Hydrology Issues at ISR Facilities

Elise A. Striz, Ph.D.
Hydrogeologist
Uranium Recovery and Licensing Branch
US Nuclear Regulatory Commission

Ground Water

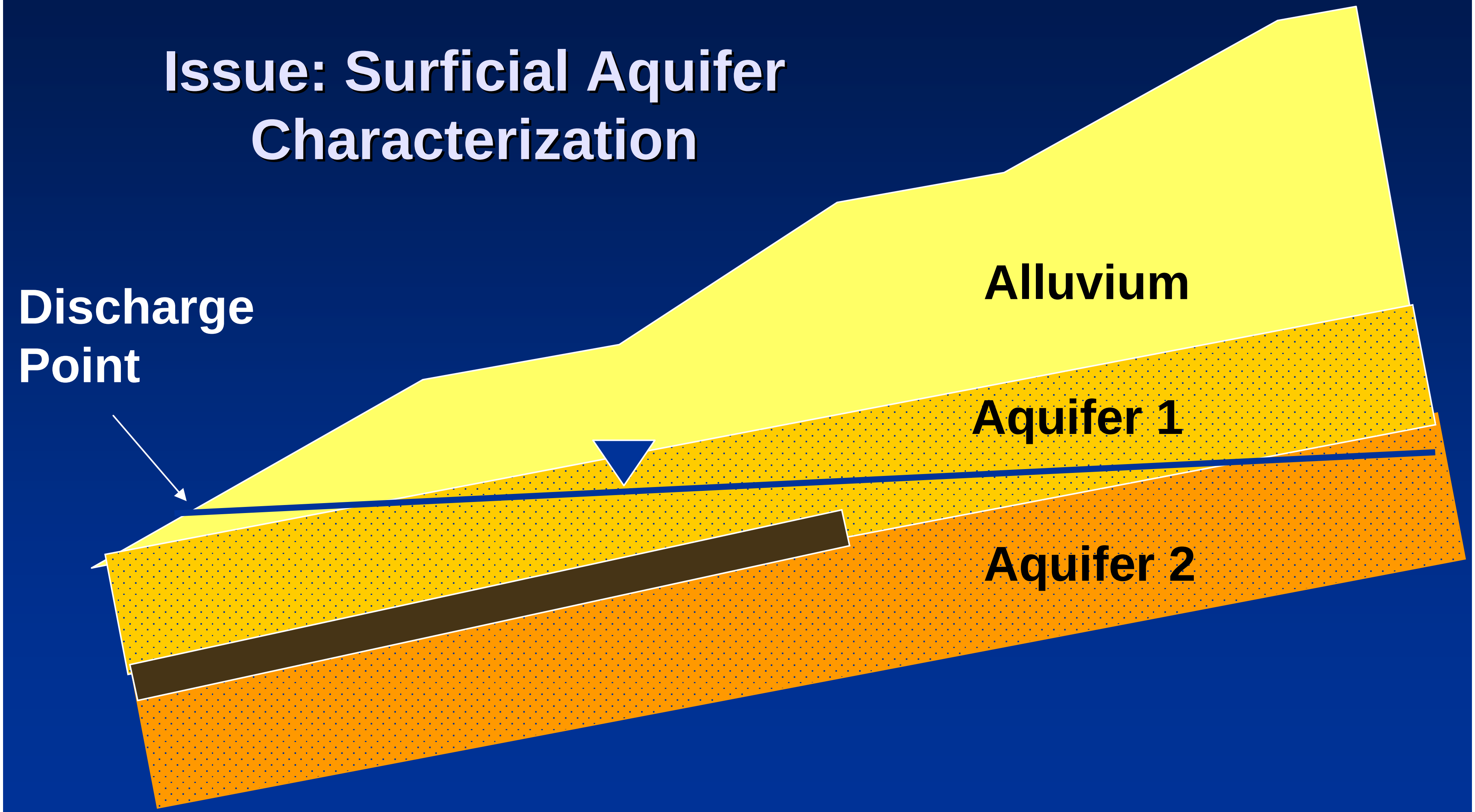
- Hydrogeologic Characterization (Section 2.7)
- ISR Processes (Section 3.1)
- GW Monitoring (Section 5.7.8)
- GW Restoration (Section 6.1)

Hydrogeologic Characterization

Issues

- Surficial aquifer characterization
- Unconfined (unsaturated) aquifer characterization
- Fault characterization
- Missing confining layers

Issue: Surficial Aquifer Characterization



Characterizing surficial aquifer

- Provide maps of depth to water below ground surface to surficial aquifer
- Indicate which formations act as the surficial aquifer
- Characterize water quality of each formation which acts as the surficial aquifer
- Include any connection of surficial aquifer to surface water such as in alluvium near drainages

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

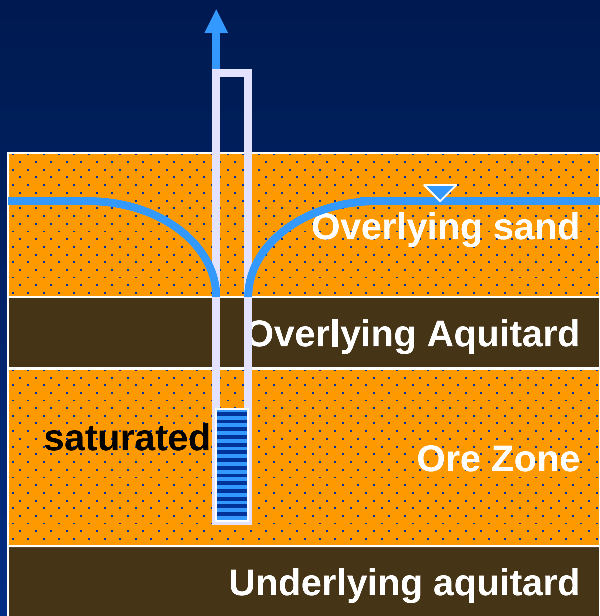
Issue: Unconfined Aquifer Characterization

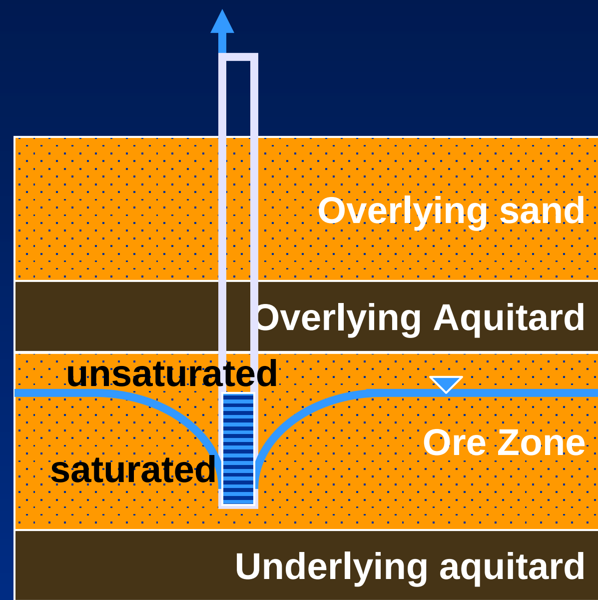
Why is an unconfined ore zone setting different from confined?

