Reconsidering Horizontal to Vertical Well Ratios for Site Clean-up

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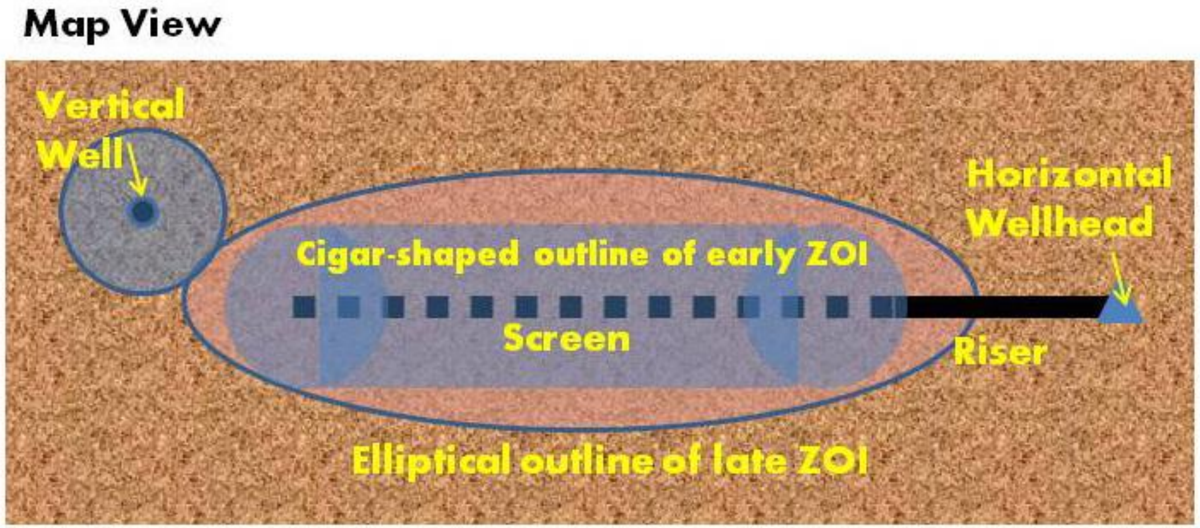
March 19th, 2019; Session 4: A renaissance in the Use of Horizontal Wells (4:00 – 4:30 pm)

Reconsidering Horizontal to Vertical Well Ratios for Site Clean-up

- Directional drilling has been used for a variety of purposes; utilities, dewatering, and remedial activities. Cutting costs for remedial activities it is always of consideration. What the costs are to clean-up a site via traditional vertical extraction wells versus using a horizontal well system needs to be reconsidered based upon todays remedial challenges. Traditionally, it has been stated that a single horizontal well is worth 4-11 vertical wells. This seems arbitrary in that both depth of the system and hydrogeological conditions play a large role that does not seem to be considered. A better way to evaluate the cost benefit of one system over another is to base it on the number of vertical wells per linear foot of directional well and base it more on zone of influence of both designs.

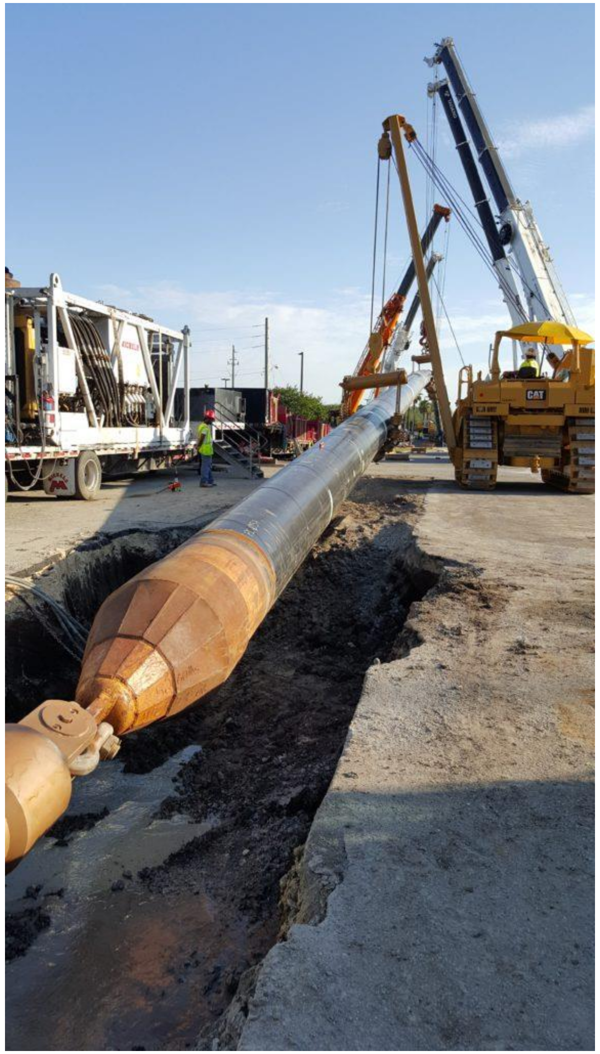
Content

- History
- Horizontal Wells
- Capture Area
    - Purpose of Well
    - Fluid
    - Geology
    - Extraction Rate (Q)
- Vertical to Horizontal Well Ratios
- Conclusions



History

- Yes we stole it from the oil industry!
  - First recorded installation 1942.
  - 1980’s really got off the ground.
  - Late 1980’s began to be used in the environmental field.



- More common now that in past.
- Better technology for locating and directing tools.
- More contractors familiar with horizontal/directional drilling.

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Horizontal Wells

- Remediation
  - Extraction (SVE)
  - Groundwater Extraction
  - Injection (sparging)
  - Bio-venting
  - Free product recovery

  - Monitoring
  - Mining
  - River Crossing
  - Dewatering

- Advantages over vertical wells

  - The wellhead does not need to be directly over the well.
  - The screen orientation coincides with the major axis of most remediation targets.
  - Fewer wells are required, thus more cost-effective over the life of the remediation project.

