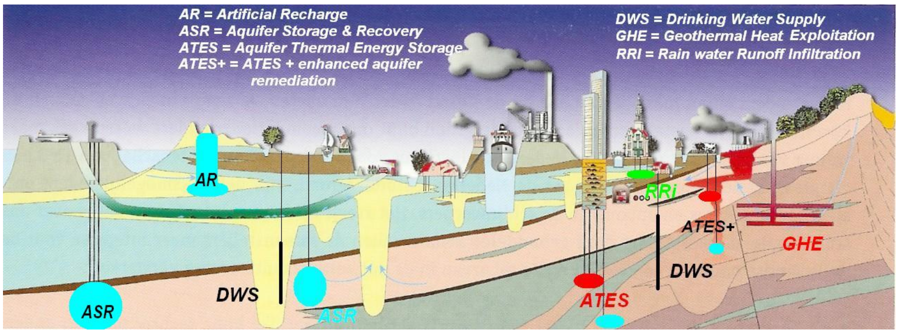

Aquifers as a storage and reaction vessel: a cure-all for climate change?

Pieter J. Stuyfzand (KWR, VU)
and Gertjan Zwolsman (KWR)

KWR Watercycle Research Institute

Deltas in CC Sept. 29- Oct.1, 2010, Rotterdam

Aquifers as a cure-all

Subsurface storage reservoir (protected against algae blooms, fall-out, evaporation and earthquackes): water, quality, heat/cold and fuel (oil, gas)

→ aquifer = natural storage vat/vessel

Purification / natural attenuation (elimination susp solids, pathogens, TEs, OMPs, Rads, NO_3 etc.)

→ aquifer = natural reaction vat/vessel

Damping quality and temp. fluctuations (a.o. by mixing)

→ aquifer = natural mixing vat/vessel

Subsurface waste disposal of undesired waters + CO_2 (effluents, brine from RO plants, UR)

→ aquifer = waste storage vat/vessel

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Pressures to apply more artificial recharge of aquifers, also in the Netherlands !

CC → **Climate change:** more water storage needed due to (1) stronger fluctuations in river discharge / groundwater table, (2) enhanced sea water intrusion

Costs of:

- → **Purification.** Increasing costs and water demands make ASR (peak shaving) and SIR economically attractive
- → **Well maintenance:** may reduce by applying ASR and SIR
- → **Land subsidence:** prevented or partly cured

CC → **ATES and geothermal heat exploitation:** a more sustainable energy supply with much lower CO_2 emissions

CC → **Disposal of:**

- → **Membrane conc.** from RO treated brackish groundwater
- → **UR.** Reducing load of sewage treatment plants (which pollute surface water during peak flows via shunting)

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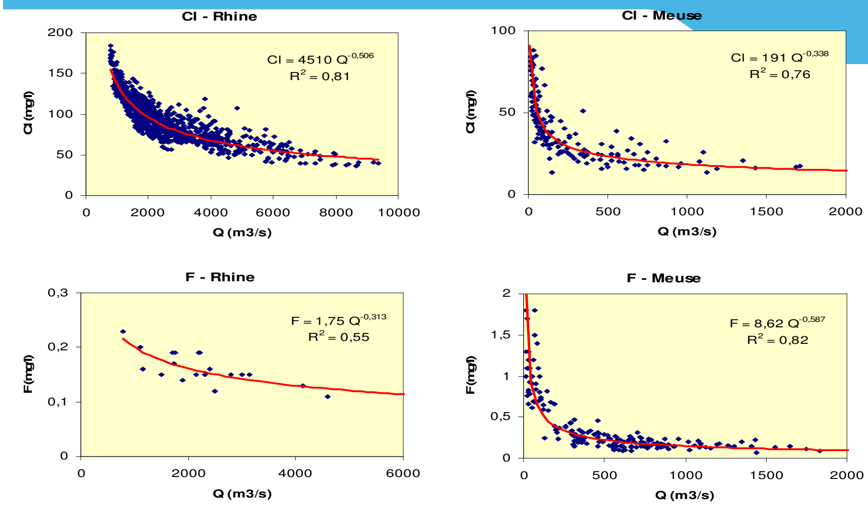
Low flow periods expected to become more frequent and severe → intake stops will increase