**Confined aquifer: Water to meet pumping rate is released by compression of sediments and expansion of water so much larger volume of aquifer is impacted.
Produces "pressure cone of depression."**

**Unconfined aquifer: Water to meet pumping rate is released by dewatering so much smaller volume of aquifer is impacted.
Produces "dewatered cone of depression."**

Drawdown in confined vs. unconfined aquifer





Confined drawdown equation

$$s = \frac{264Q}{T} \log \frac{0.3Tt}{r^2 S}$$

S=coefficient of storage

Unconfined drawdown equation

$$s = \frac{264Q}{T} \log \frac{0.3Tt}{r^2 S_y}$$

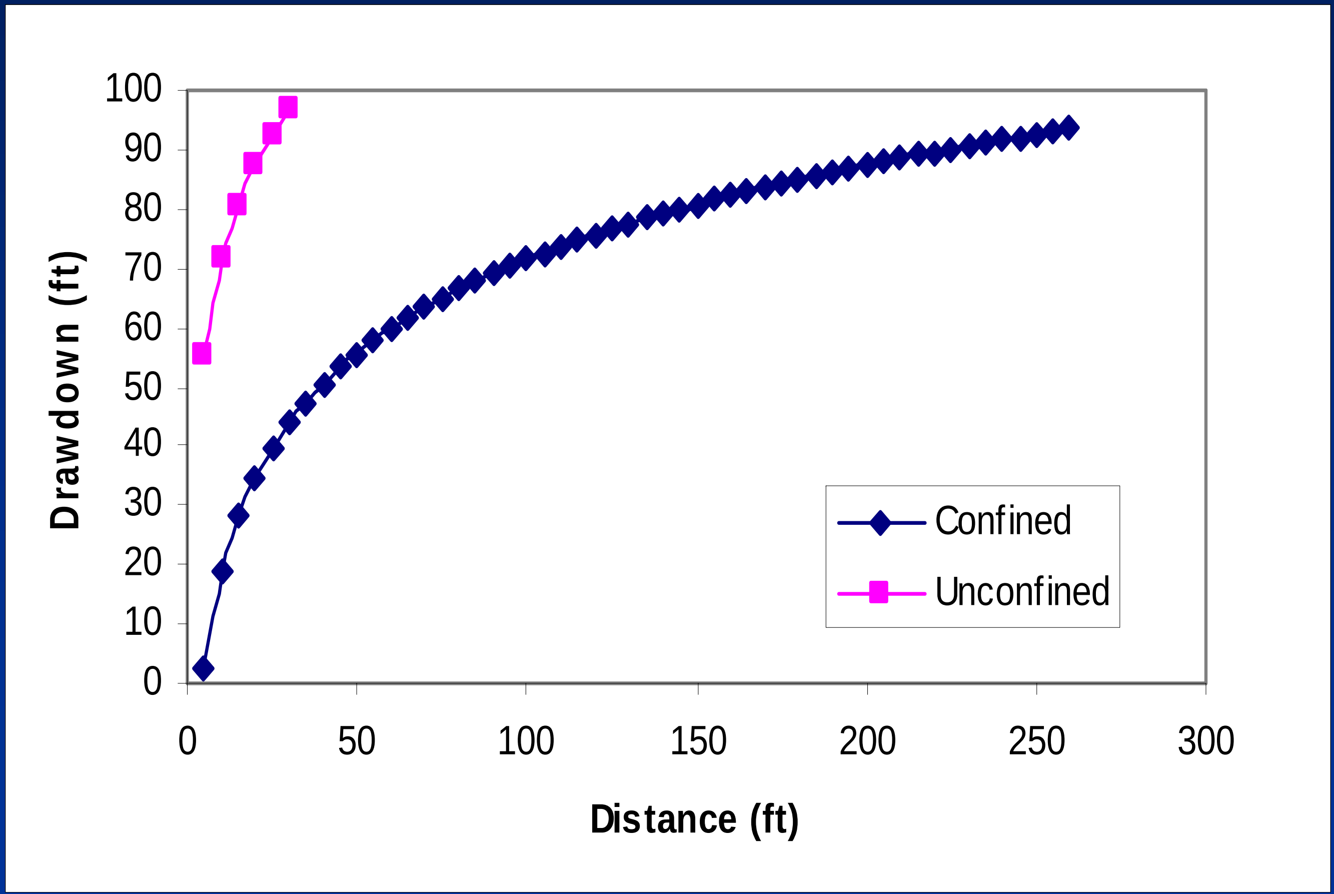
S= Sy= Specific Yield

s=drawdown (ft)   Q=pumping rate (gpm)   T =transmissivity (gpd/ft)

