Actions for Management of Groundwater Quantity

(This is a matter of controlling recharge and consumptive use. Keep return flows in mind!)

Promote Conservation

Control / Adjust:

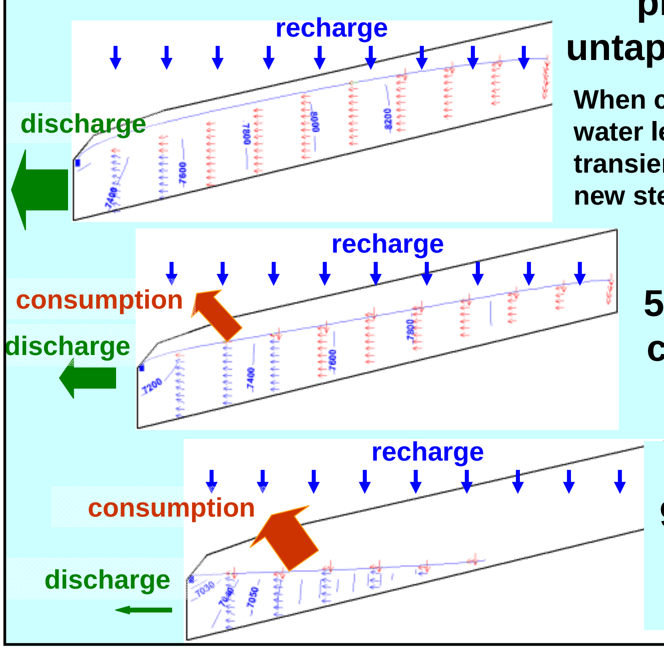
land use

water price structure

timing of water withdrawal and use

treatment and reuse practices

Consumptive use will alter basin balance



pristine untapped basin

When consumption begins water levels decline during a transient period then reach a new steady state

steady state 50% of recharge consumed each yr

steady state 90% of recharge consumed each yr

SAFE YIELD:
Amount of water that can be withdrawn annually from a ground water basin without producing an undesired result.

OVERDRAFT: Withdrawal over this amount.

UNDESIRED RESULT:
depletion of groundwater reserves
intrusion of water of undesirable quality
interference with existing water rights
deterioration of economic advantages of pumping
excessive depletion of stream flow
land subsidence

OPTIMAL YIELD:
all social and economic conditions considered
alternative overall management plans evaluated
cost-benefits considered
optimal plan selected

Entities are entitled to use of natural water as defined by law in the form of **WATER RIGHTS**

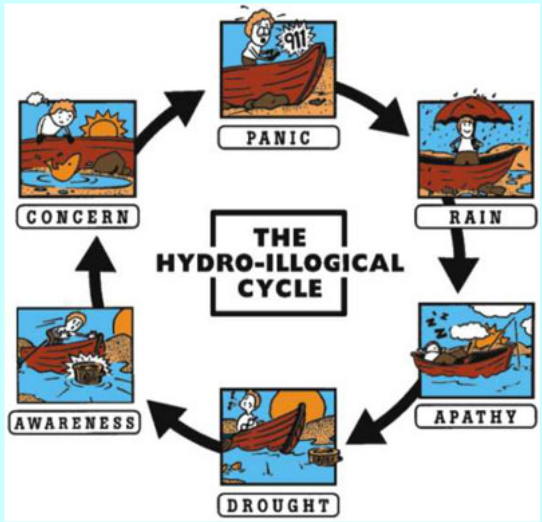
Two major doctrines for water rights law in the U.S.

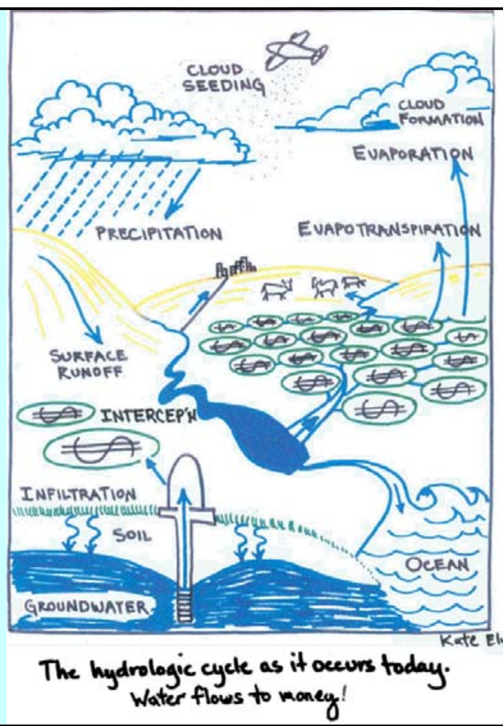
RIPARIAN RIGHTS
Based on land ownership contiguous to natural water supply
Rights to water cannot be transferred separately from the property
Depends on "reasonable use" relative to other riparian owners
Water cannot be transferred out of the watershed

PRIOR APPROPRIATION
Public owns water and grants rights to use
Earlier rights have preference over later
Each water right has a yearly quantity and an appropriation date
When sold the right carries its original appropriation date, but only the amount of water historically consumed can be transferred
If the water right is not used for a beneficial purpose for a period of time it may lapse