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Plumes under buildings or landfills also can be monitored or characterized using horizontal wells.

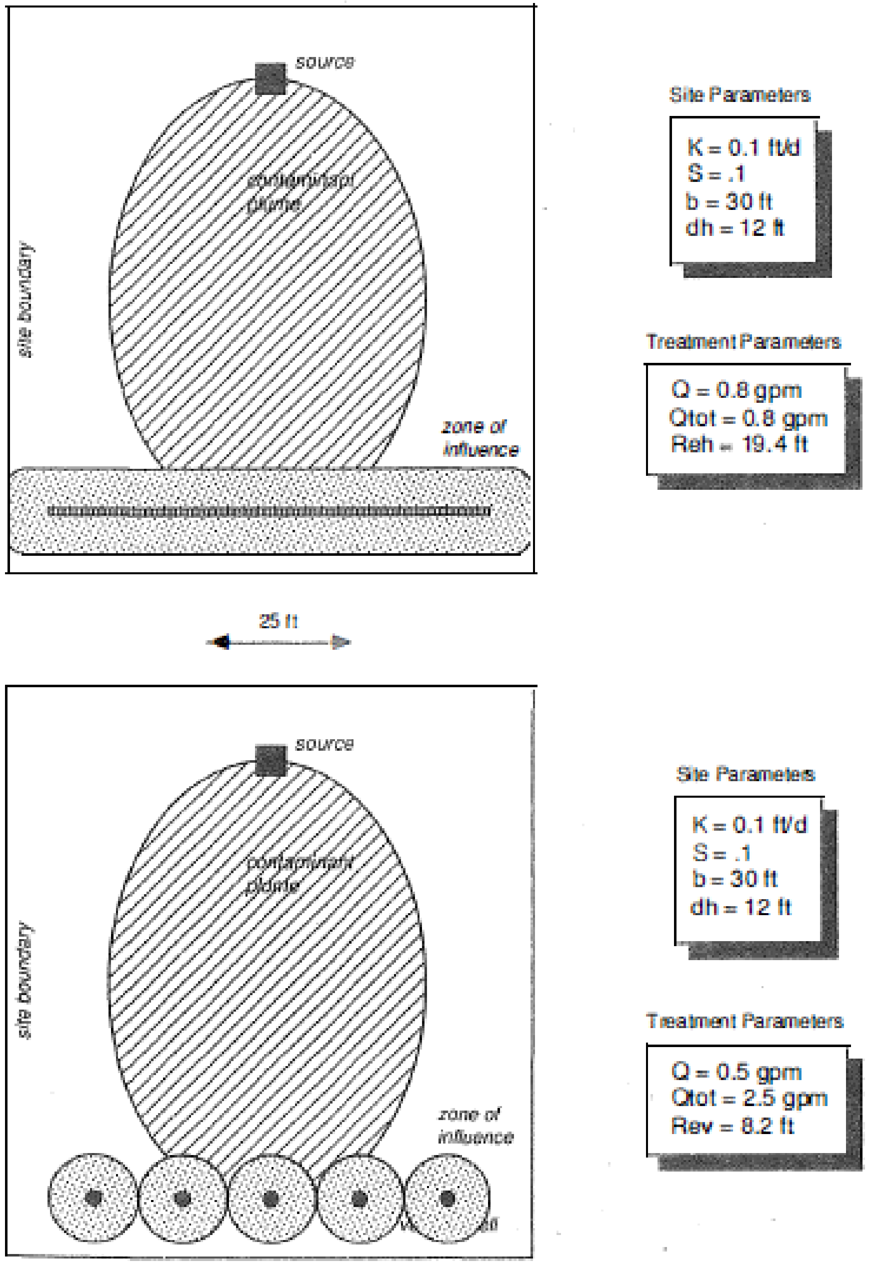
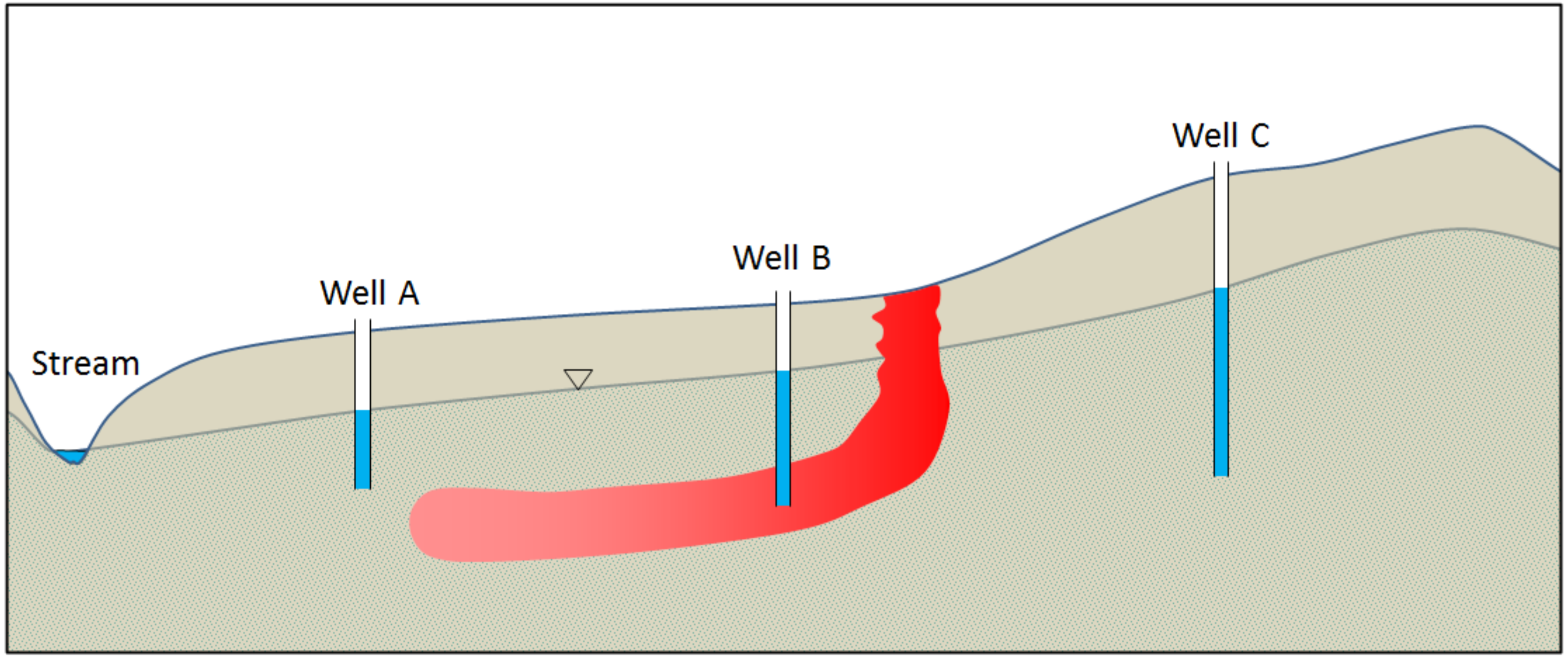