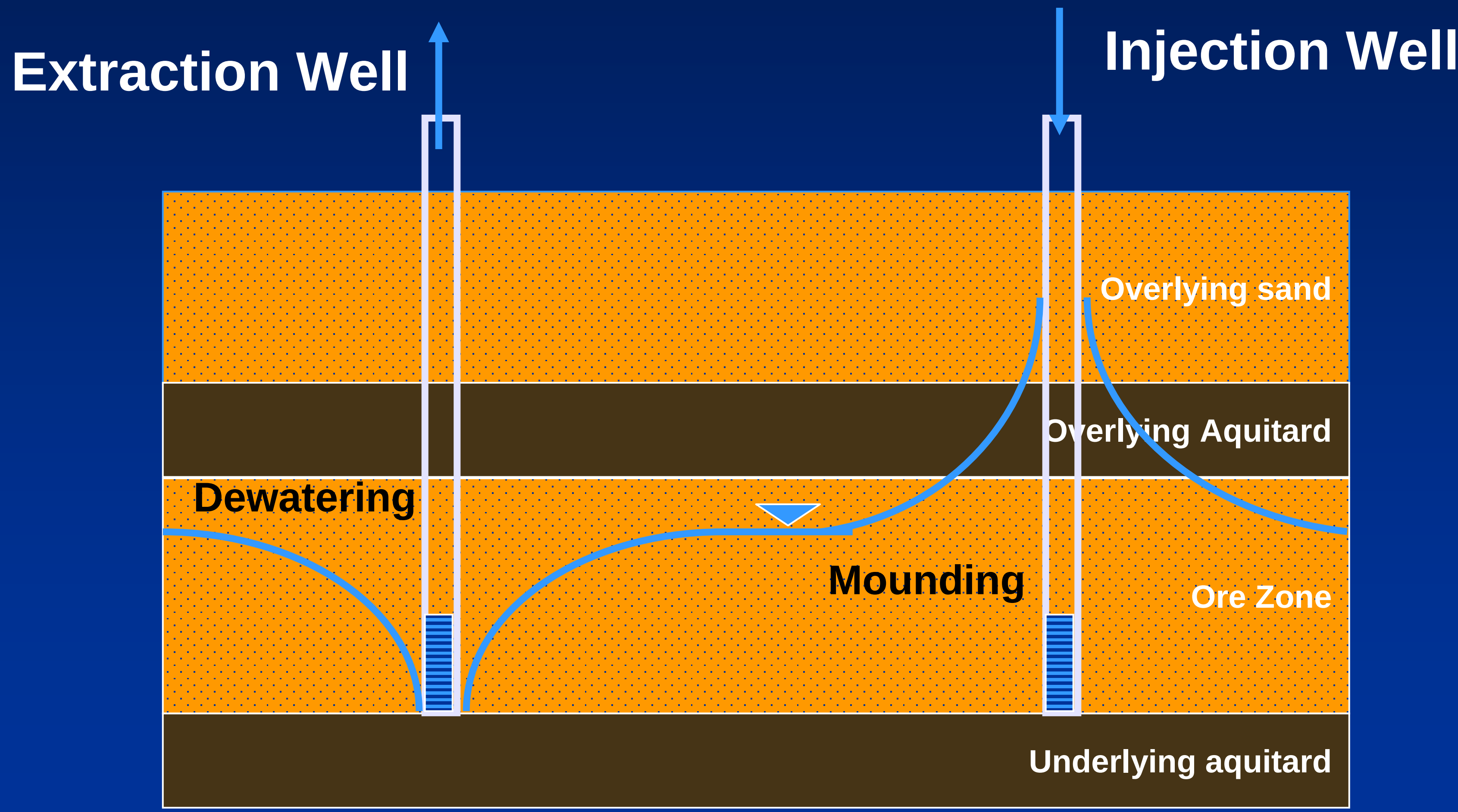
t=time (days) r=distance of observation from pumping well (ft)

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Example: Well Q=20 gpm, T=200 gpd/ft, t =1 day, S=.0005 (confined), Sy=.05 (unconfined)



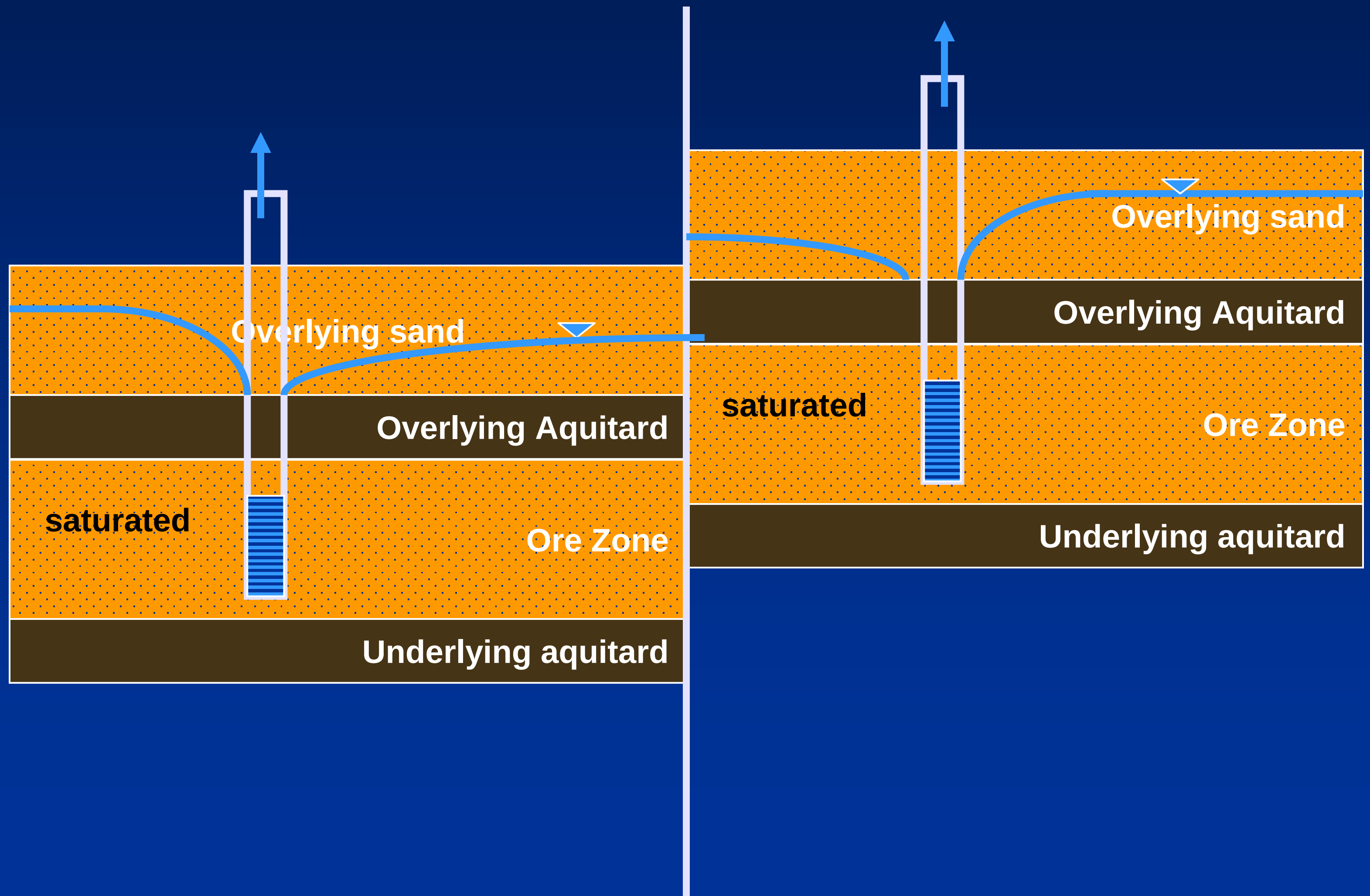
Water levels in unconfined aquifer in response to extraction/injection