Conc = A/Q + b ; A = anthropogenic; b = nat background

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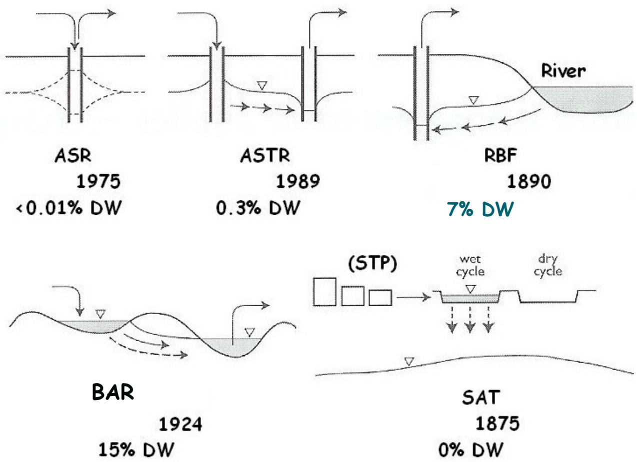
Most common aquifer recharge types in the Netherlands



ASR = Aquifer Storage Recovery

ASTR = Aquifer Storage Transfer Recovery

RBF = River Bank Filtration

BAR = Basin Artificial Recharge

SAT = Soil Aquifer Treatment

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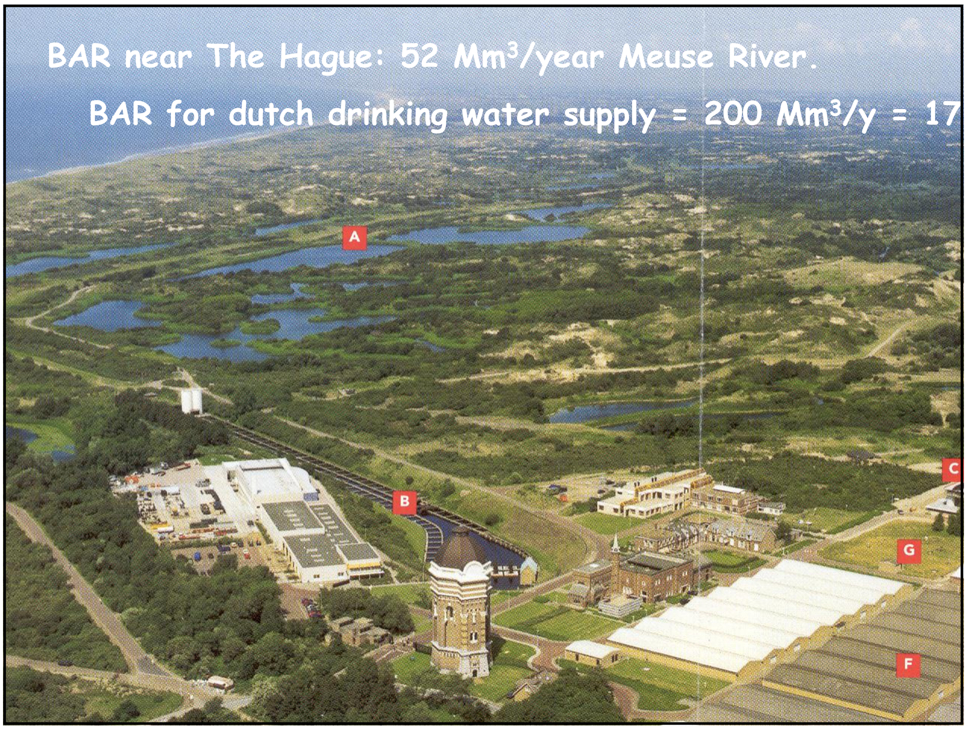
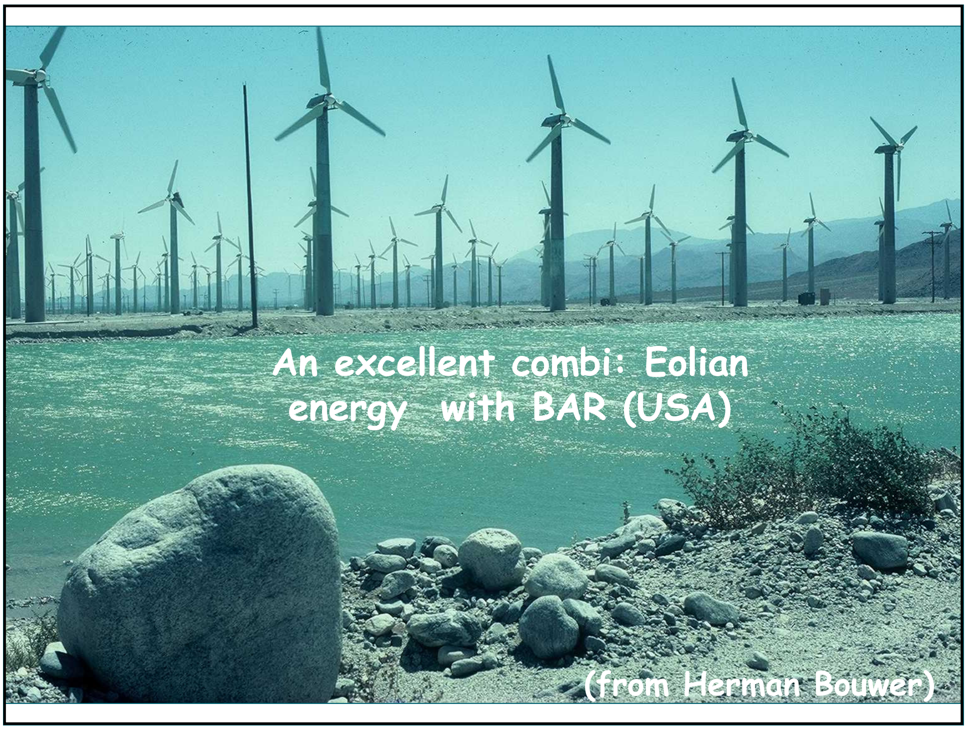