Figure 4
Groundwater Recovery



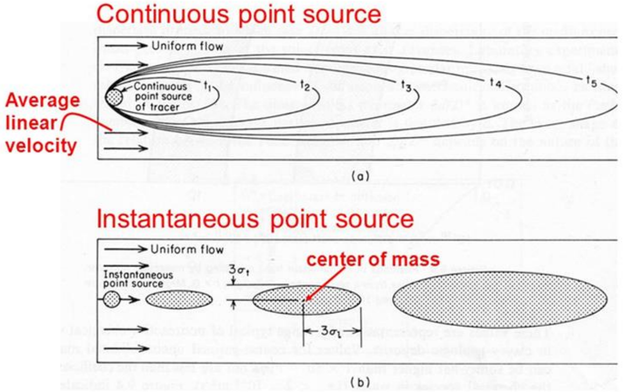


Figure from Freeze & Cherry (1979)

How many vertical wells can be replaced by a single horizontal/directional well

- From 1 - ? (Laton, 2019)
- 1-30 vertical wells/horizontal well (Parmentier & Klemovich, 1996)
- 1-11 (Wilson, Kaback and Oakley, 1990's)
- 5-10 (Karlsson, 1993)
- 1-8 (Fileccia, 2015)

- Others who have studied this include:
  - Cleveland, 1994
  - Zhan and Coa, 2000

Case Studies

Horizontal wells may offer more significant advantages over vertical wells where the target is an unconfined aquifer with a small cone of depression, i.e. a low-permeability site. At **Williams Air Force Base**, models estimated that one horizontal well could replace 80 vertical wells, due to the low permeability of the formation.

On the other hand, at a sandy site such as **Savannah River Site**, tests showed that one horizontal well could replace five vertical wells undergoing soil vapor extraction for removal of volatile organics in the unsaturated zone above the water table.

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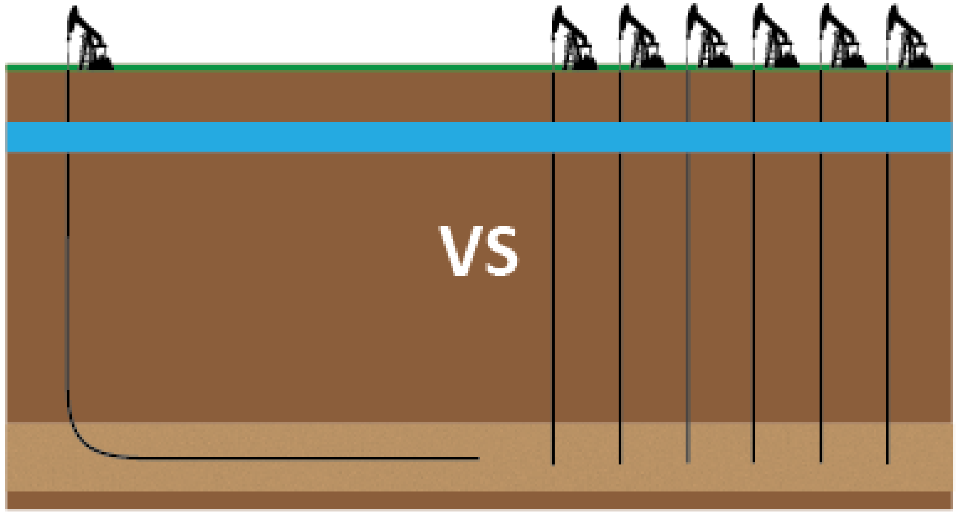
Things to Consider?

- This seems arbitrary in that both depth of the system and hydrogeological conditions play a large role that does not seem to be considered.

- A better way to evaluate the cost benefit of one system over another is to base it on the number of vertical wells per linear foot of directional well and base it more on zone of influence of both designs.

Vertical to Horizontal Well Ratios

Traditionally, it has been stated that a single horizontal well is worth 4-11 vertical wells.



- BUT WHY?
  - Why not 100 or more?

- This does not take into consideration, geology, hydrogeology, type of fluid, etc.