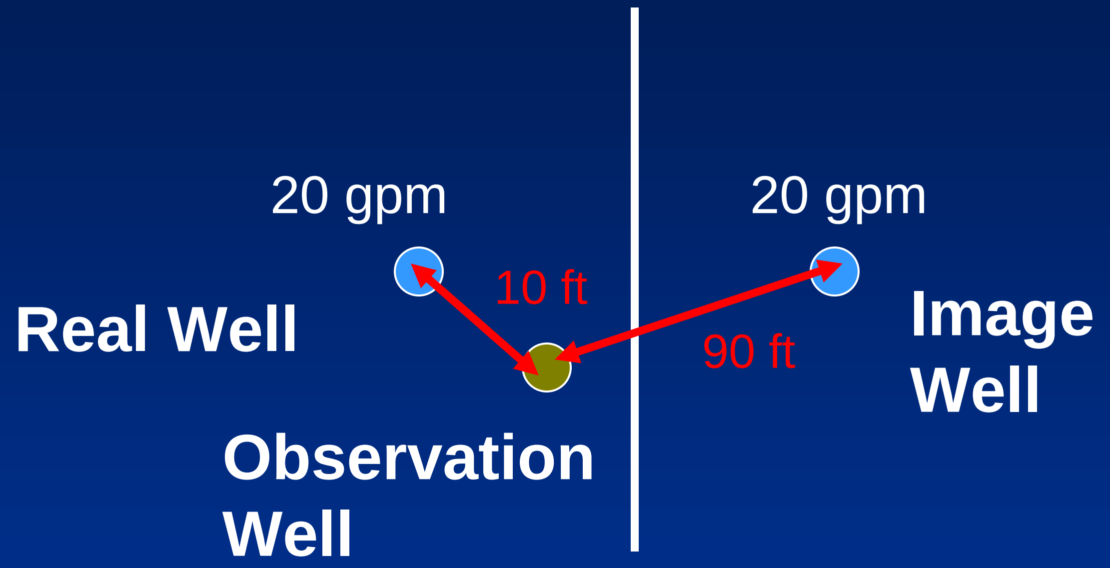
Characterizing ore zone unconfined aquifer

- Determine water levels for ore zone aquifer and assess whether unconfined or confined
- Design pumping tests for appropriate conditions (unconfined: closer observation wells, longer test time)
- Analyze results with the appropriate methods: confined or unconfined. Calculate S for confined, Sy for unconfined
- Groundwater flow modeling can be very useful to predict and verify field behavior

Issue: Fault Characterization



Drawdown near a Sealing Fault



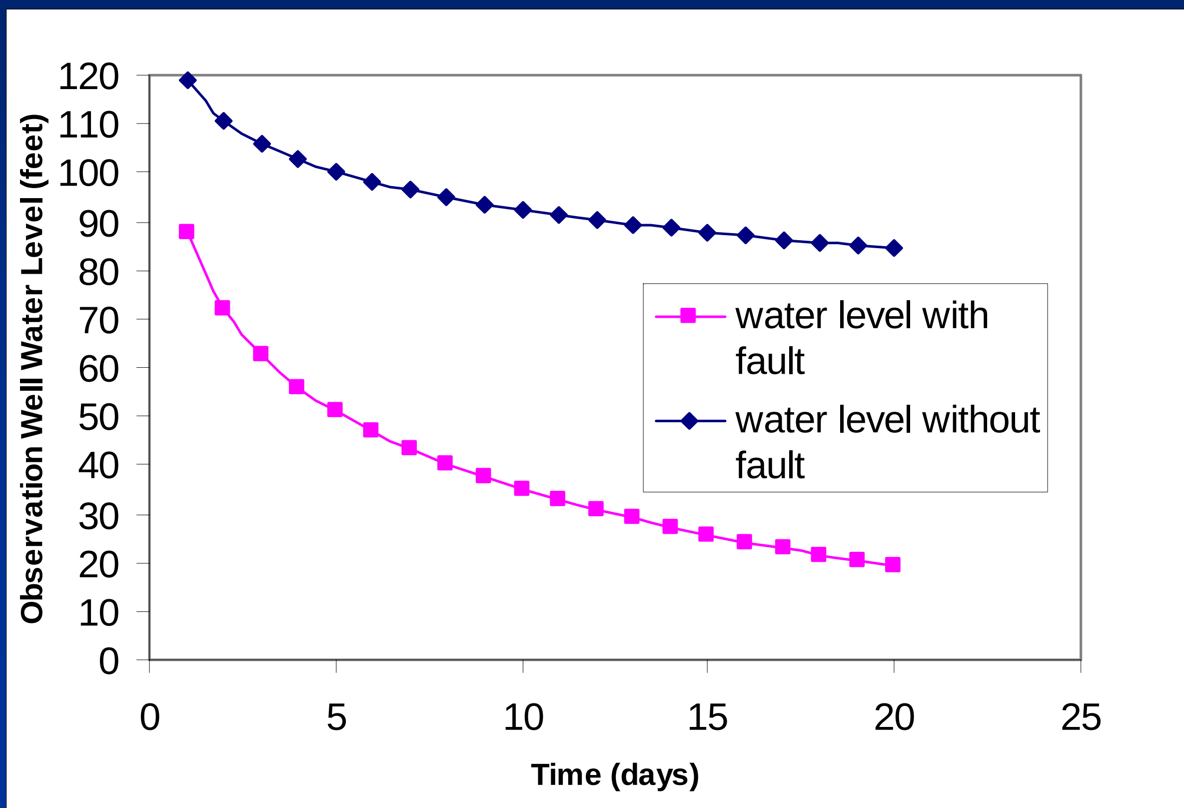
Add drawdown from combined wells at observation well

$$s_T = \frac{264\ Q}{T}\log\frac{0.3Tt}{r_i^{\,2}S} + \frac{264\ Q}{T}\log\frac{0.3Tt}{r_r^{\,2}S}$$

Example: Q=20 gpm, T=200 gpd/ft, t=1 day at observation well 10 ft from real well and 90 ft from image well (r_r=10 ft, r_i=90ft)

$$s_T = \frac{264(20gpm)}{200gpd/ft}\log\frac{0.3(200gpd/ft)(1day)}{(90ft)^2(.0005)} + \frac{264(200gpm)}{200gpd/ft}\log\frac{0.3(200gpd/ft)(1day)}{(10ft)^2(.0005)}$$