Unlike other natural disasters, drought does not have a clear beginning and end so our reaction to drought is not timely

http://www.drought.unl.edu/plan/cycle.htm





Agriculture is the biggest water user

see

"Running Dry"

Economist article from Sep 2008

There is a link from class web page for today

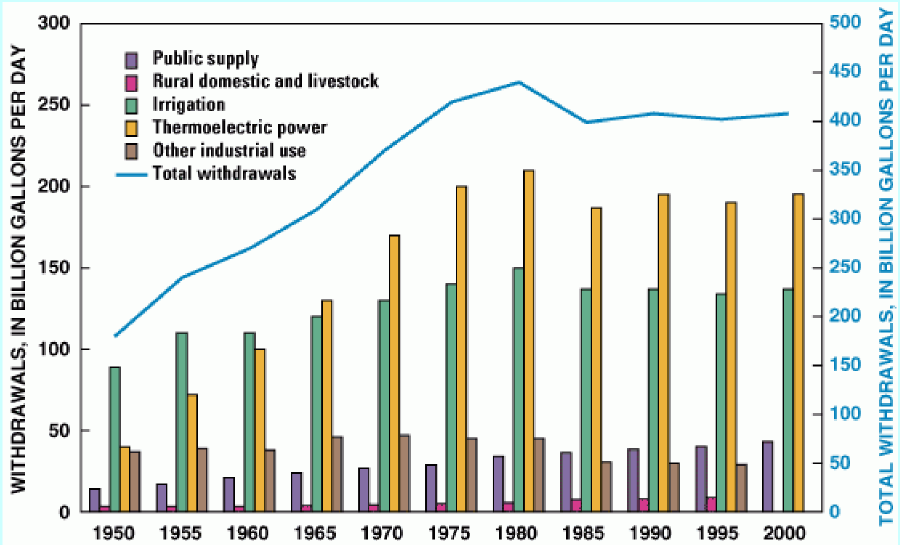


Image from http://ga.water.usgs.gov/edu/totrendbar.html

Actions for Management of Groundwater Quality

health advisories

monitoring

remediate if possible

limit/terminate aquifer use

develop alternative water supply

import alternative water supply

Ground Water Contamination

2 broad categories

Constituents Disssolved in the Water

Immiscible Liquids
(these are associated with a dissolved plume)

Actions for Management of Ground Water Contamination

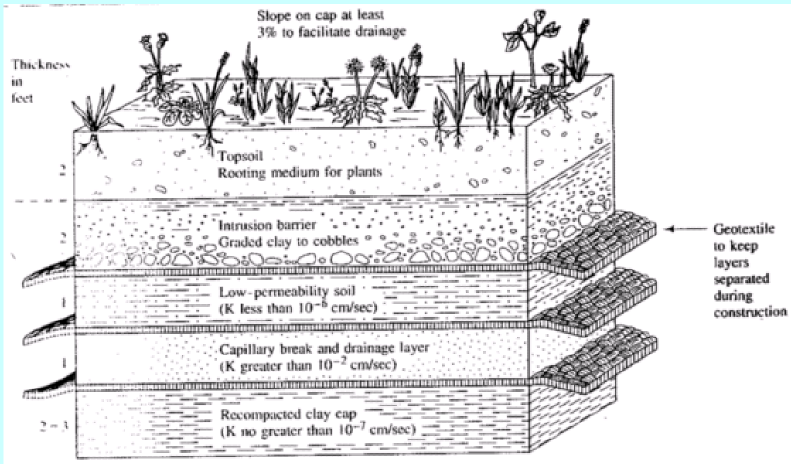
source removal digging up source

containment
- infiltration barrier (cap)
- cut-off walls
- hydrodynamic isolation

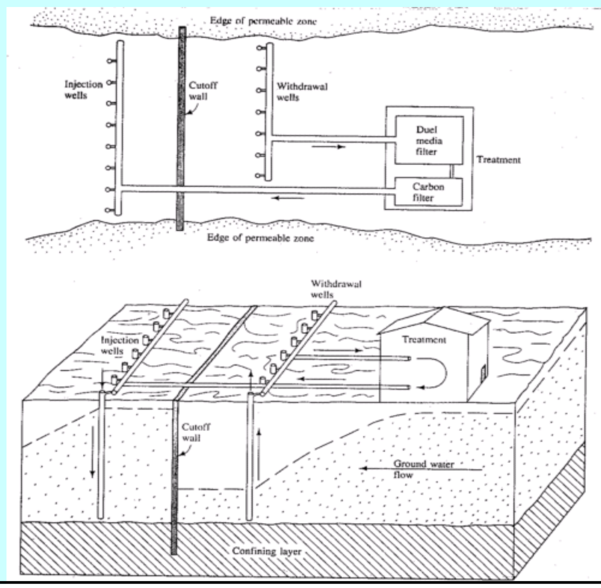
contaminant removal
- pump and treat
- funnel and gate systems
- skimmer pumps (LNAPLs)
- soil vapor extraction
- air sparging
- in-situ bioremediation (enhanced)
- natural attenuation

