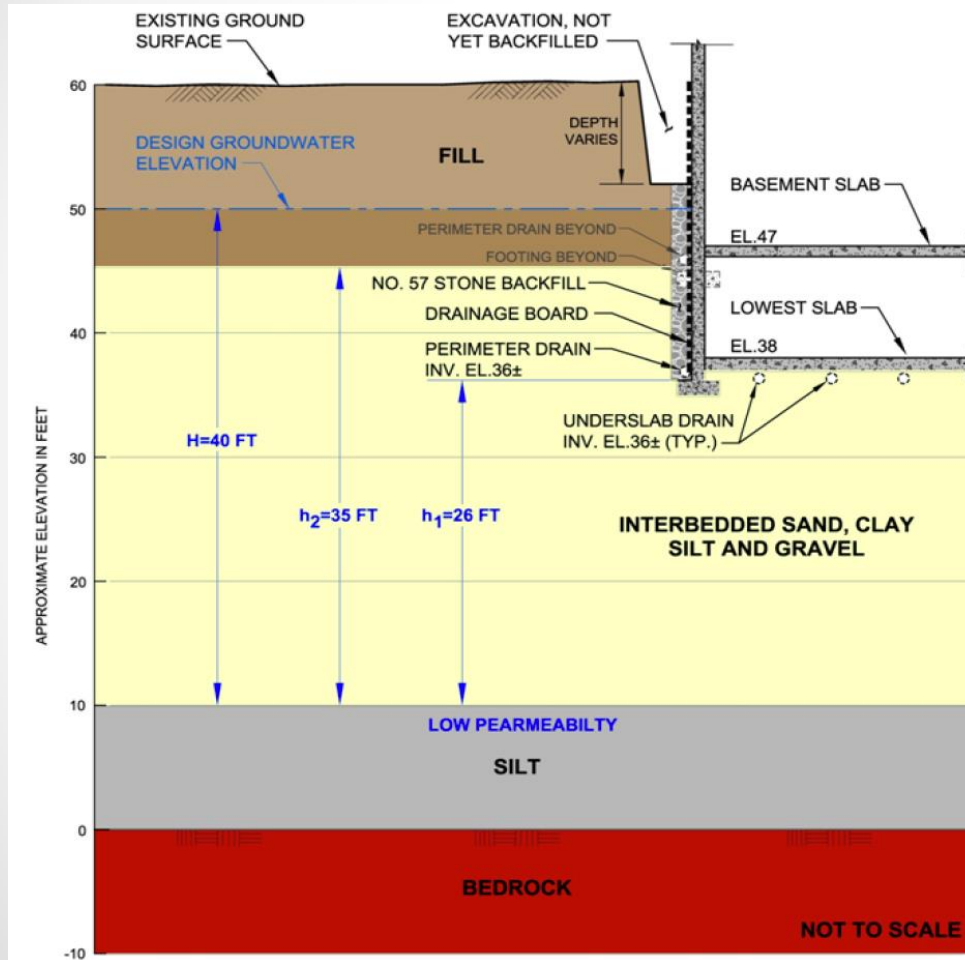
Typical Conceptual Model



Project Example

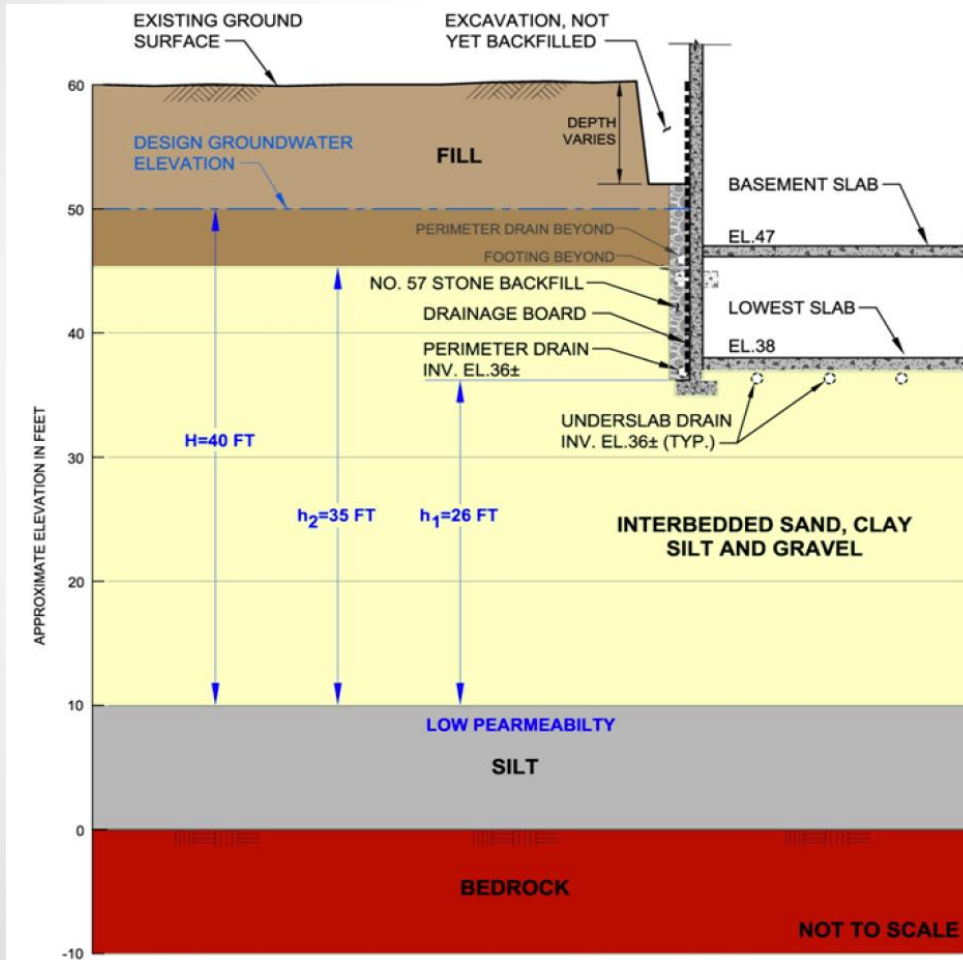
- Subdrainage system below the water table.
- Concerns raised that system may be under designed.
- Third party reviewer engaged to assess flow based on available data.
- Data available was soil borings and grain size distribution curves of sandy soils.

Conceptual Model



- Ground water level and geology based on available data.
- Flow assumed through sand, clay, silt, and gravel.
- Sieve data used for K.
- Flow assumed to be isotropic and homogeneous.
- SEEP/W used for modeling and assume steady state flow with constant head boundary at estimated edge of assumed cone of depression.

Results



- Predicted flows of up to 250 gpm and recommended design for 150 gpm.
- Original design said flow of 25 gpm or less (**uh oh**)
- Long term measurements in sumps draining subdrainage system indicate 2 to 6 gpm flow.
- Reanalysis assuming factor of 10 to 100 vertical anisotropy in flow zone resulted in predicted flow of less than 5 to 25 gpm.

Vertical Gradients

- Vertical gradients are everywhere – in virtually every place you investigate a vertical gradient will be present.
- Gradient can be up or down.
- Gradients into excavations that approach the “critical gradient” will cause soil effective stress to go to zero and liquefy.