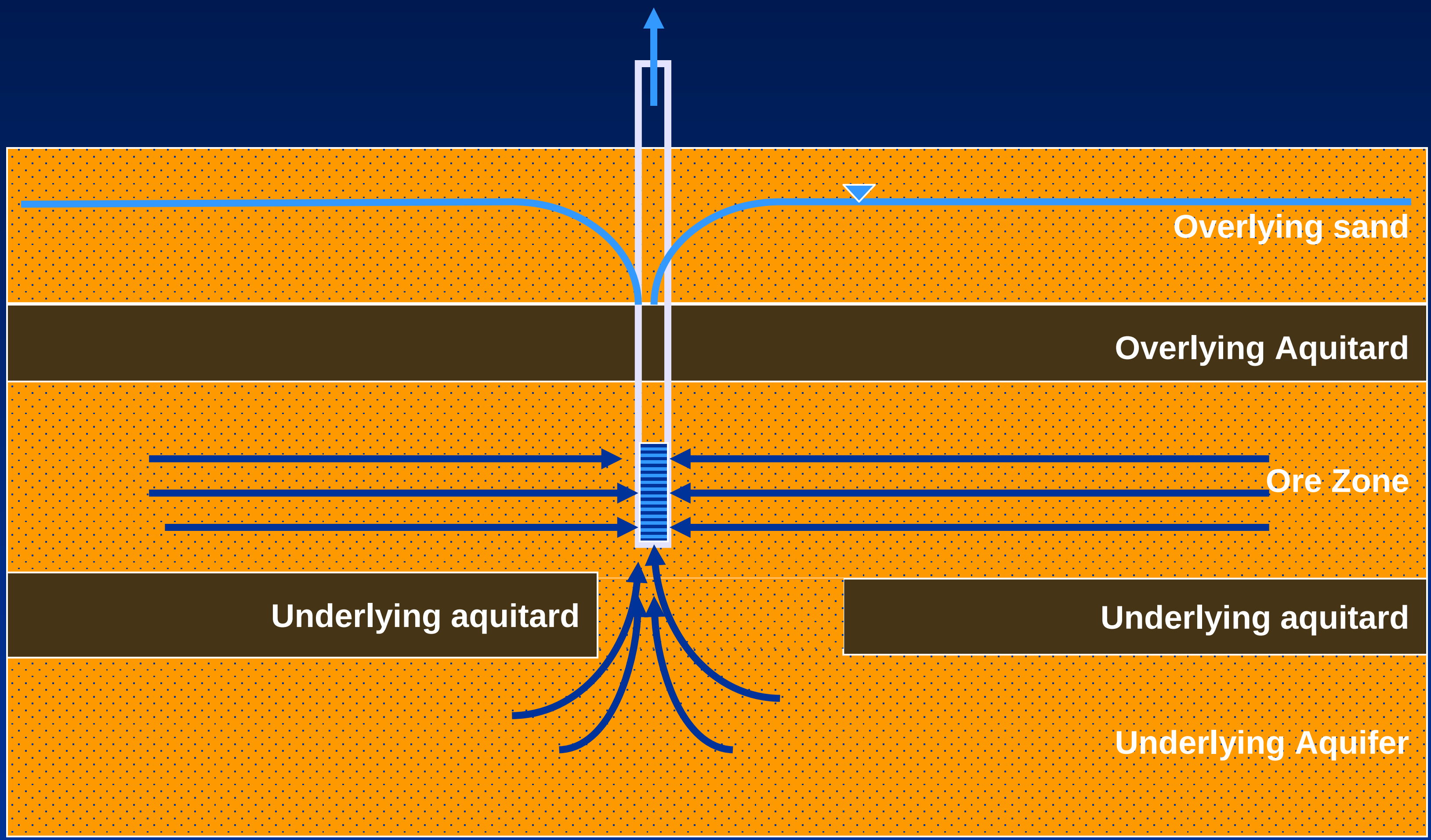
Image well drawdown Real well drawdown



Characterizing Faults

- Provide structural maps of faults and show offsets on cross sections
- If faults are present, design pumping tests to take into account fault behavior and analyze pumping test results with an awareness of the impact of the fault
- Consider using groundwater flow models to characterize and predict behavior

Issue: Missing confining layers



Pumping tests will show reduced drawdown as underlying aquifer provides recharge

Characterization when confining layers are missing

- Provide well defined isopachs of overlying aquifer, overlying aquitard, production zone aquifer, underlying aquitard using well boring logs/cores.
- Be aware that pumping test analysis is affected by flow from connected aquifer (s).
- Consider using groundwater flow models to characterize and predict behavior in these locations.