BAR near The Hague: 52 Mm³/year Meuse River.
BAR for dutch drinking water supply = 200 Mm³/y = 17
A
B
C
G
F


An excellent combi: Eolian energy with BAR (USA)
(from Herman Bouwer)

Aquifers as a reactor vessel (large scale, extensive) compared with treatment steps (small scale, intensive)

Desired process	Treatment technology	Aquifer passage of:	Aquifer passage: Feasible/Sustainable
Elim. Susp solids	Sed., RSF, Coag	Middle fine sand	+++/+++
Disinfection	SSF, Cl_2, O_3, UV	Sand > gravel	+++/+++
De-acidification	MeCO3-filtr., NaOH	Calcareous sand/ limestone	+++/+++
Hardness reduction	IonExch., NaOH, Hyperfiltr.	Sands with BEX > 0	++/-
Reduction Org.sub, color, taste	Coag., Cl_2, $KMnO_4$	Sands > gravel	+++/+++
Denitrification	Limestone-S, Hyperfiltration	Sand with pyrite or peat	+++/++
Elim. OMPs	ACF, Hyperfiltr.	Sand with peat	++/++
Elim. Trace Elems	Coag., Hyperfiltr.	Calc sand, peat and clay	+/-
Mixing	Storage reservoir	Any aquifer	+++/+++

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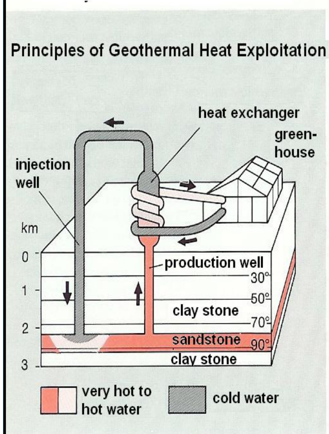
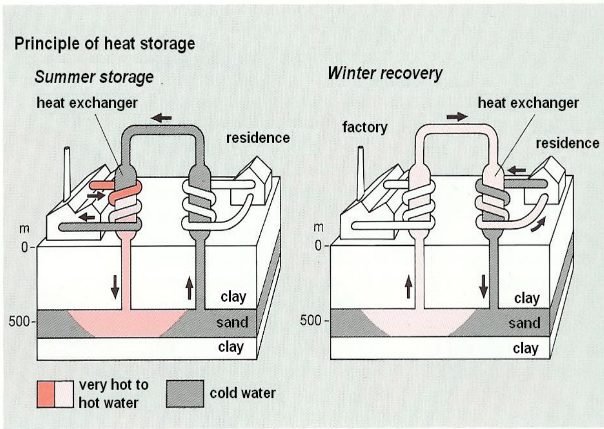
Still not so frequently applied but expected to boom: GHE and ATES medium high temp





