

Notes for PUMP and treat

Pump and treat is one of the most widely used groundwater remediation methods. As of 1997, at 89% of Superfund sites (588 sites) pump and treat was only ONLY remedy specified in the ROD for groundwater treatment; pump and treat is used in combination with other in-situ technologies at an additional 6% of Superfund sites with groundwater contamination (another 39 sites). Pump and treat is also used at many RCRA site remediations and state-supervised remediations.

Although the ability to actually REMEDIATE a contaminated site is limited, groundwater control via pumping is still necessary to contain contaminant plumes and for use in concert with other techniques (such as lowering the water table to allow SVE, bioremediation, etc). Complete aquifer restoration by pump-and-treat is ineffective due to:

- a) tailing – the mass of contaminant removed with the extracted groundwater decrease over time, and extreme “tails” may mean that 50 years or more of continual pumping are needed to reach drinking water concentrations in the water
- b) rebound – sometimes, the concentrations of contaminant in the extracted groundwater decreased to “acceptable” levels (generally drinking water MCLs). Then pumping was stopped, and it was believed that remediation complete. However, contaminants at the site continued desorbing from contaminated soil and dissolving from NAPLs... and without actively pumping the groundwater there was less dilution so monitoring post-pumping showed contaminant concentrations had “REBOUNDED” to unacceptable levels.

At some sites remediation has been achieved by pump and treat. One site in California has achieved MCL levels for all contaminants, and another 10 California sites achieved MCL levels for a few of the contaminants present. Therefore, pump and treat may be appropriately used and/or combined with other approaches at some sites.

Since one of the primary goals of pump and treat is to contain the plume of contamination, it is necessary to calculate containment areas in order to design a system. For every well being actively pumped, there is a “capture zone” associated with that well. For example, if the groundwater is flowing directly west, then a well can theoretically capture all contaminants flowing directly to the well (water that would normally pass through the well itself). However, pumping also causes localized changes in the hydraulic gradient. With the “low” head at the well itself, groundwater within a circular radius around the well can also be captured.

In order to design a pump and treat system:

- 1) determine the hydrogeology at the site (water levels or “head”, hydraulic gradient, hydraulic conductivity, porosity, etc)
- 2) determine the location of contaminant plumes and the “targets” to which prevention of contamination spreading is needed

Modification of the Theim equation can be used for estimating T (modified from Boonstra and de Ridder, 1981):

$$T = 43.08Q / S_w^2$$

where: Q = the constant well discharge in feet³/day.

S_w = the stabilized drawdown inside the well at steady flow in feet.

T = the transmissivity. = K b

The equation can be applied to data for both confined and unconfined zones; however, for unconfined zones, drawdown (s_w) must be corrected to s_w' = s_w - (s_w² / 2b), where b is the saturated zone thickness in feet.

Table 4.3 Recommended pumping well diameter for various pumping rates. (Dawson and Istok, 1991, after Driscoll, 1986).

<i>PUMPING RATE</i>		<i>DIAMETER</i>	
<i>Gal</i>	<i>m³</i>		
<i>Min</i>	<i>day</i>	<i>(in)</i>	<i>(mm)</i>
<100	<545	6	152
75-175	409-954	8	203
150-350	818-1910	10	254
300-700	1640-3820	12	305
500-1000	2730-5450	14	365
800-1800	4360-9810	16	406
1200-3000	6540-16400	20	508

Jacob Method: for large time or small radius

$$\text{drawdown (at a given distance } r \text{ and time } t) = s = Q/4pT * \ln (2.25 T t / r^2 S)$$

plot drawdown at given monitoring location versus log time

find slope & extrapolate linear part down to 0 drawdown which is "t₀"

$$T = 2.3Q / 4p \text{ slope} \quad \text{and} \quad S = 2.25 T t_0 / r^2$$

Q = flowrate of groundwater being extraction, m³/min

r = distance from monitoring well where the drawdown was measured, m

t₀ = TIME with zero drawdown, min or sec or days

According to Jacob (1944), data for unconfined zones can be corrected for saturated thickness change with the following equation:

$$s_{\text{corrected}} = s - s^2 / 2b$$

where: s_{corrected} = corrected drawdown.

s = observed drawdown.

b = initial saturated thickness.

T = transmissivity = K b = length squared per time

K = hydraulic conductivity of water, cm/sec or m/d

b = thickness of the aquifer, cm or m

with low transmissivity get large drawdown at well and small radius of influence

with high transmissivity get small drawdown at well and large radius

example: $T = 124 \text{ m}^2/\text{d}$, $s = 6.7 \text{ m}$ at well, $R_i = 5490 \text{ m}$

$T = 1240 \text{ m}^2/\text{d}$, $s = 0.8 \text{ m}$ at well, $R_i = 12,200 \text{ m}$

S = storativity = unitless = $S_s b$ = amount of water released per unit drop in head per unit area of aquifer

S_s = storage coefficient = $\rho g (\alpha + n \beta)$ where α = compressibility of porous media and