For any type of Contamination entering the system via infiltrating groundwater from the surface or from the unsaturated zone a COVER may be appropriate

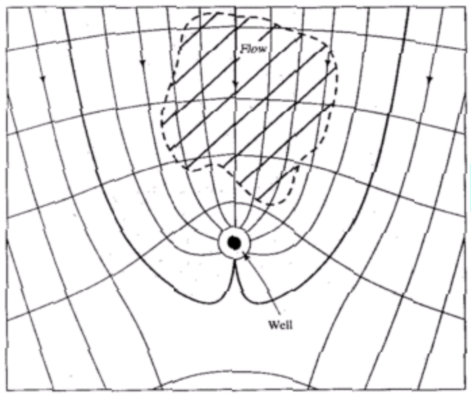
(an indirect removal of source)



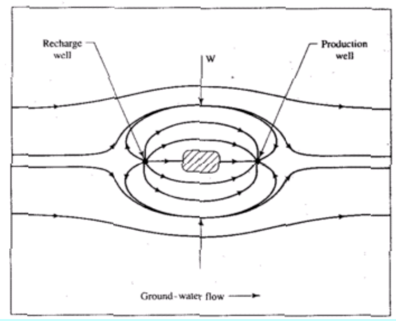
For Dissolved Constituents
CUT-OFF Walls + PUMP & TREAT is an option
e.g. Rocky Mountain Arsenal



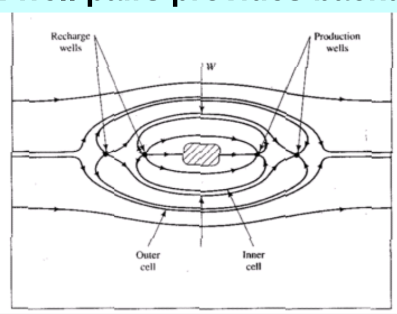
PUMP & TREAT
capture zone needs to include the contaminated water and not too much clean water



Pump and re-inject

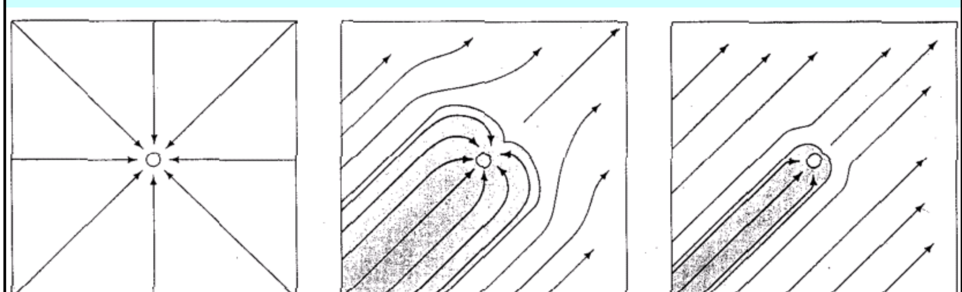


2 well pairs provides backup

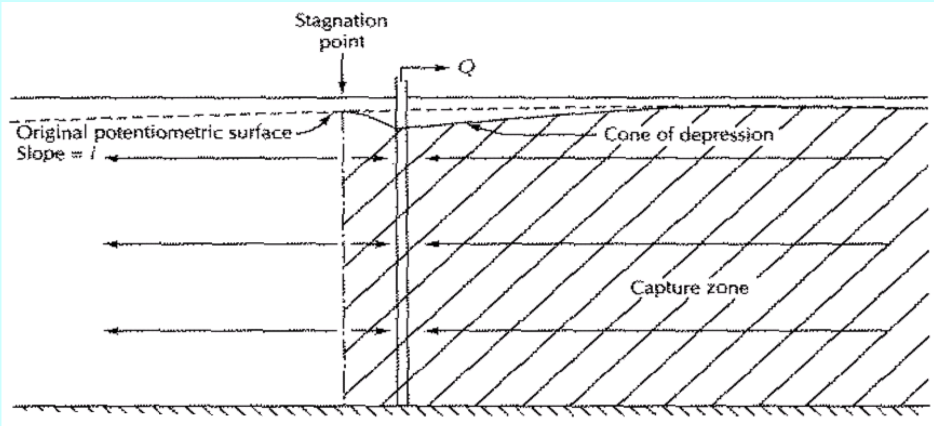


PUMP & TREAT
Under different prevailling flow fields

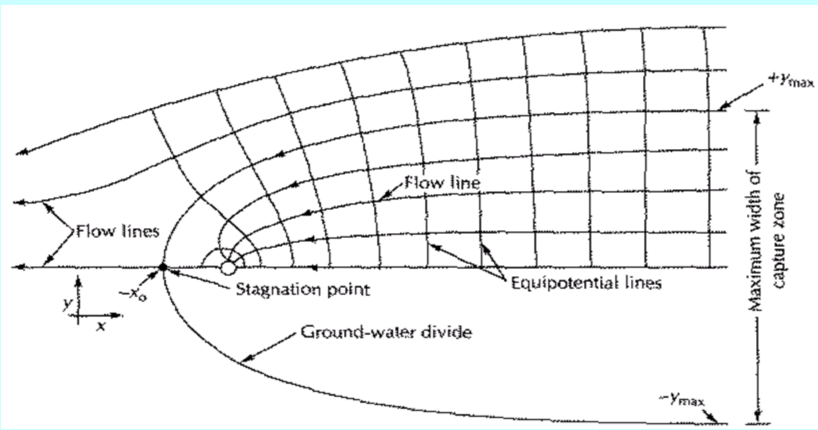
no gradient **moderate gradient** **strong gradient**