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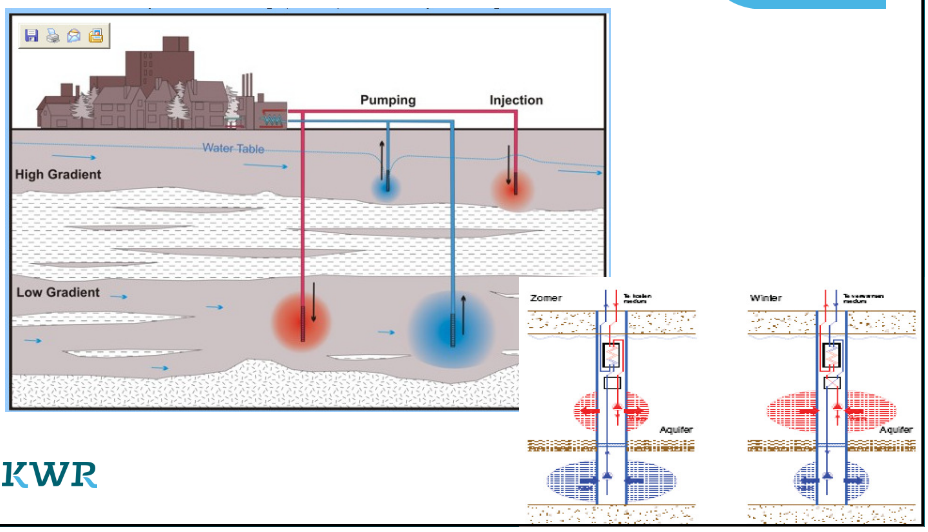
Already booming: tandem and monowell ATES systems:low temp (7-14°C) for seasonal applic.



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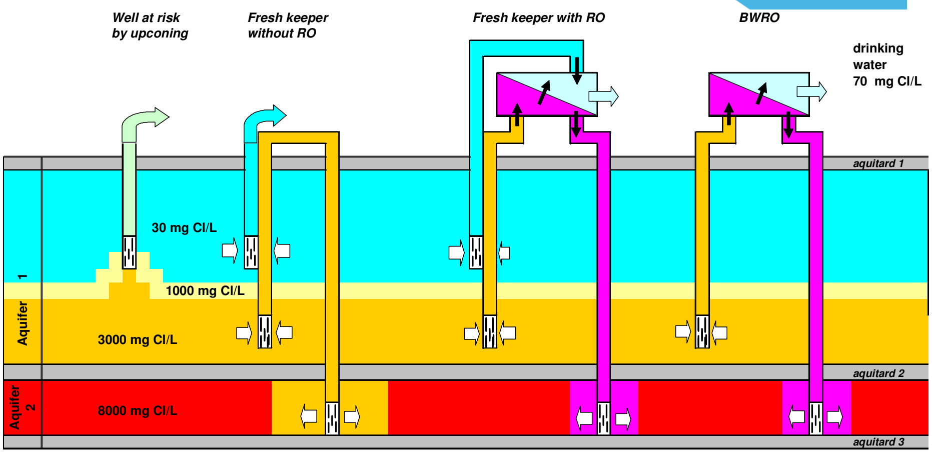
The aquifer for waste disposal: MC from brackish groundwater RO (BWRO)



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It can be concluded that aquifers are indeed excellent storage+reaction vessels, helping to combat CC (effects)

But storing water or heat in aquifers may also be difficult or even create adverse effects !