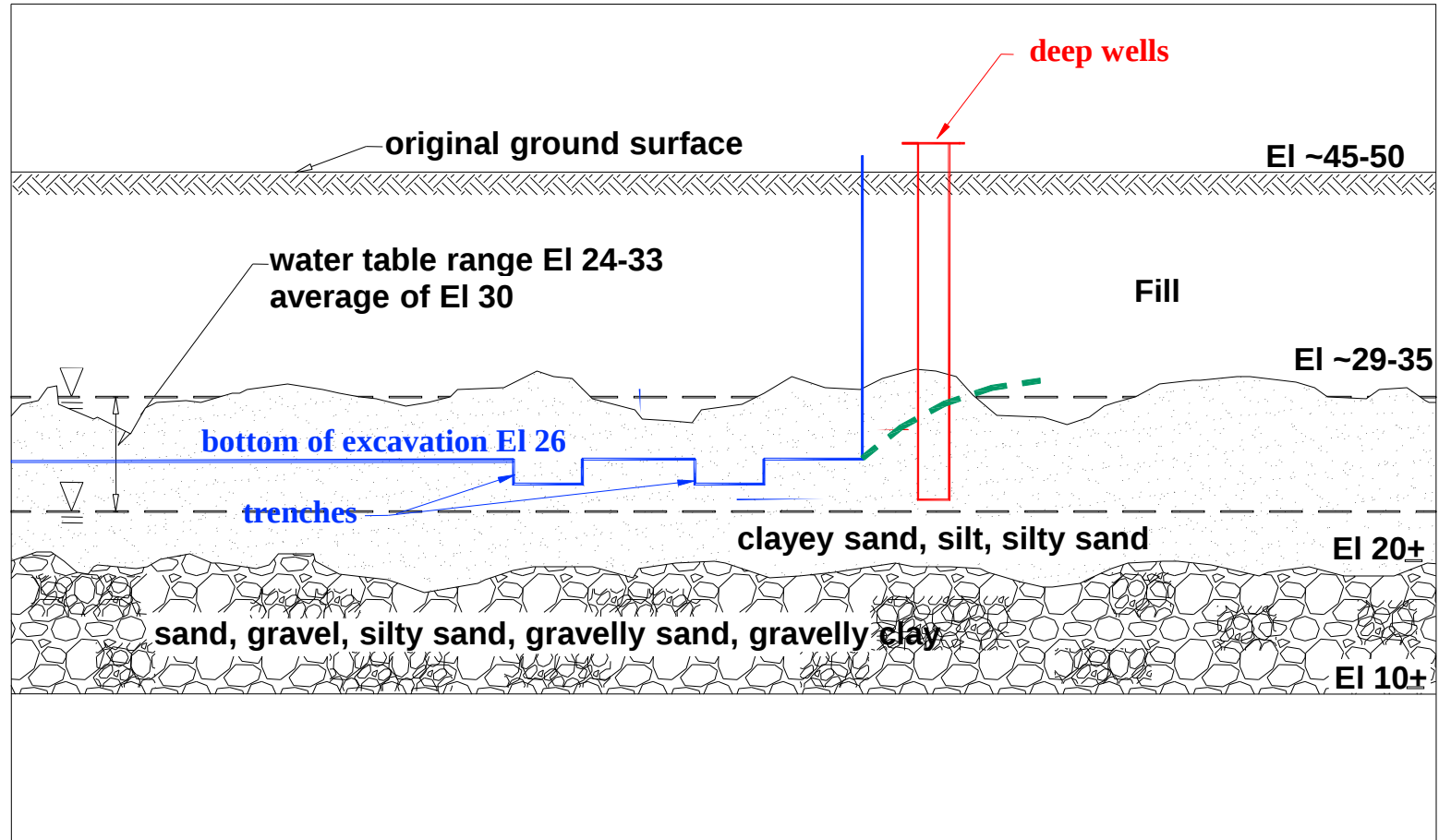
Vertical Gradients

- Often can get gradient information by watching change in water levels in borings.
- If the “upon completion” level rise overnight in multiple boring at about the same depth then a vertical gradient may be present.
- Water monitoring wells at different depths needed to verify presence.