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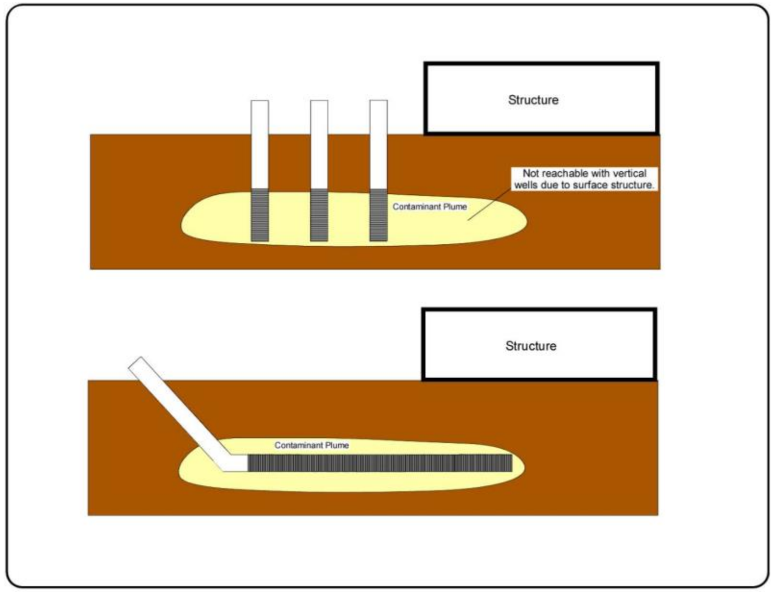
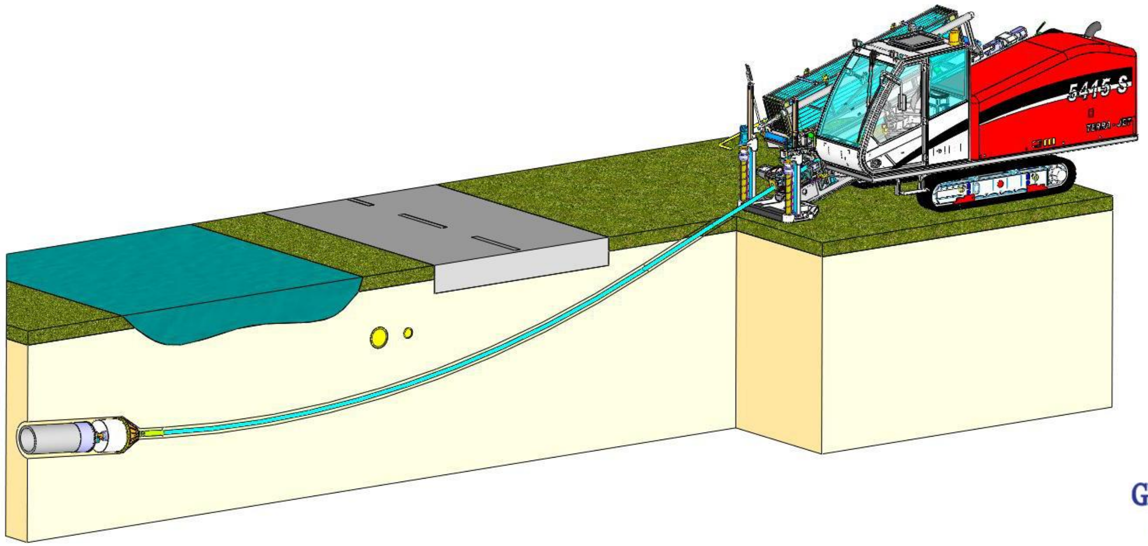
What is the Capture Area – Area of Influence?