ISR Processes

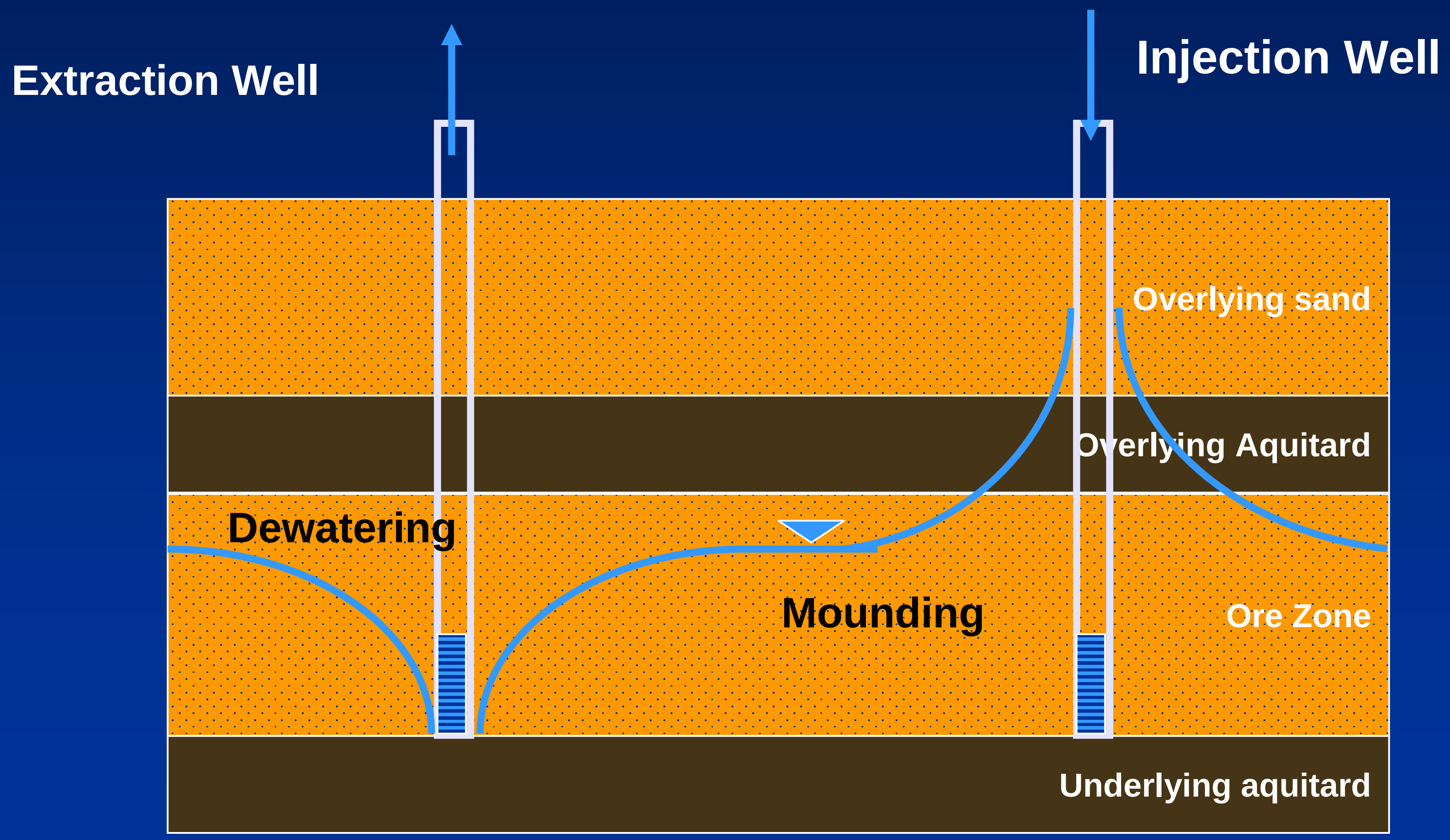
Issues

- Unconfined aquifers
- Faults
- Lixiviant composition and gas lock

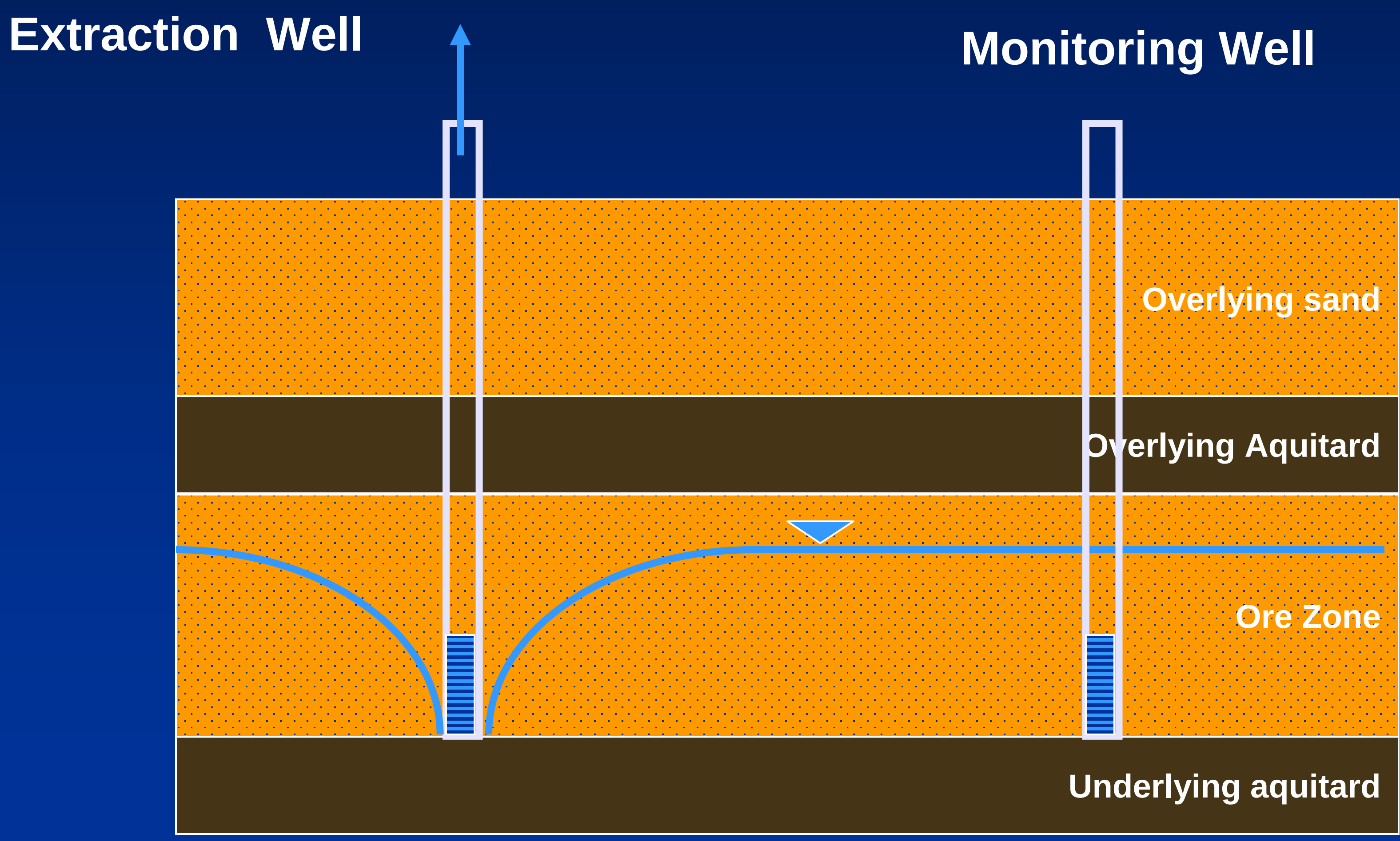
Why is the unconfined aquifer setting of concern as a safety issue?

- Extraction causes dewatering of aquifer - can limit rates
- Cone of depression has limited areal extent- demonstration of cone of depression and communication across ore zone and with monitoring well ring requires more pumping wells
- Dewatering and limited extent of cone of depression may make it more difficult to capture excursions
- Low hydrostatic head can impact dissolved oxygen solubility in ore zone and impact conductivity- “gas lock”