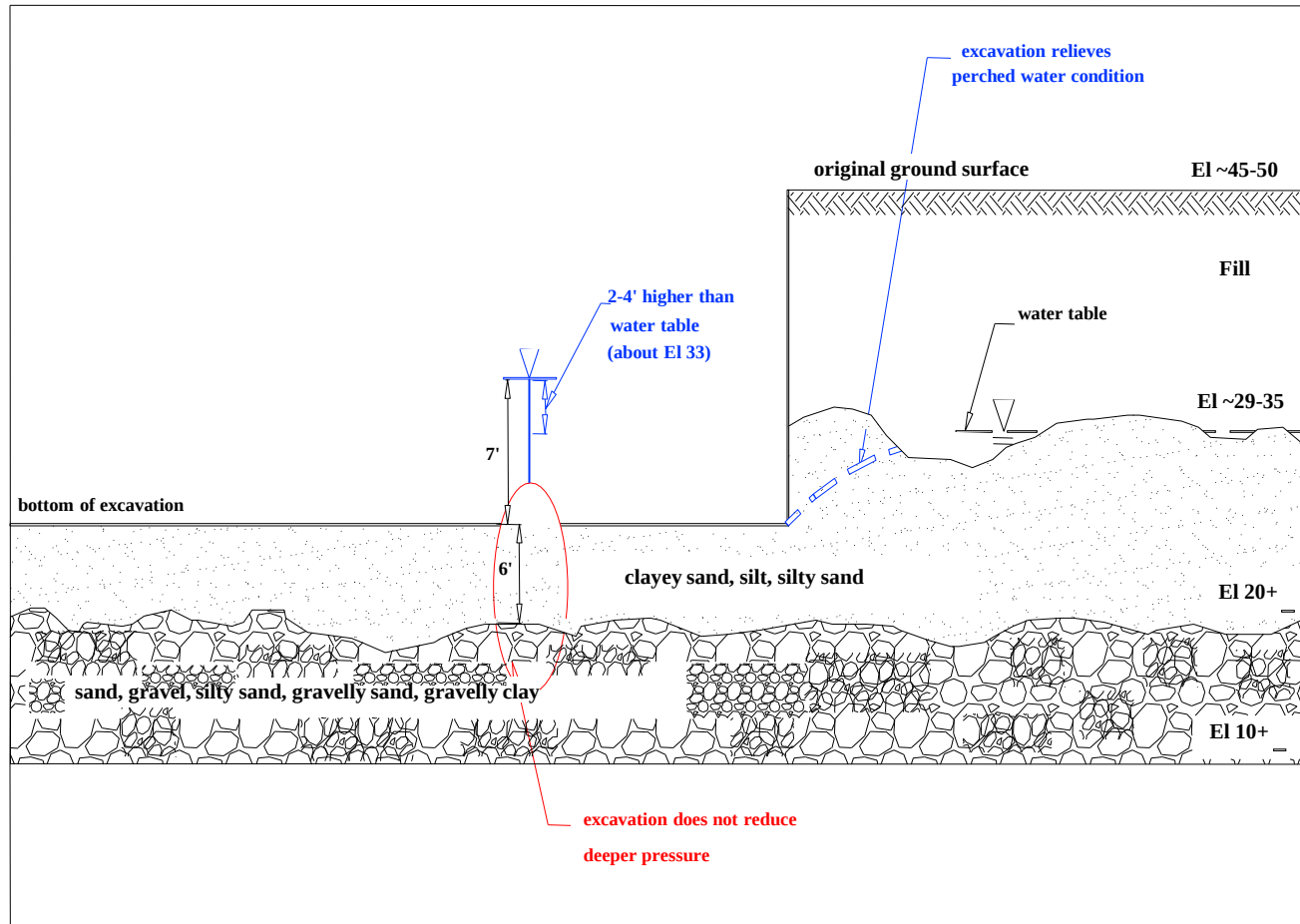
Vertical Gradient Example

- Building foundation level going below water table.
- Control of water was to be through widely spaced wells and trenches and sumps (“minimalist approach”)
- During excavation for footing, could not keep water out of footings and bottom of footings has “sand boils”.
- Resulted in contractor walking off job due to schedule delays and liquidated damages. Resulted suit against contractor for delays and damages and counter suit for incomplete design.