- Capture area v. Cone of depression
- Radial Drainage v. trench

- Purpose
- Fluid type
- Geology
- Extraction/Injection Rate





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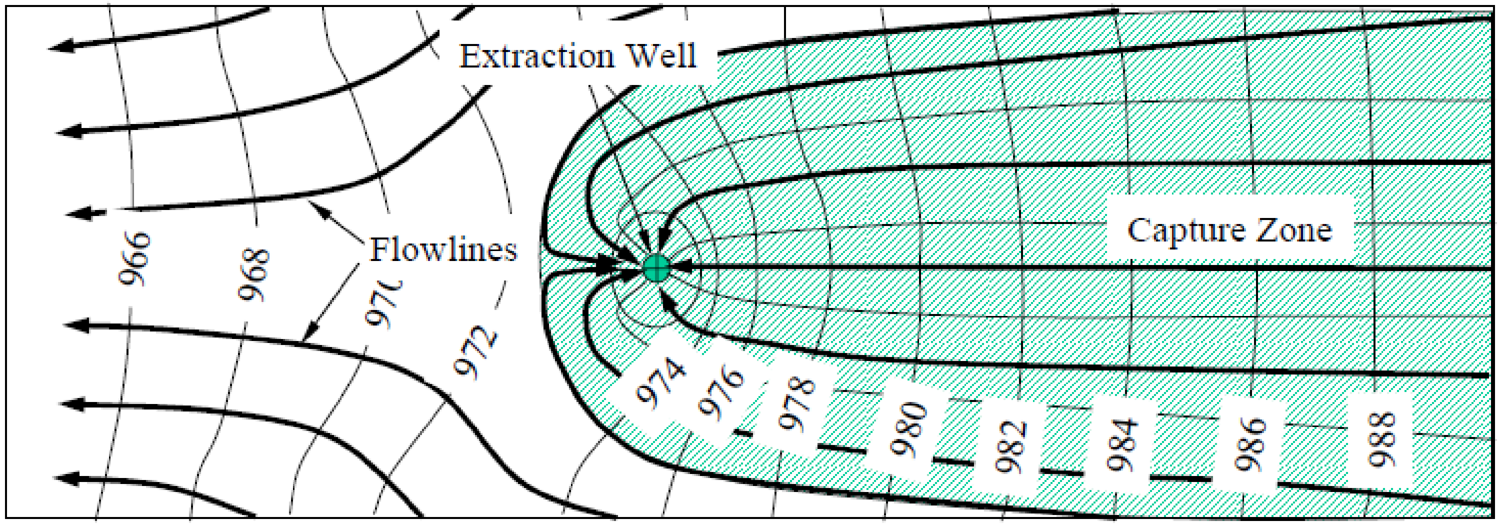
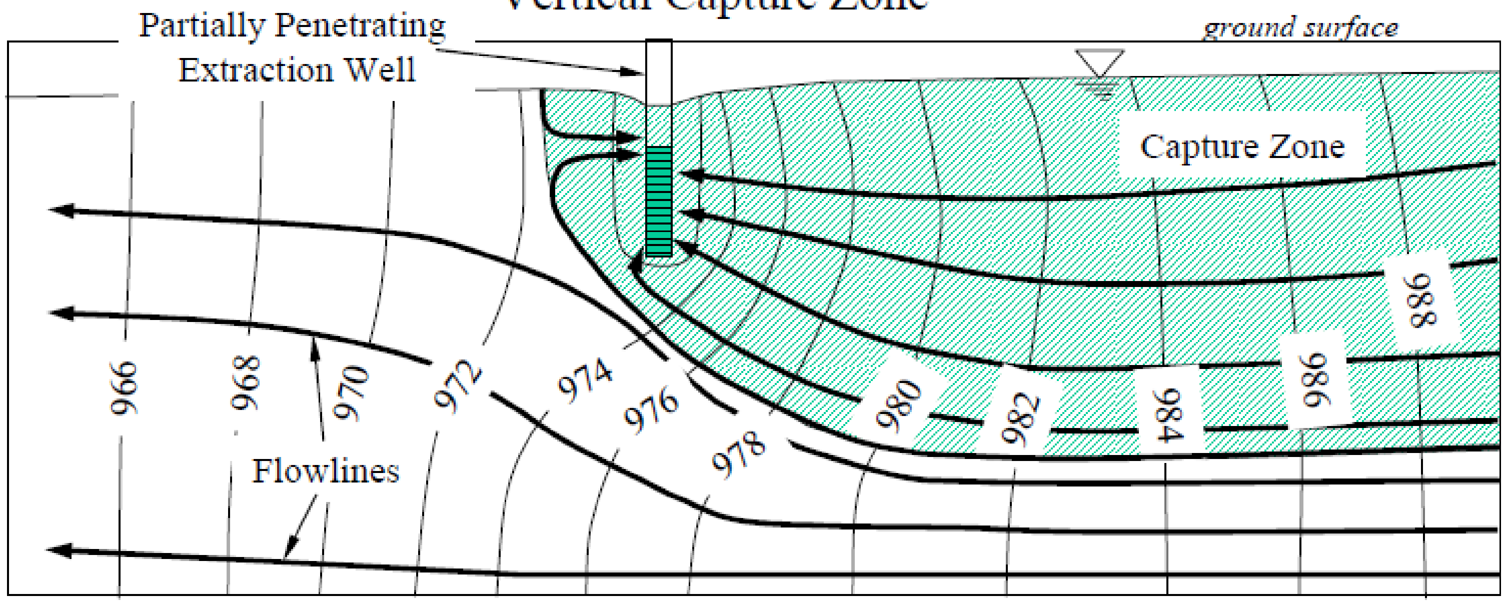
Capture Zone Schematic

Horizontal Capture Zone



Vertical Capture Zone



Greenwald, R. and Burden, D., 2005

Zone of Influence (Effective Drainage Radius)

- Horizontal Well

- $R_{eh} = \sqrt{[R_{ev}\sqrt{[(L/2)^2 + R_{ev}^2]}]}$
  - R_{eh} = effective drainage radius of a horizontal well
  - R_{ev} = effective drainage radius of a vertical well
  - L = screen length

- Vertical Well

- $R_{ev} = (3/2)\sqrt{[Tt/S]}$

Using Jacobs method
  - T = transmissivity
  - t = time
  - S = storage

For a horizontal well to replace *n* vertical wells, its length must be *2n* greater than R_{ev}.

Source: Losonsky, G. and Beljin, M.S., 1992

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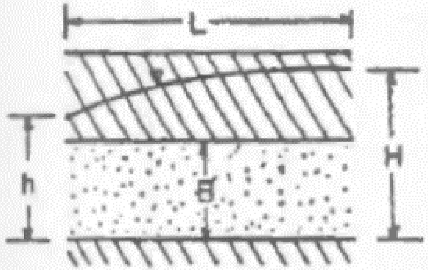
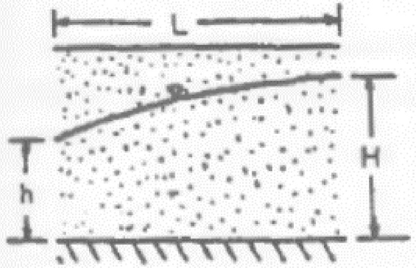
Zone of Influence (flow to a line/trench sink)

	Basic Equation	US units	Metric units
	$\frac{Q}{x} = \frac{KB(H-h)}{L}$	$\frac{Q}{x} = \frac{KB(H-h)}{1440L}$	$\frac{Q}{x} = \frac{KB(H-h)}{1.67 \times 10^{-5}\ L}$

Confined flow from a line source to a drainage trench

x = unit length of trench, for flow from 2 sides, use twice the indicated value
K = hydraulic conductivity

	Basic Equation	US units	Metric units
	$\frac{Q}{x} = \frac{K(H^2-h^2)}{2L}$	$\frac{Q}{x} = \frac{K(H^2-h^2)}{2880L}$	$\frac{Q}{x} = \frac{K(H^2-h^2)}{3.34 \times 10^{-5}\ L}$

Water table flow from a line source to a drainage trench

x = unit length of trench, for flow from 2 sides, use twice the indicated value
K = hydraulic conductivity

Source: Powers, 1992

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Purpose of Horizontal Well

- Remediation
  - SVE
  - Air Sparging
  - Injection
  - BioVenting
  - Monitoring
- Dewatering
- Production well
  - Ranney Well
  - Radial Well
- Construction, River crossing, mining, etc.