→ Technological developments and water management strategies needed

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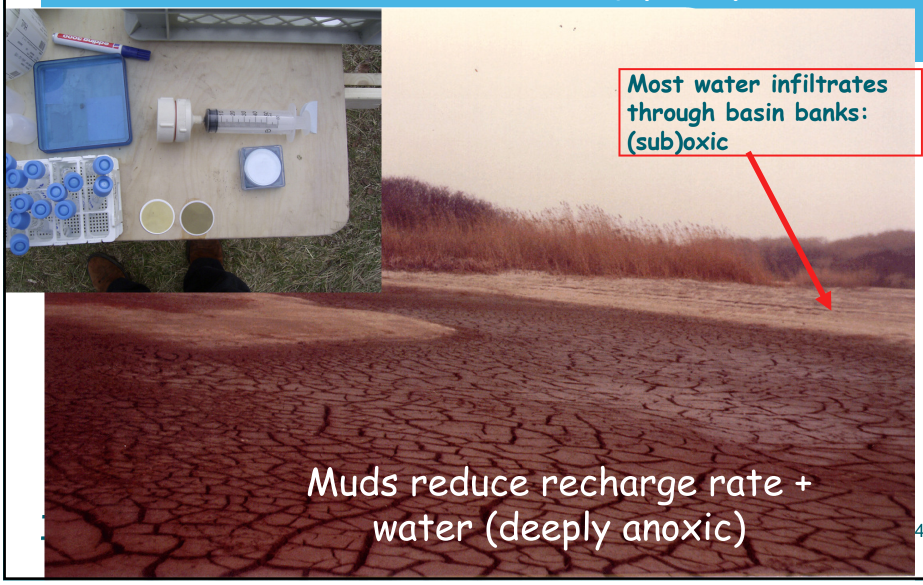
Clogging of recharge basins and wells. Also neoformation of BOM + $CaCO_3$ precipitation



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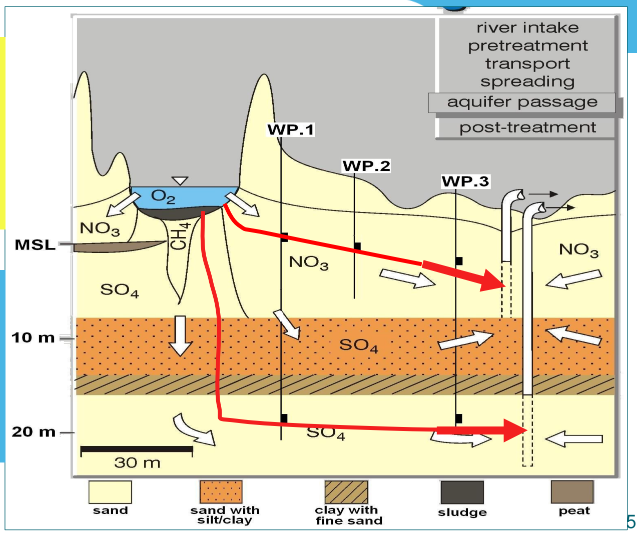
BAR: variety of Redox environments offers broad barrier against redox sensitive pollutants!

Crucial for pollutants:

- mobility
- (bio)degradation
- toxicity

Zoning:

O_2 = oxic
NO_3 = suboxic
SO_4 = anoxic
CH_4 = deep anoxic



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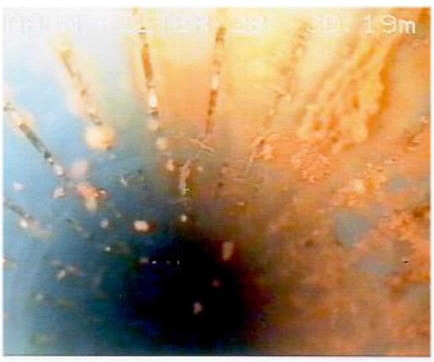
$Fe(OH)_3$ clogging of recovery / pumping wells Diagnosis by camera inspection + chem analysis



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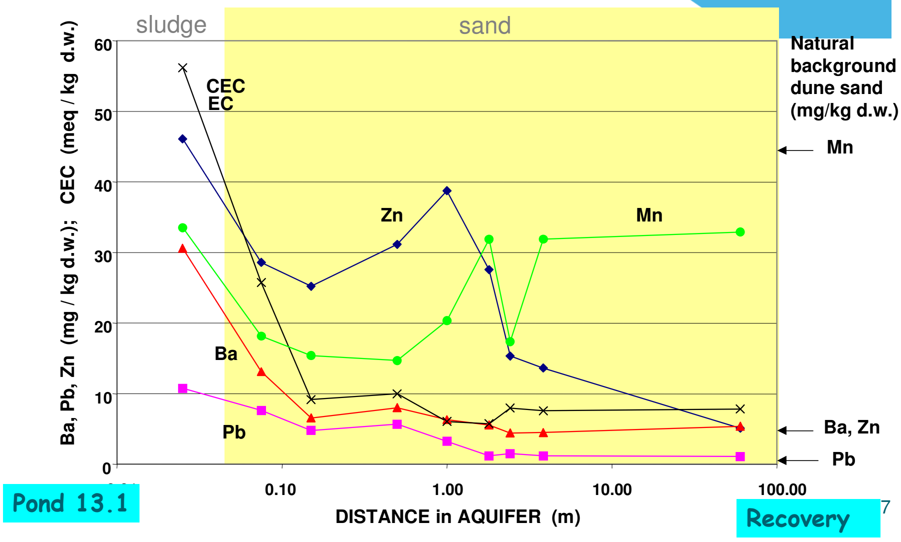
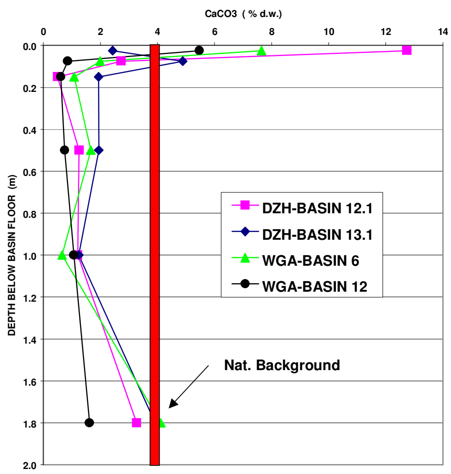
Accumulation of Ba, Pb and Zn along a flow path in a dune infiltration system: very low!