β = compressibility of water, and ρ = density of water

Capture Zone dimension formulas

# wells	optimal distance between pairs of wells	width of capture zone at line of wells ($x = 0$)	maximum width of capture zone (very large x)
1	NA	$Q / 2 b K i$	$Q / K b i$
2	$Q / p b K i$	$Q / b K i$	$2Q / b K i$
3	$2^{0.33} Q / p b K i$	$3Q / 2 b K i$	$3Q / b K i$

where Q = extracted water flow rate, volume / time

b = thickness of aquifer being pumped, length

K = hydraulic conductivity, length / time

i = natural (pre-pumping) hydraulic gradient (length / length)

downgradient stagnation point = $x_o = -Q / 2 p K b i$

for 1 well: $x = -Y / \tan [2pKbiy / Q]$ where well is located at $x=0$ and $y = 0$

Example: if $Q = 50,000 \text{ ft}^3/\text{day}$, $b = 30 \text{ ft}$, $K = 1000 \text{ ft/d}$, and $i = 0.006$; what is the location of the downgradient stagnation point and maximum width of capture zone?

answer: $x_o = -44.2 \text{ ft}$; capture zone = 554 ft

Optimal REMEDIATION may be achieved by both groundwater extraction pumping and treatment with re-injection; this serves to FLUSH a greater volume of water through the site than would be achieved with extraction only.

a) can extract and one point, and re-inject at another (doublet)

b) can re-inject at 2 locations with 1 extraction point in the middle (3-spot)

c) can inject at 4 locations (in a square) with 1 extraction well in the middle (5-spot)

d) can inject at 3 wells in a triangle and extract with a triangle of 3 extraction points (double triangle)

e) can extract at 2 wells in a line with 2 injection wells (double cell)

“cartoons” of these are below, with O = extraction well, X = injection well

- a) X O
b) X O X
c)
 X X
 O
 X X
d) X O
 X O
 X O
e)
 X X O O

The well configuration significantly effects clean-up time.

a, b, e configurations are effective with low hydraulic gradient (~0.0008), and minimize cleanup time, volume of water circulated, and volume of water treated.

b worked best with high hydraulic gradient (~0.008), high drawdown (>10 ft), and either low or high longitudinal dispersivity (10 to 30 ft)

no configuration worked well for high gradient, low drawdown (<5 ft), and high dispersivity (longitudinal 30 ft) conditions

c was the least effective of the well patterns studied

The above “rules of thumb” were developed based on computer modeling by the US Geological Survey, and ignored problems with tailing or rebound effects.

Beyond optimizing well configuration, other methods can enhance the cost-effectiveness and efficiency of pump and treat:

adaptive pumping – having multiple extraction and injection wells, so that operation can be varied to minimize stagnant zones; both wells used and flowrates can be varied. For a simulated site, computer models indicated that adaptive pumping could cut remediation time from 100 years to 50 yrs used adaptive pumping.

pulsed pumping – can increase the mass of contaminant removed per volume of water. This allows diffusion and desorption time to increase the concentrations of contaminants in the groundwater while the pumping is off, so that when pumping is resumed more efficient mass extraction occurs. A potential problem is to maintain hydraulic containment during off pumping periods. About 17 locations in California have used this approach, but longterm benefits are uncertain.

Addition of surfactants may increase the partitioning of hydrophobic contaminants into the groundwater, thereby speeding remediation. However, care must be taken to ensure that off-site

mobilization of contaminants does not occur. (Surfactants can also lower surface tension, increasing the potential to mobilize NAPLs.)

So, once the contaminated groundwater is pumped out, what happens to it?

1) it is treated to remove the contaminant

treatment methods include:

bioreactors, (for biodegradable organic compounds)

carbon adsorption (exhausted carbon must be regenerated or disposed in landfill),

chemical precipitation of metals,

ion exchange (exhausted resin; will have concentrated waste solution)

reverse osmosis (concentrated solution requires disposal)

air stripping (for volatiles, and then contaminated gas treatment is needed)

chemical oxidation

ultraviolet light assisted oxidation by ozone (destroys organics)

etc. (methods covered well in LaGrega text)

2) after treatment water may be discharged in stream, to municipal sewer

OR

re-injected at the site

NAPL FYI: Can NAPLs be PUMPED out to extract them from the subsurface?

Head gradients required to mobilize NAPL ganglia:

$$dP / dl = \rho g dh/dl = 2 \sigma_{wn} \cos \phi (1 / lb) (1/rt - 1/rp)$$

where σ_{wn} = interfacial tension of water:napl (look up in a table)

ϕ = contact angle (look up in table or measure in experiment);

lb = length of NAPL blob, rt = radius of pore throat, rp = radius of pore

Generally a LARGE amount of pumping needed to move NAPL, and residual NAPL trapped at the pore throats will still remain

DNAPL mound of top of water table before it will displace the water and penetrate below the water table: $zn = 2 \sigma_{wn} \cos \phi / (rp g (\rho_n - \rho_w))$

DNAPL pool on low permeability layer: $zn = 2 \sigma_{wn} \cos \phi (1/rf - 1/rc) / (g (\rho_n - \rho_w))$

example: PCE $\phi = 40^\circ$, $\sigma_{wn} = 44.4$ dyne / cm; density = 1.63 g/mL; radius pore throat in coarse soil = 10^{-3} cm ; TCE $\phi = 45^\circ$, $\sigma_{wn} = 34.5$ dyne / cm; density = 1.5 g/mL (dyne = g - cm / s²)

References:

Pump-and-Treat Ground-Water Remediation: A guide for decision makers and practitioners. U.S. EPA. 1996. EPA/625/R-95/005.