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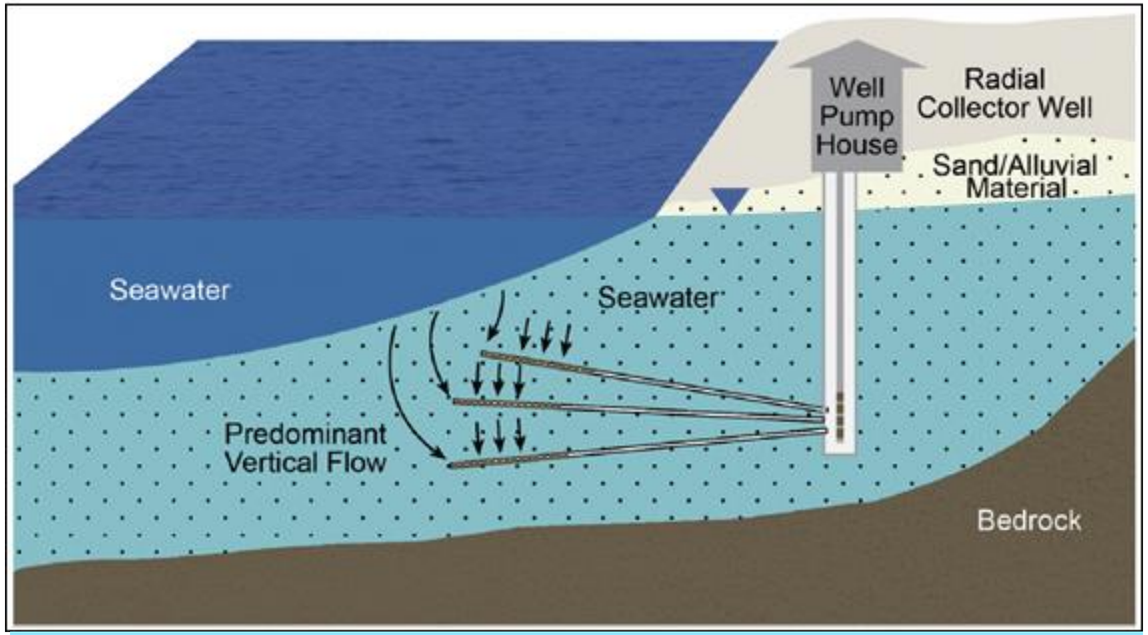
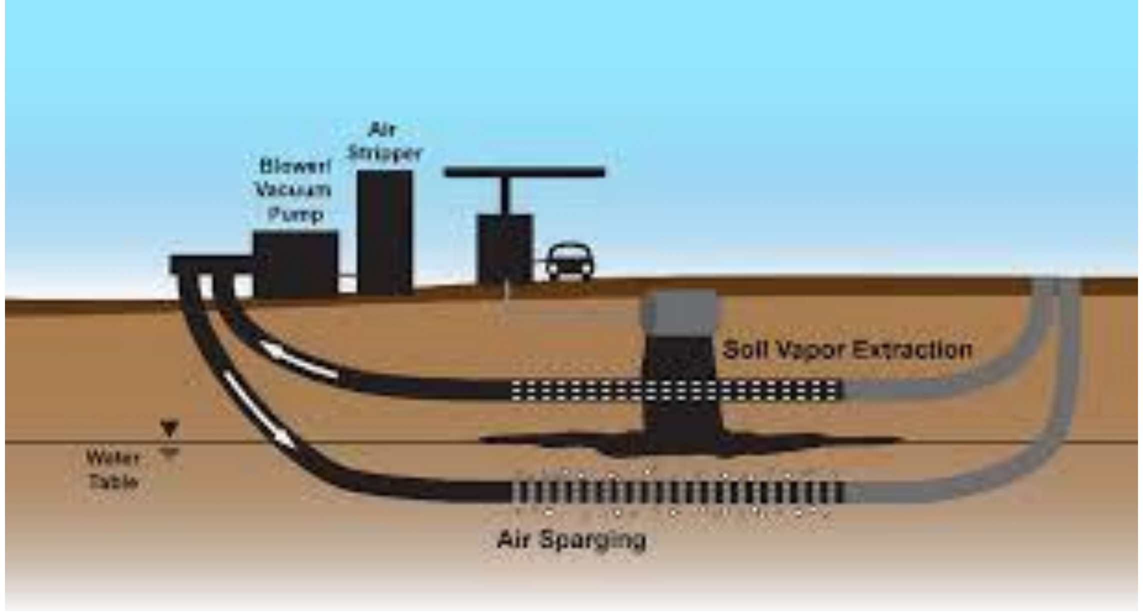
Fluid Type