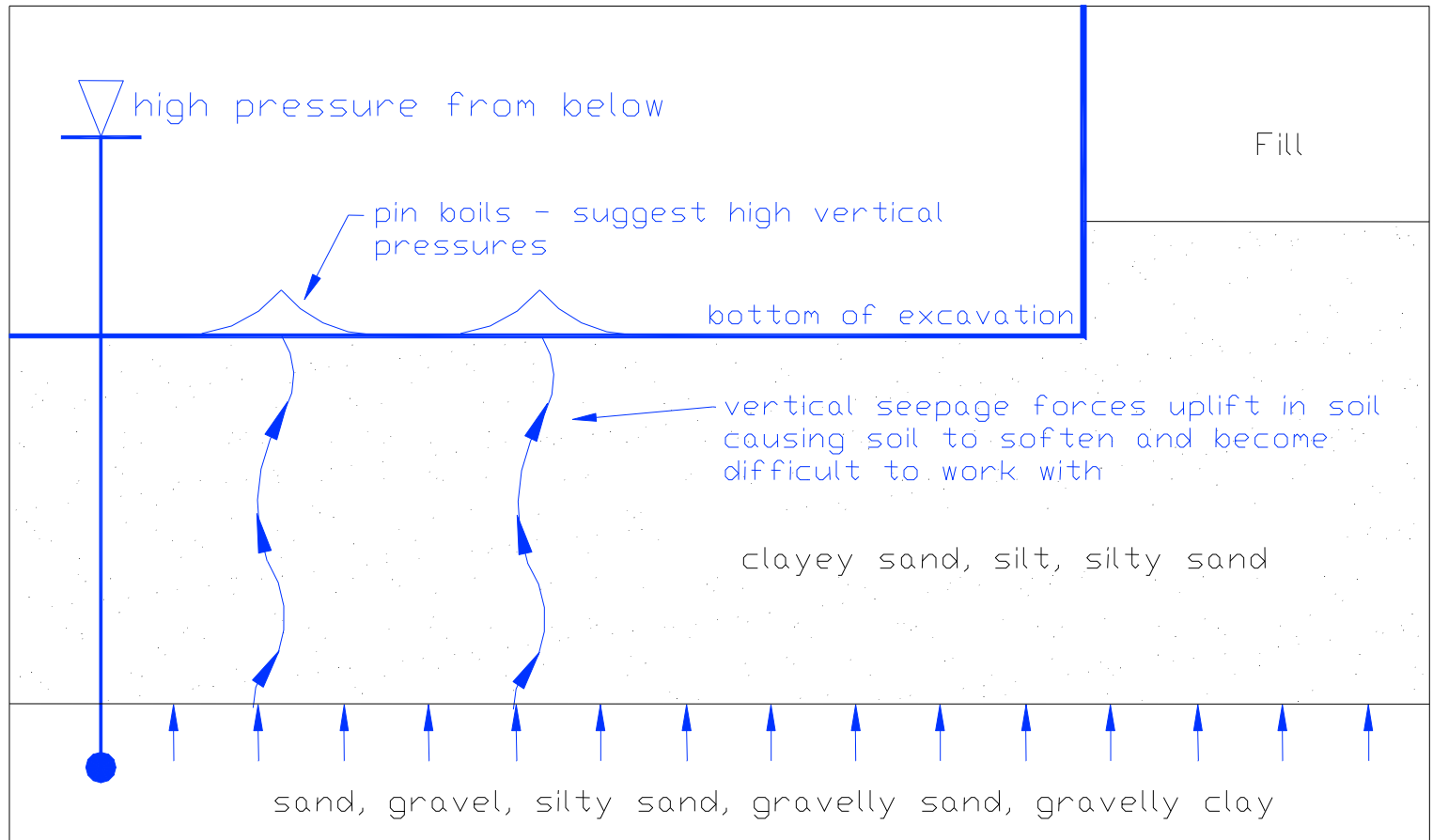
Vertical Gradient Example



What Happened



Conceptual Model



When do “pin boils” begin to show up? $i \sim 0.5$



More than \$10M later...suites are settled.