Cross section of a CAPTURE ZONE



Plan view of a CAPTURE ZONE



From what you know of water budgets and Darcy's Law, what is the maximum width of the capture zone?

Capture Zone in a Confined Aquifer:

Maximum Width:

$$y_{max} = \frac{\pm Q}{2Kbi}$$

Often we solve for Q to capture a given width

b = aquifer thickness

substitute smaller y values to find X location of various widths

$$x = \frac{-y}{\tan\left(\frac{2\pi Kbiy}{Q}\right)}$$

NOTE: tangent of angle in radians

down gradient distance to stagnation point

$$x_p = \frac{-Q}{2\pi Kbi}$$

Capture Zone in an Unconfined Aquifer:

Maximum Width:

$$y_{max} = \frac{\pm QL}{K\left(h_1^2 - h_2^2\right)}$$

L = distance between pre-pumping up&down gradient heads h_1 and h_2

substitute smaller y values to find x location of various widths

$$x = \frac{-y}{\tan\left(\frac{\pi K\left(h_1^2 - h_2^2\right)y}{QL}\right)}$$

NOTE: tangent is for angle in radians

down gradient distance to stagnation point

$$x_p = \frac{-QL}{\pi K\left(h_1^2 - h_2^2\right)}$$

Confined

$$y_{max} = \frac{\pm Q}{2Kbi}$$

$$x = \frac{-y}{\tan\left(\frac{2\pi Kbiy}{Q}\right)}$$

$$x_p = \frac{-Q}{2\pi Kbi}$$

Unconfined

$$y_{max} = \frac{\pm QL}{K\left(h_1^2 - h_2^2\right)}$$

$$x = \frac{-y}{\tan\left(\frac{\pi K\left(h_1^2 - h_2^2\right)y}{QL}\right)}$$

$$x_p = \frac{-QL}{\pi K\left(h_1^2 - h_2^2\right)}$$

Let's explore this

K = 0.01 m/sec   effective porosity = 0.26

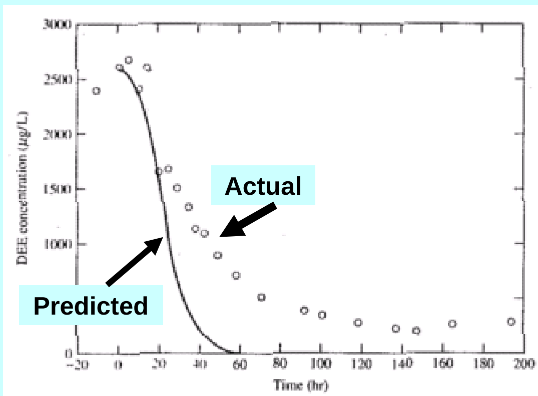
b = 20 m

i = 0.001

plume ~300m across ~1200m long

What rate do we need to pump to collect this plume?

Predicted Contaminant Concentration via Pump & Treat vs Actual Concentration



Causes of pump and treat failure:

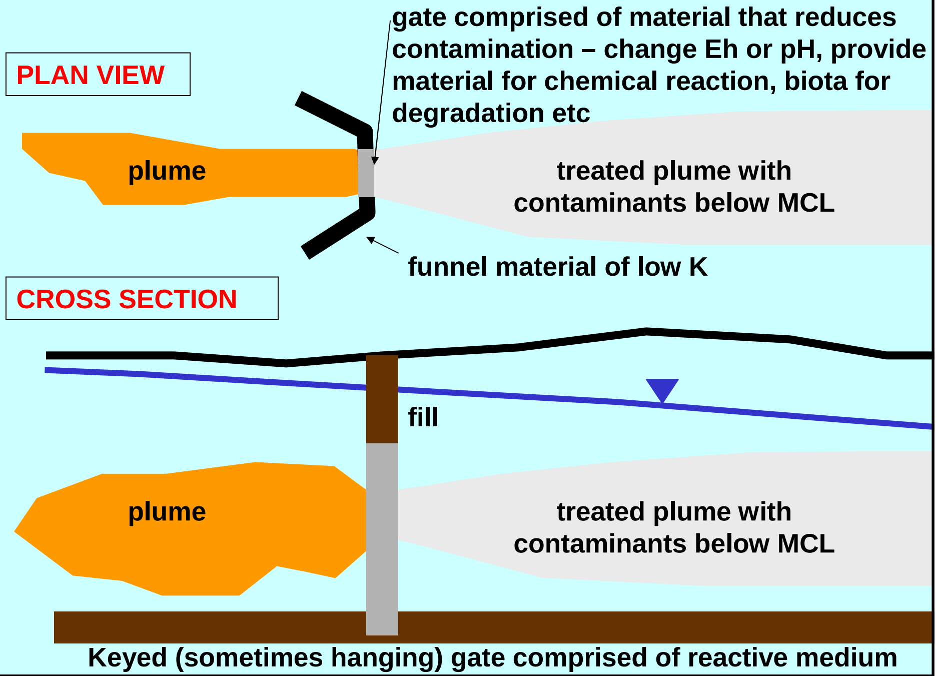
heterogeneity

sorption

multiphase fluids

poor characterization

Funnel and Gate Systems



Before discussing Immiscible Liquids

Consider MULTI-PHASE FLOW

The most common multiphase flow system associated with ground water is the air/water system in the VADOSE ZONE

So take a moment to consider that

UNSATURATED FLOW

VADOSE ZONE (Air and Water Phases)

Darcy's Law is still applicable but nonlinear
i.e. K is a function of moisture content

θ = moisture content = Volume water/ Total Volume Material
higher moisture content $\Rightarrow$ larger effective flow area
therefore higher bulk conductivity

$$v(\theta) = K(\theta)\frac{dh(\theta)}{dl}$$

$K = K_{sat}$ for positive pressures
$\theta = \theta_{sat}$ for positive pressures
moisture content is a function of negative pressure
so K is a function of negative pressure

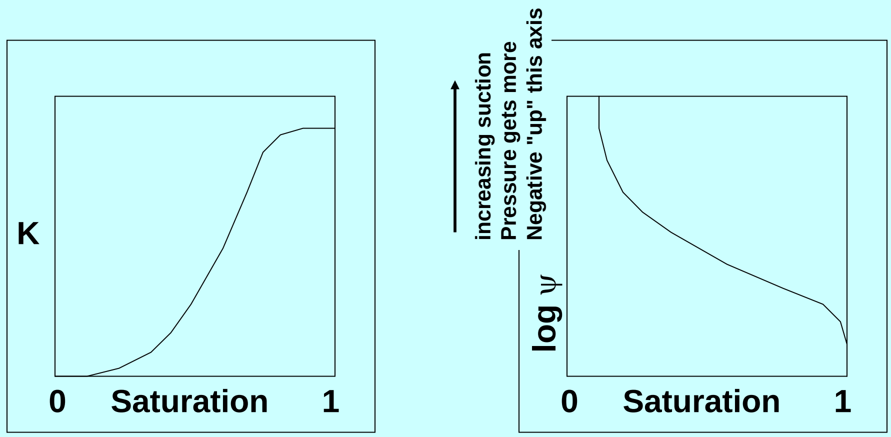
For Unsaturated Flow Driving Force is a combination of
elevation (gravity) = z
pressure (moisture potential) = ψ

ψ represents suction
pressure is more negative (greater suction) in drier soils
lower moisture content is associated with
more negative pressure and lower K

Either z or ψ may dominate total head, $h = \psi(\theta) + z$

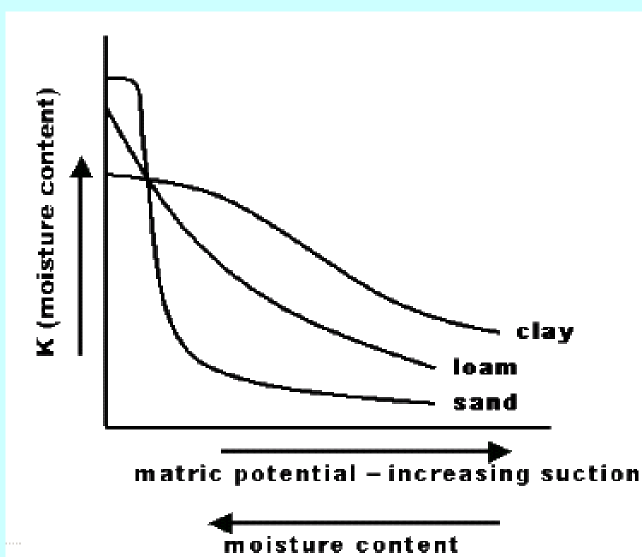
- for θ near saturation, z dominates
-for very dry soils, ψ dominates

VADOSE ZONE Conditions (Air and Water Phases)

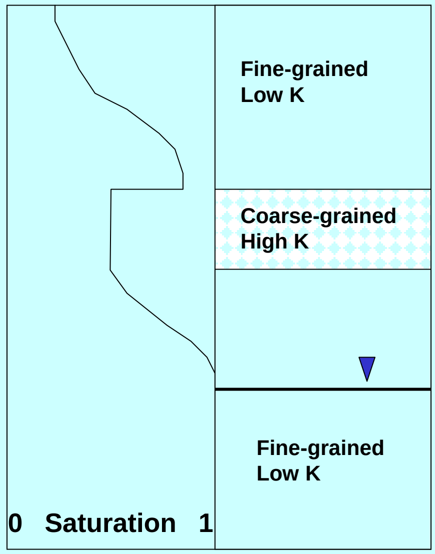


Saturation = Volume Water / Volume Voids

VADOSE ZONE
K as a funciton of moisture content can lead to some surprising results