Injection/Extraction= Dewatering/Mounding
Dewatering can limit extraction rates

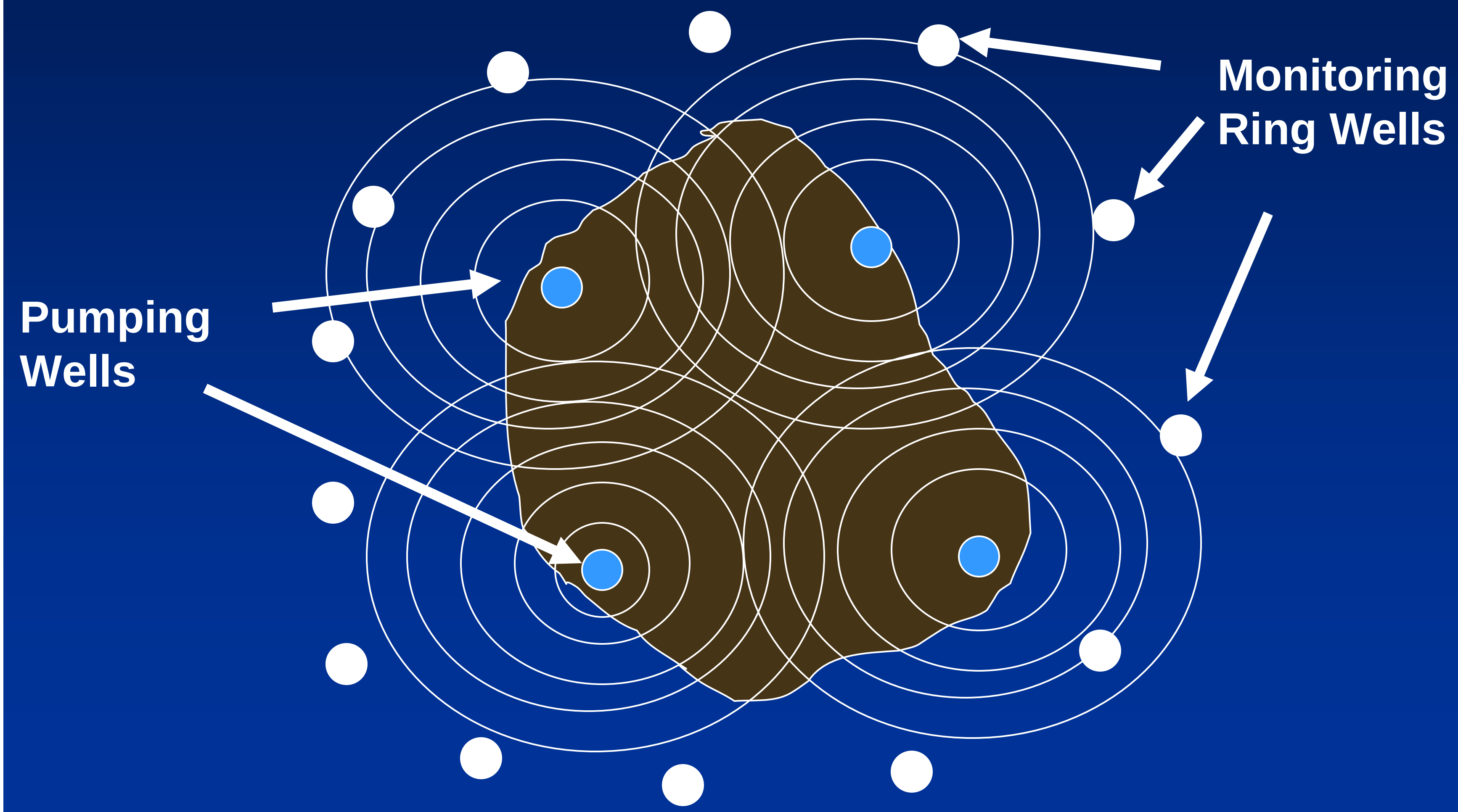


Dewatering limits areal extent of drawdown- impacts cone of depression inward gradient



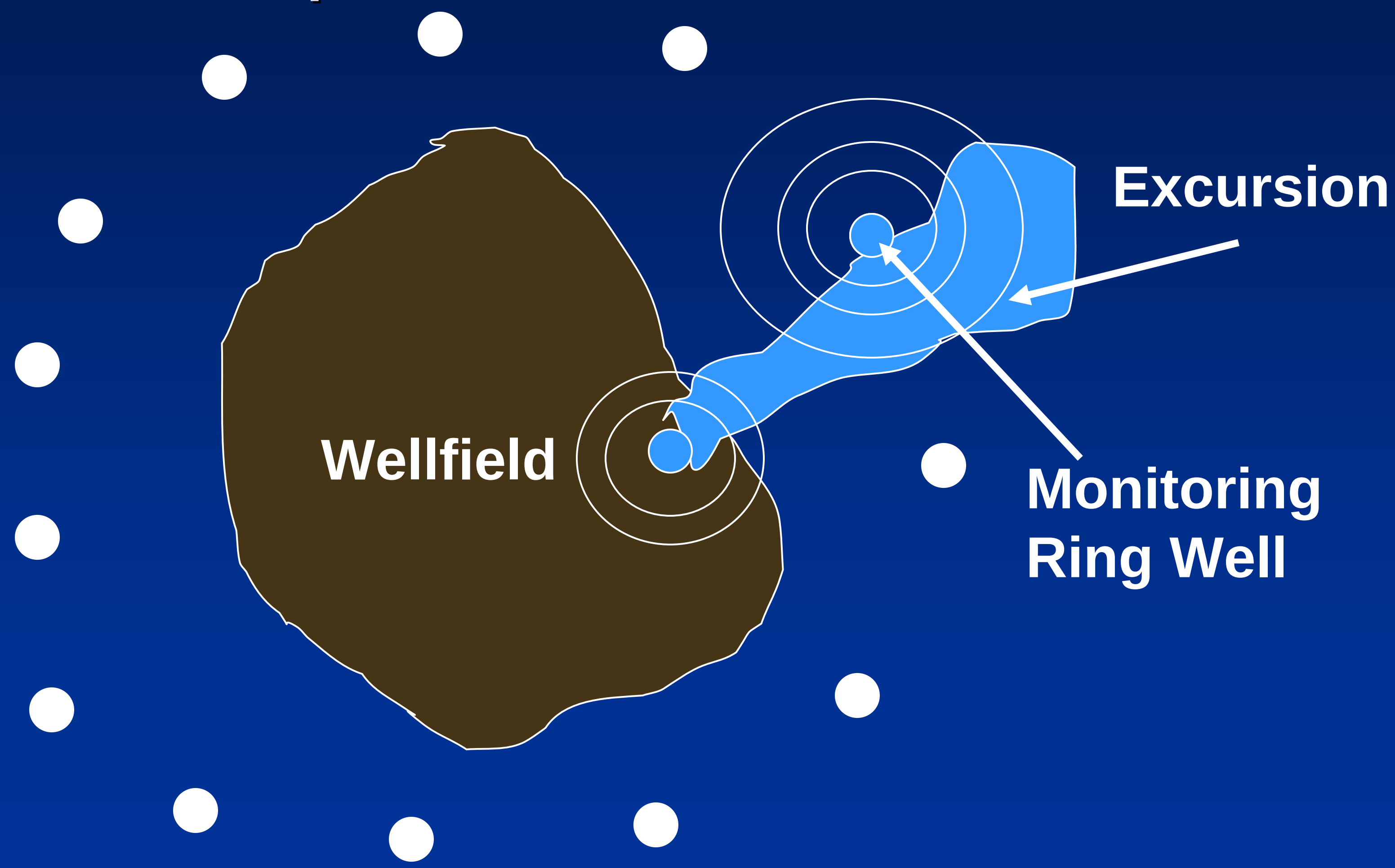
U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

To demonstrate communication across wellfield may take several pumping wells acting simultaneously



U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Excursion capture may be limited by extent of dewatered cone of depression and extraction rate