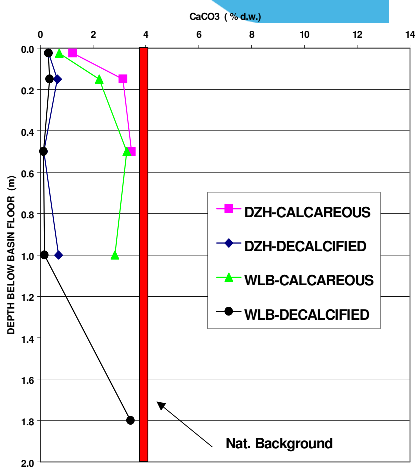


Leaching of $CaCO_3$ with and without AR

Time needed: 50 yr

Time needed: 250-3700 yr

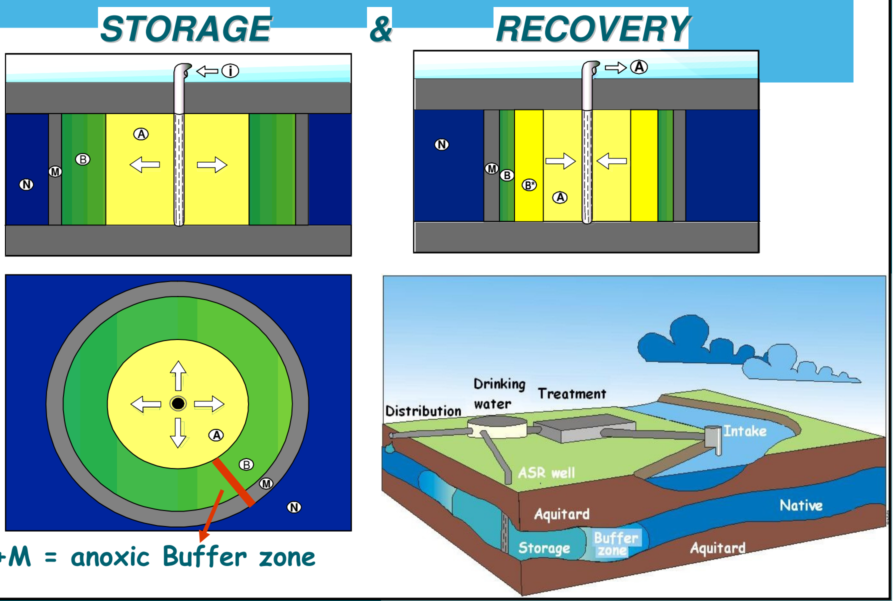




With artificial recharge

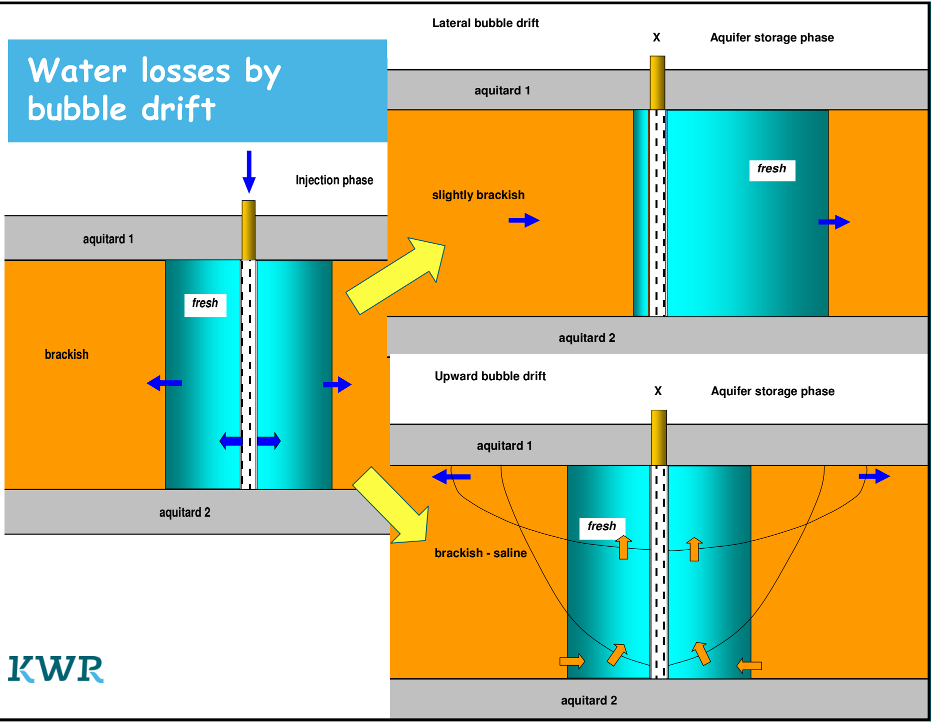
Without artificial recharge

Typical zoning in ASR bubbles