VADOSE ZONE
K as a function of moisture content can lead to some surprising results



NAPL's --- NonAqueous Phase Liquids
(e.g. gasoline, solvents)
are immiscible with water
and may enter the groundwater system

resulting in a multi-phase flow system:
Water
Air
NAPL
vapors from the NAPL

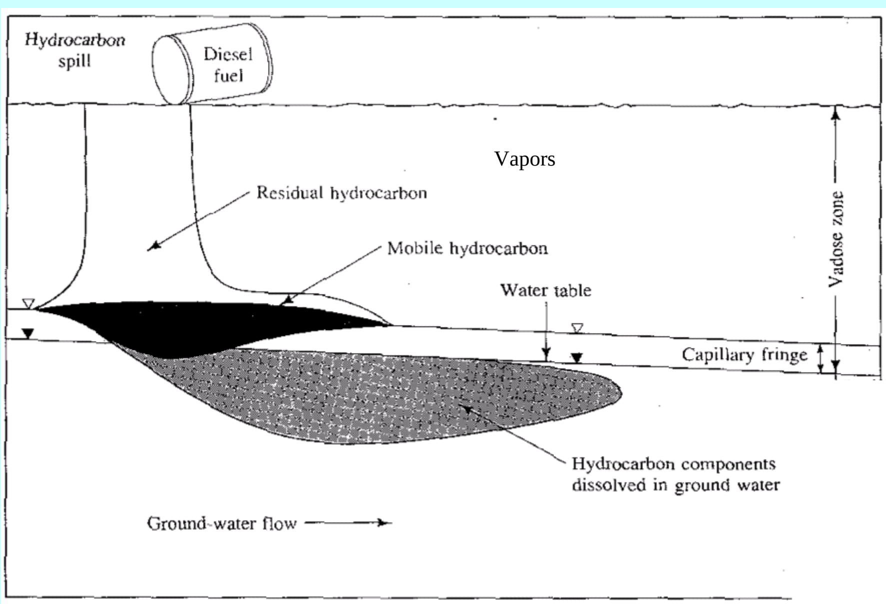
concepts similar to the unsaturated zone apply
two immiscible liquids and a gas
result in varying saturations & permeabilities of 3 phases

There is a separate K, Head, & Saturation for each phase

View the Spill Animation

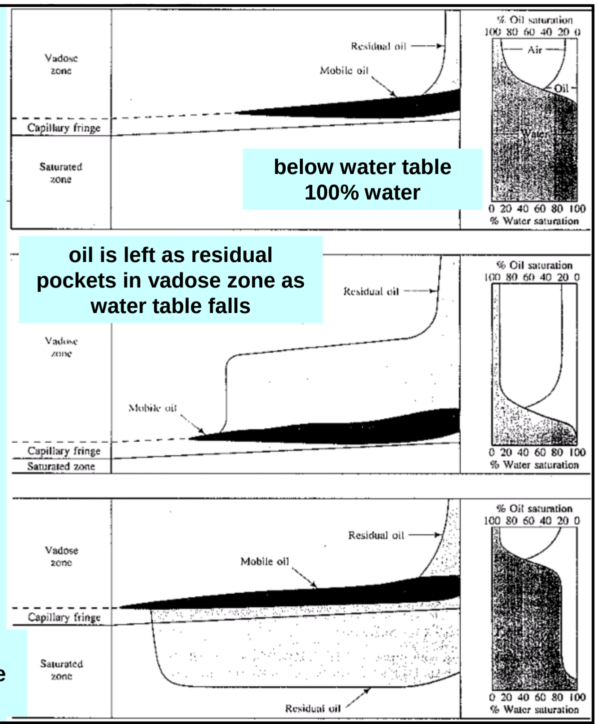
http://inside.mines.edu/~epoeter/_GW/23Management-Remediation/Spill.html