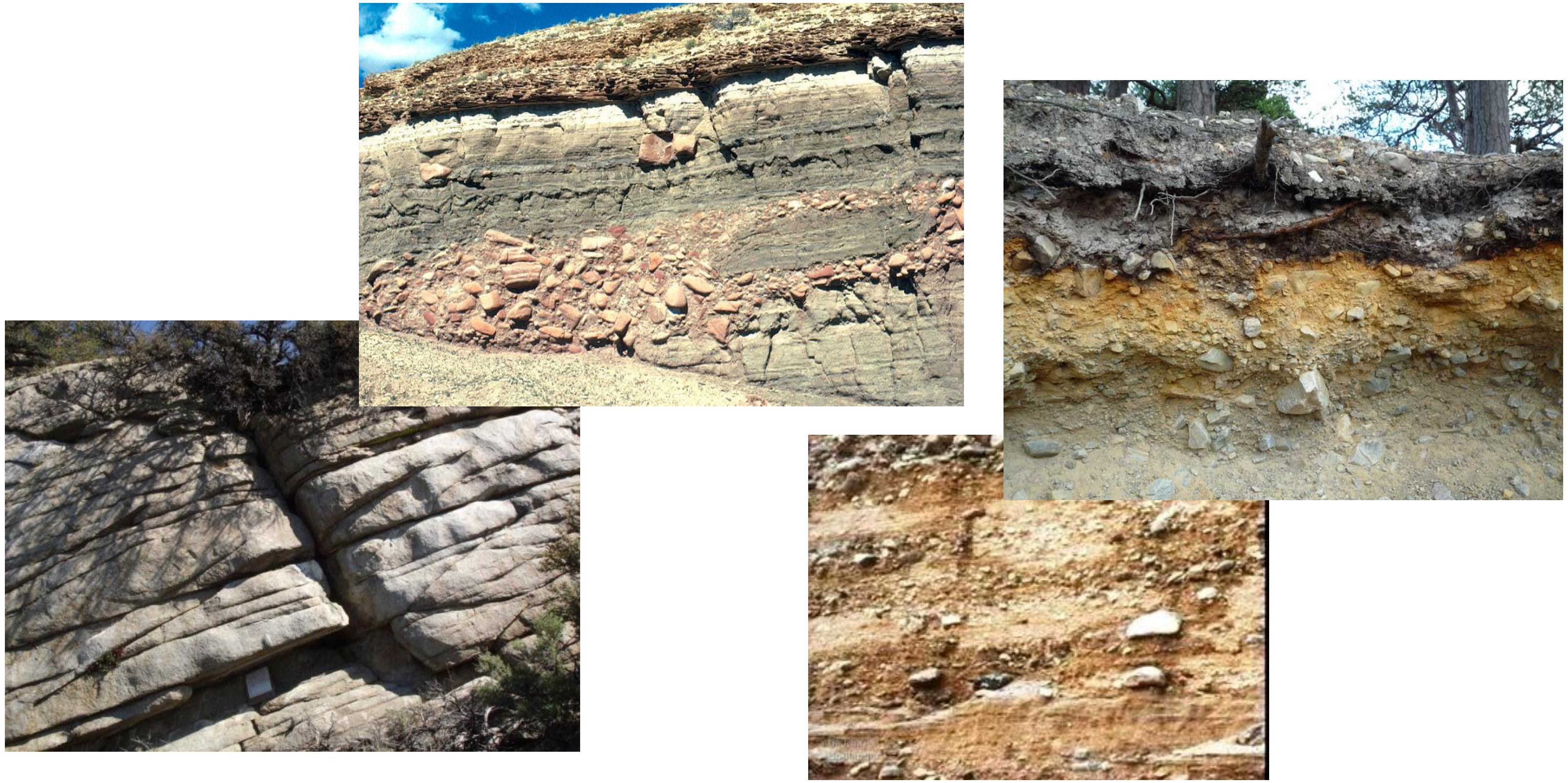
- Vapor
- Groundwater
- Sea water
- Petroleum
- Other contaminants

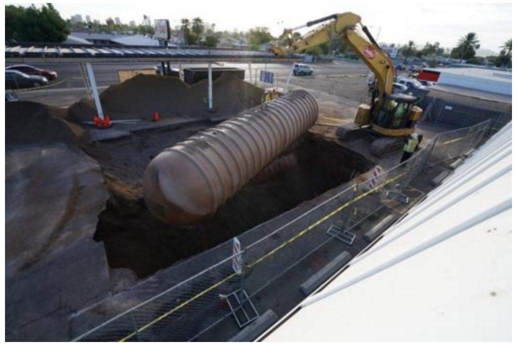


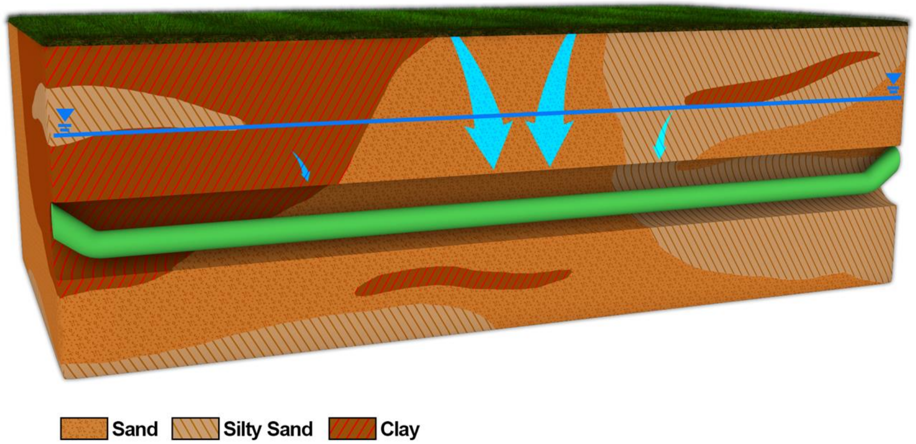


Geology

- Geology
  - Alluvium
  - Bedrock
- Depth
  - Shallow
  - Deep
- Hydrogeology
  - Groundwater
  - Depth of placement







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Examples of Geology and Radius of Influence

Tab. 1 - Variation of radius of influence due to hydraulic conductivity (Bogomolov, Silin 1955).

Tab. 1 - Variazione del raggio di influenza con la conducibilità idraulica (Bogomolov, Silin 1955).

Soil type	min diameter (mm)	max diameter (mm)	K min (m/d)	K max (m/d)	min discharge (l/s)	max discharge (l/s)	Radius of influence (m)
silt	0,01	0,05	0,5	5	0,03	0,1	65
fine sand	0,1	0,25	10	25	0,14	0,5	75
medium sand	0,25	0,5	20	50	0,16	5,5	100
coarse sand	0,5	2	35	75	5	14	125
gravel	2	50	60	125	11	30	150

For Vertical Wells

Acque Sotterranee - *Italian Journal of Groundwater* (2015) - AS14065: 007 - 023

Extration Rate (Q)

- Pumping
- Injections
  - Material/Fluid that is being injected

- The larger the tweak the bigger the bang!