B+M = anoxic Buffer zone

Water losses by bubble drift



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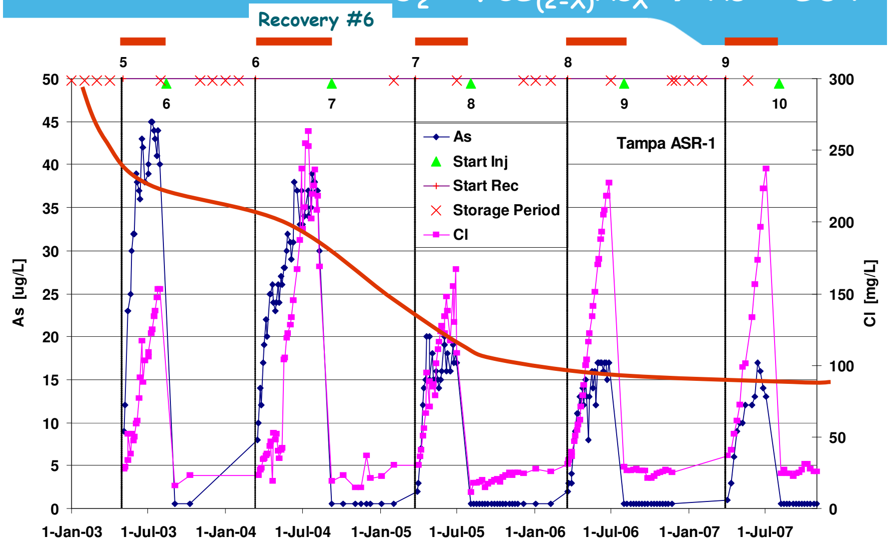
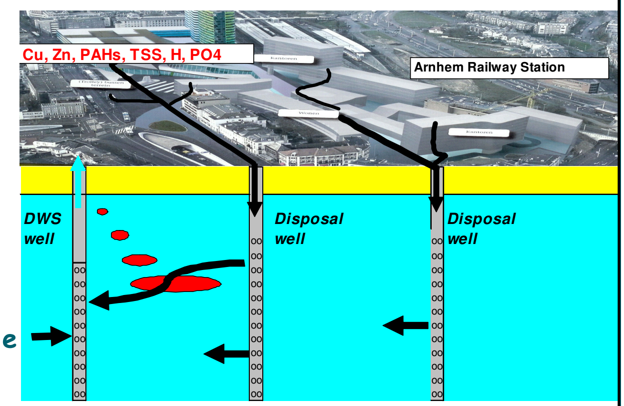
Arsenic mobilization in Florida ASR systems: $O_2 + FeS_{(2-X)}As_X \rightarrow As + SO4$