LNAPL Contamination

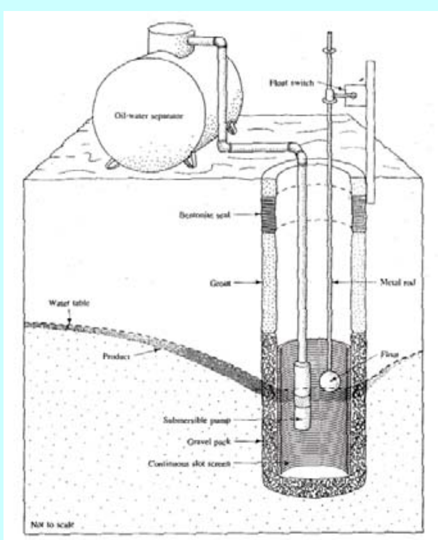


LNAPL Contamination

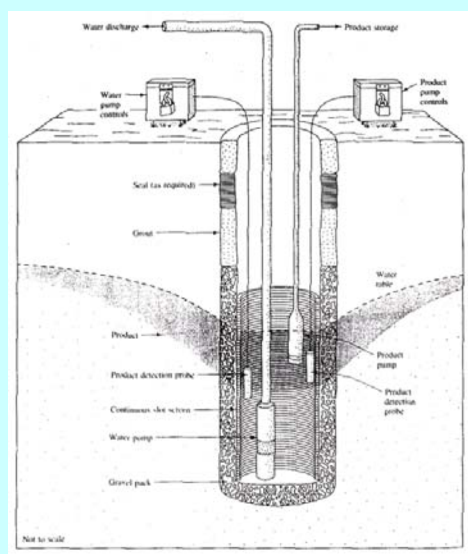
Rise and fall of the water table results in a smearing of the NAPL through the vadose AND the saturated zones