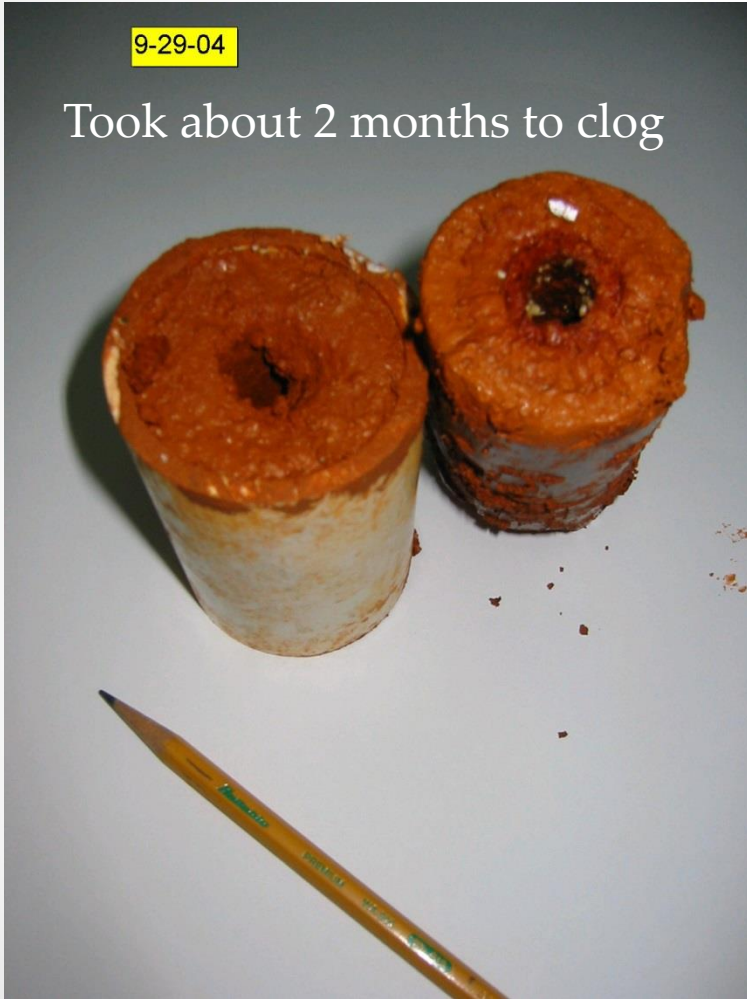
Water Chemistry

- Rarely evaluated in geotechnical reports except for environmental or concrete purposes.
- Groundwater with high iron can incrust in pipes and cause significant damage if not identified early on.
- Testing is easy and low cost although proper sampling procedures must be followed.

Incrustation/Iron Bacteria

9-29-04

Took about 2 months to clog



Corrosion

- Dissimilar metals in contact will cause corrosion.
- Certain environments promote corrosion.
- Most corrosive environments have high TDS in water and low pH



Corrosion and Incrustation

Indicators of Corrosive Water	Indicators of Incrusting Water
1. A pH less than 7	1. A pH greater than 7
2. Dissolved oxygen in excess of 2 ppm	2. Total iron (Fe) in excess of 2 ppm
3. Hydrogen sulfide (H_2S) in excess of 1 ppm, detected by a rotten egg odor	3. Total manganese (Mn) in excess of 1 ppm in conjunction with a high pH and the presence of oxygen
4. Total dissolved solids in excess of 1,000 ppm indicates an ability to conduct electric current great enough to cause serious electrolytic corrosion	4. Total carbonate hardness in excess of 300 ppm
5. Carbon dioxide (CO_2) in excess of 50 ppm	
6. Chlorides (Cl) in excess of 500 ppm	

(Courtesy of UOP Johnson Division)

Thank You For Your
Attention

Questions or Discussion?