Typical problems in disconnecting urban runoff from the sewer network, to feed AR wells

- **Clogging** of infiltration facilities (especially wells)
- **Pollution** of receiving aquifer (concentrated inputs, no unsat zone, less biodegradation)
- **Leaching / dispersion** of pollutants already present in urban aquifer, provoked by high flow and low pH
- **Rise** of groundwater table (damage to cellars, houses)

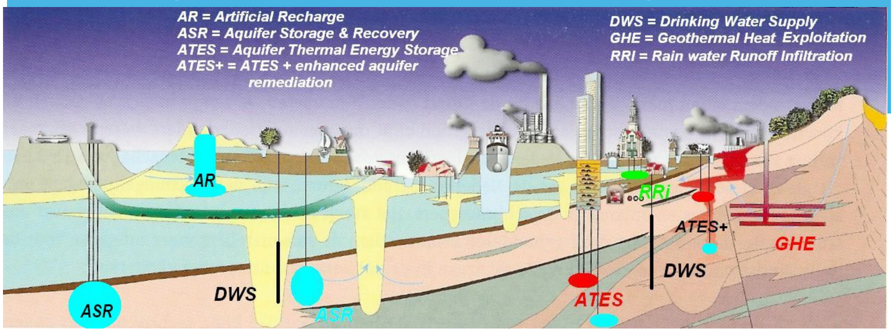


Water utilities fear negative effects ATES on groundwater to be pumped for drinking water supply

	Negative effects ATES on DWS using groundwater	Consequences @	Gravity #
A	HYDROLOGICAL		
1	Changes in piezometric levels / position groundwater table	Wetting, desiccation, subsidence	2
2	Changes in size and position protection zone	Increasing vulnerability, pollution	5
3	Decreasing flexibility of abstraction	Rise of costs, reduced assurance of delivery	5
4	Increasing chance on well clogging (phys + chem)	Rise of costs, reduced assurance of delivery	3
B	PHYSICO-CHEMICAL		
1	Changes in water temperature	Temp, viscocity, reaction kinetics	2
2	Mixing --> Pollution, chem reactions (oxidation, dissolution)	Salts, IMPs + OMPs, post-treatment	4
3	Pollution through reactivation / attraction plumes	IMPs + OMPs, post-treatment	4
4	Oxidation of organic matter in aquifer	NH4, CO2, HCO3, PO4, taste, colour	2
5	Oxidation of iron sulfides in aquifer	Fe, SO4, As, Ni, Co, Zn	2
6	Dissolution of carbonates in aquifer	HH, Ca, HCO3, Sr	2
7	Dissolution of silicates	SiO2	1
8	Dissolution/desorption materials used	Cd, Cu, Cr, Ni, Pb, VC, oil	1
9	Leakage from installation itself	Glycol etc.	1
10	Leakage via bore holes and abandonned ATES-units	IMPs + OMPs, post-treatment	3
11	Effects of well regenerations	Cl, HH, THM, suspended solids	1
12	Increasing insufficiencies existing water treatment	Rise of costs, reduced assurance of delivery	2
13	Salinization by upconing and mixing	Loss of fresh water	3
C	MICROBIOLOGICAL		
1	Enhanced mobility pathogens	pathogens	1
2	Changes in rate of biodegradation and die-off	NO3, NH4, OMPs	1
3	Changes in microbial population	biofilms distribution system, Legionella?	1
4	Increasing insufficiencies existing water treatment	Rise of costs, reduced assurance of delivery	1
D	MONITORING and MANAGEMENT		
1	Intensification of monitoring	Rise of costs	5
2	Reduced control because of escalating growth of ATES units	Rise of costs	5
3	Increasing number of disputes in court	Rise of costs	4

@ = IMPs = Inorg MicroPollutants; OMPs = Org MicroPollutants; HH = Total Hardness;
THM = trihalomethanes (byproducts of chlorination); VC = vinyl chloride (decay product PVC)
# = 1 =very low; 2 = low; 3 = moderate; 4 = high; 5 = very high

Conflicting interests and lots of challenges !



→ Develop simple technol to better remove TSS

→ Develop strategies to reduce WRI in ASR applications (As, Ni, Mn, Fe, NH_4) and to raise recovery rate of ASR and ATES systems

→ Reduce (future) interferences by effective planology for underground