LNAPL CLEANUP - PUMPING

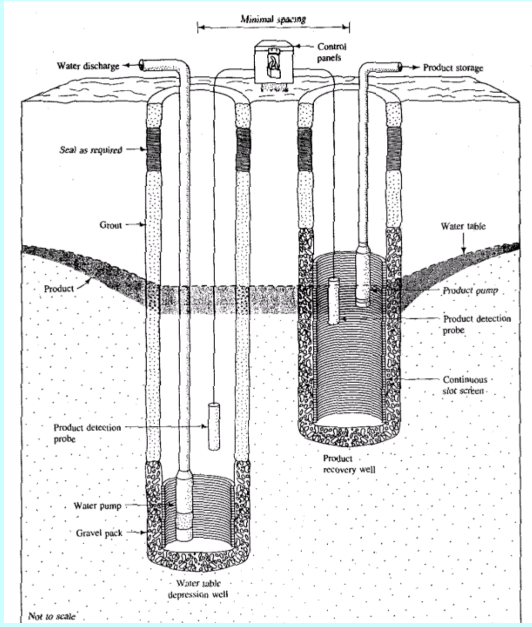


Single Well / Single Pump



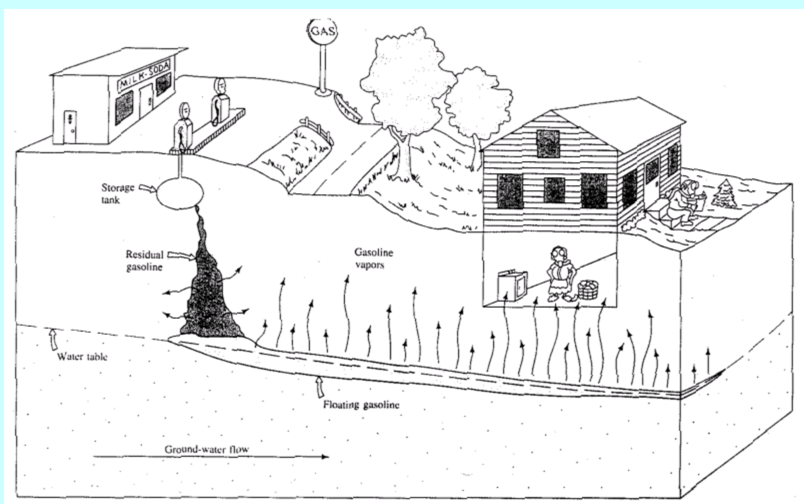
Single Well / Dual Pump

LNAPL CLEANUP - PUMPING

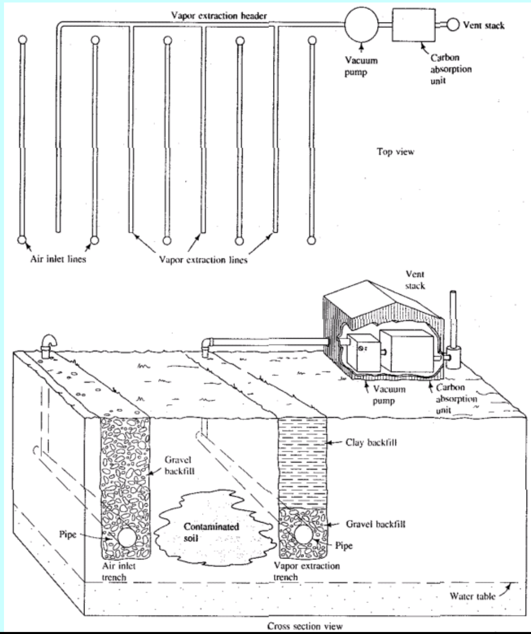


Dual Wells / Single Pump in Each

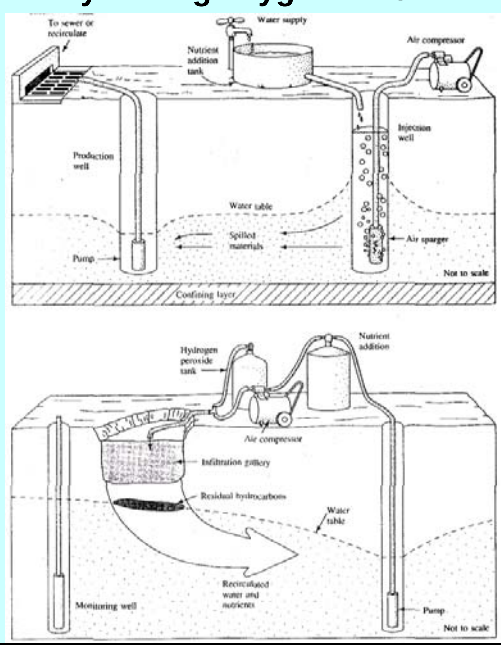
LNAPL CONTAMINATION - VAPORS



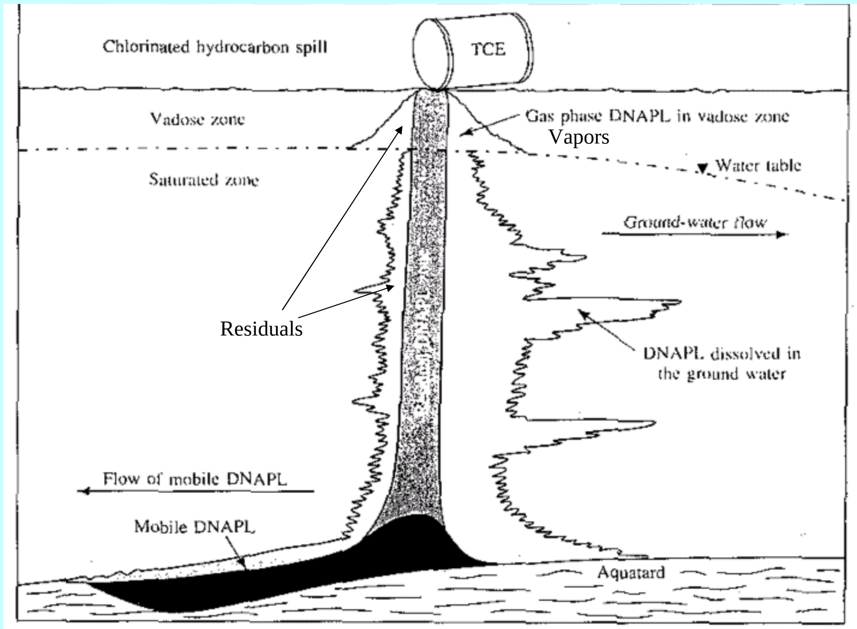
LNAPL CLEANUP - Soil Vapor Extraction



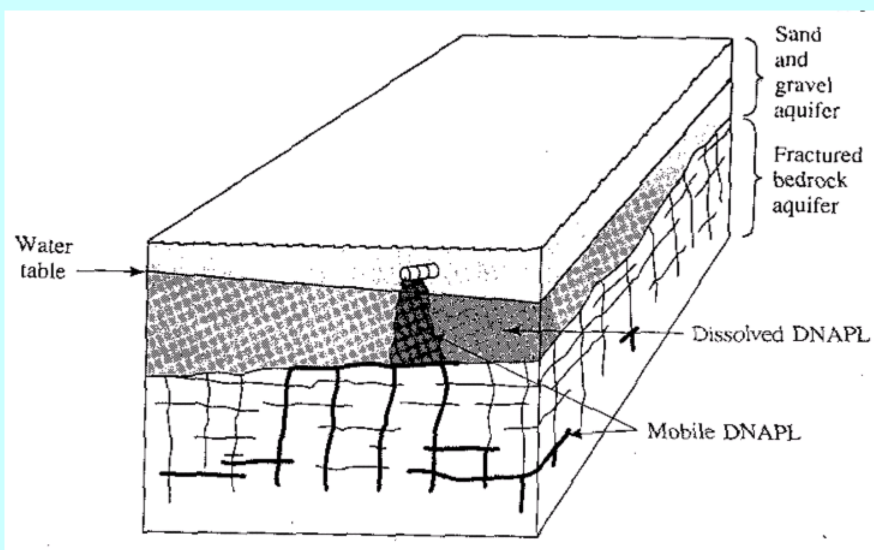
LNAPL CLEANUP – Bioremediation enhance by adding oxygen and/or nutrients



DNAPL Contamination
Sources: Drums, Leaking Pipes, Sludge



DNAPL Contamination



DNAPL CLEANUP far more difficult than LNAPL cleanup

Natural Attenuation is perhaps the most common approach

Enhanced Natural Attenuation e.g. adding sugar to enhance microbial growth and make conditions anoxic; adding microbes

Pump Free Product – IF it can be located

Collect Free Product in Trenches

Pumping aquifer water may mobilize DNAPL free product via water drive

Pump and Treat Dissolved Phase sometimes with the addition of:
- **surfactants to reduce interfacial tension**
- **cosolvents to enhance dissolution**
- **hot water or steam to enhance mobility**

Disadvantage of pumping & solubilizing
- **DNAPL may be mobilized sans control**

An area of much study, with many emerging technologies