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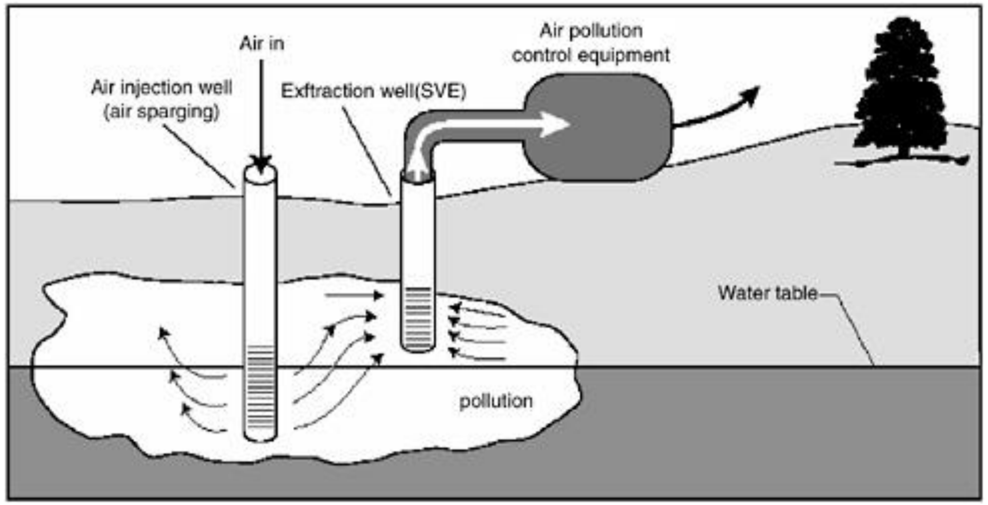
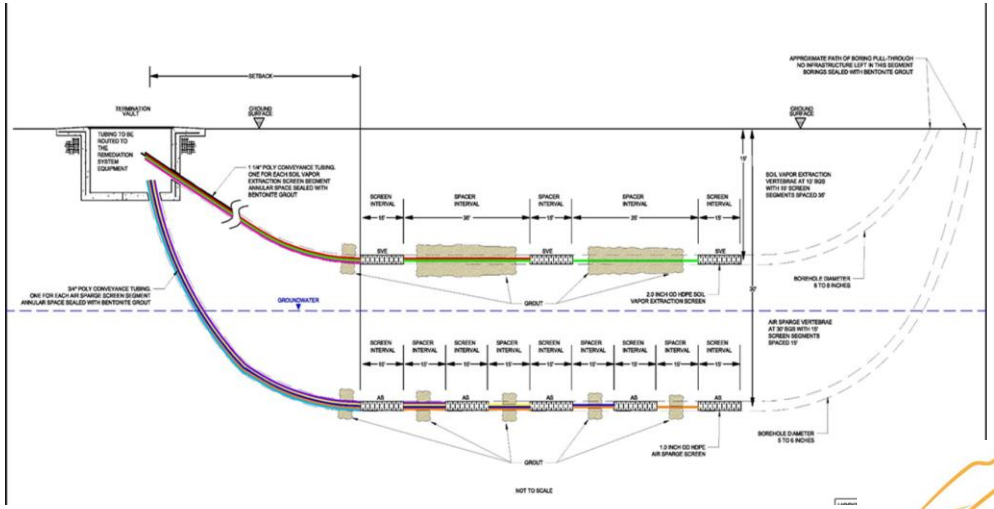
Solution

- (# vertical wells) / (linear-foot of horizontal well)
- But known hydraulic conductivity and pumping rate needs to be included in any calculation.
- Presently working with students to come up with a simple solution that can be used by the stake holders to determine the cost effectiveness of horizontal wells v. vertical wells for a variety of situations!





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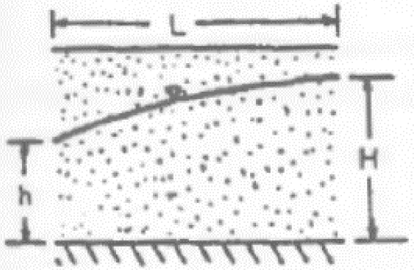
Horizontal v. Vertical



Water table flow from a line source to a drainage trench

Basic Equation

$$\frac{Q}{x} = \frac{K(H^2 - h^2)}{2L}$$

US units

$$\frac{Q}{x} = \frac{K(H^2 - h^2)}{2880L}$$

Metric units

$$\frac{Q}{x} = \frac{K(H^2 - h^2)}{3.34 \times 10^{-5} L}$$

x = unit length of trench, for flow from 2 sides, use twice the indicated value
K = hydraulic conductivity

Horizontal Well

$R_{eh} = \sqrt{[R_{ev}} \sqrt{[(L/2)^2 + R_{ev}{}^2]}$

V.

Vertical Well

$R_{ev} = (3/2)\sqrt{[Tt/S]}$

Do we have enough data to solve?

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Conclusions

We need to relook at the Horizontal to Vertical Well Ratios for Site Clean-up

- The industry needs a simple approach that takes geology, fluid and flow rate into consideration while determining the cost effectiveness of using horizontal wells v. traditional vertical wells
- New economics have come into play that have the potential to lower installation costs of horizontal wells.
- Despite past work (primarily in the 90's), there still exists work to be done.
- Horizontal well installations may be more costly than vertical well installations at some sites, costs for the life cycle remediation are likely to be less with the horizontal well system than for the vertical well system for a variety of factors, including a shorter remediation timeline.
- Sites containing vertical fractures and thin aquifers are especially appropriate for horizontal well applications.

It takes a number of vertical wells to equal a single horizontal well!

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Questions?

Recently donated to CSUF by the John Gregg Family Foundation