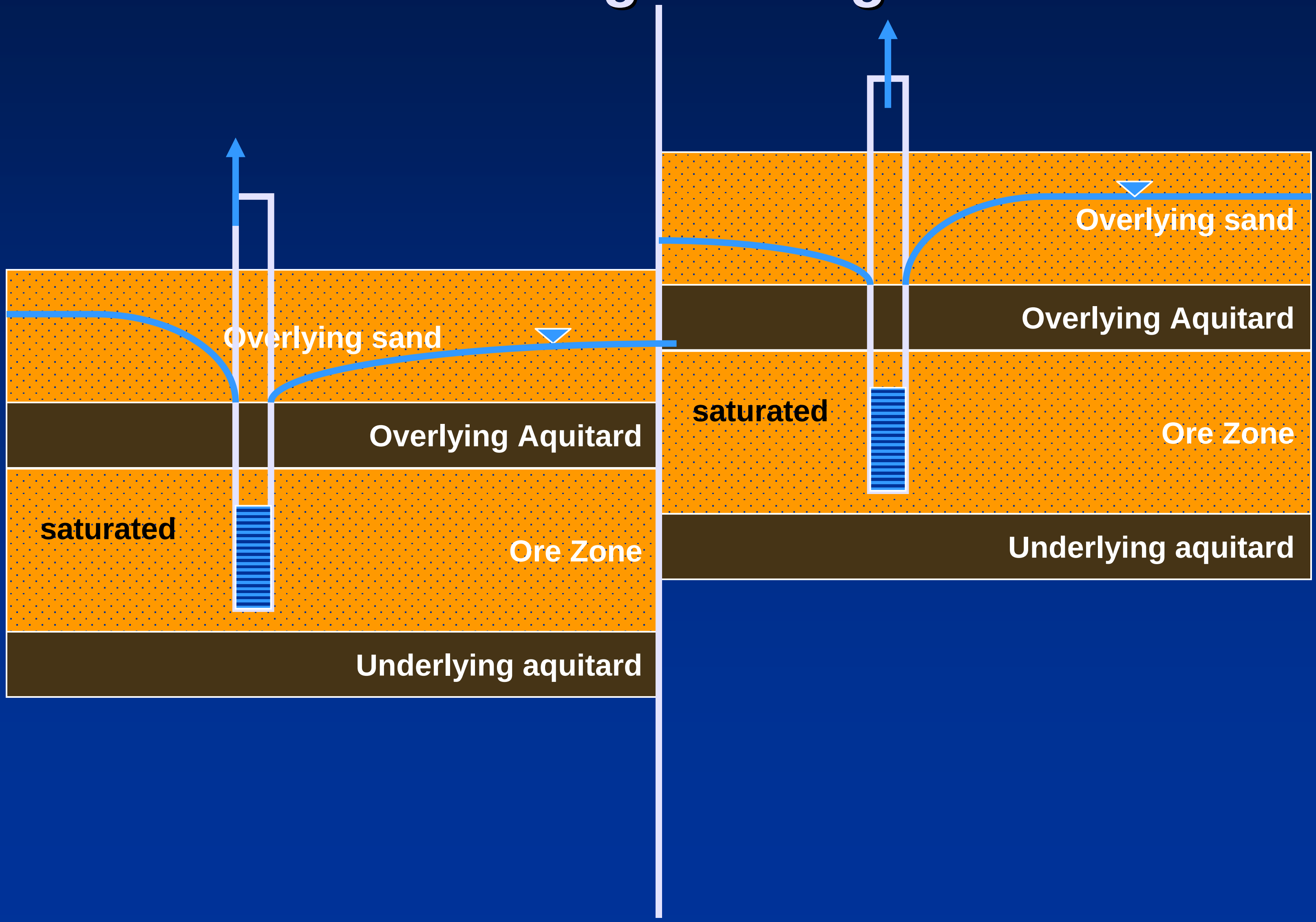


U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Characterizing ISR operations in an unconfined aquifer

- **Determine limiting extraction rate to avoid dewatering (step rate tests)**
- **To demonstrate communication, design pumping tests which consider limited extent of drawdown at each well**
- **Provide strategies for how to capture excursions given limited extraction rates and cones of depression**
- **Consider groundwater flow modeling to demonstrate unconfined aquifer behavior (cone of depression, operations, restoration)**

Issue: Sealing/Leaking Fault



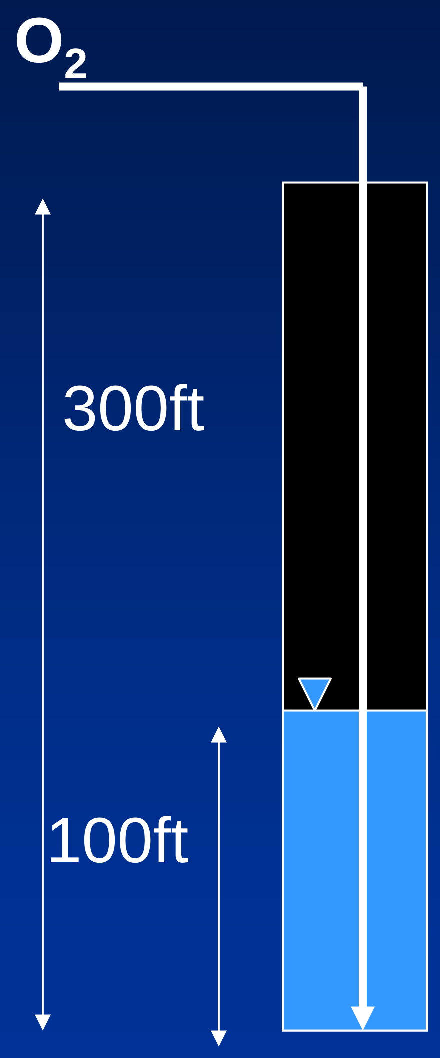
Characterizing ISR operations near a fault

- Use pumping tests to address behavior of fault and assess impact of fault on wellfield cone of depression
- Use pumping tests to assess connectivity of offset layers to ore zone to modify cone of depression
- Consider groundwater flow modeling to demonstrate behavior around fault (cone of depression, operations, restoration)

Issue: Lixiviant composition and gas lock

- Bicarbonate
- Carbon Dioxide
- Oxygen
- Hydrogen Peroxide

Oxygen solubility



Rule of thumb:
1 ppm dissolved oxygen/ foot of head

EXAMPLE: Injection Well

- **Fracture gradient limitation 1 psi/ft, so max injection pressure is 300 psi.**
- **Max well head pressure is therefore 300 psi-(300 ft*.433 psi/ft)=170psi.**
- **170 psi=392 feet so max O_2 can be 392 ppm at well head.**
- **If inject 392 ppm and solubility is 100 ppm (100ft): 292 ppm will come out of solution into ore zone**

Hydrogen peroxide in lixiviant

Hydrogen peroxide decomposes to form free oxygen, O_2, in the presence of pyrite, Fe S_2:

$$FeS_2 + 7.5H_2O_2 = Fe^{3+} + 2SO_4^{2-} + H^+ + 7H_2O$$

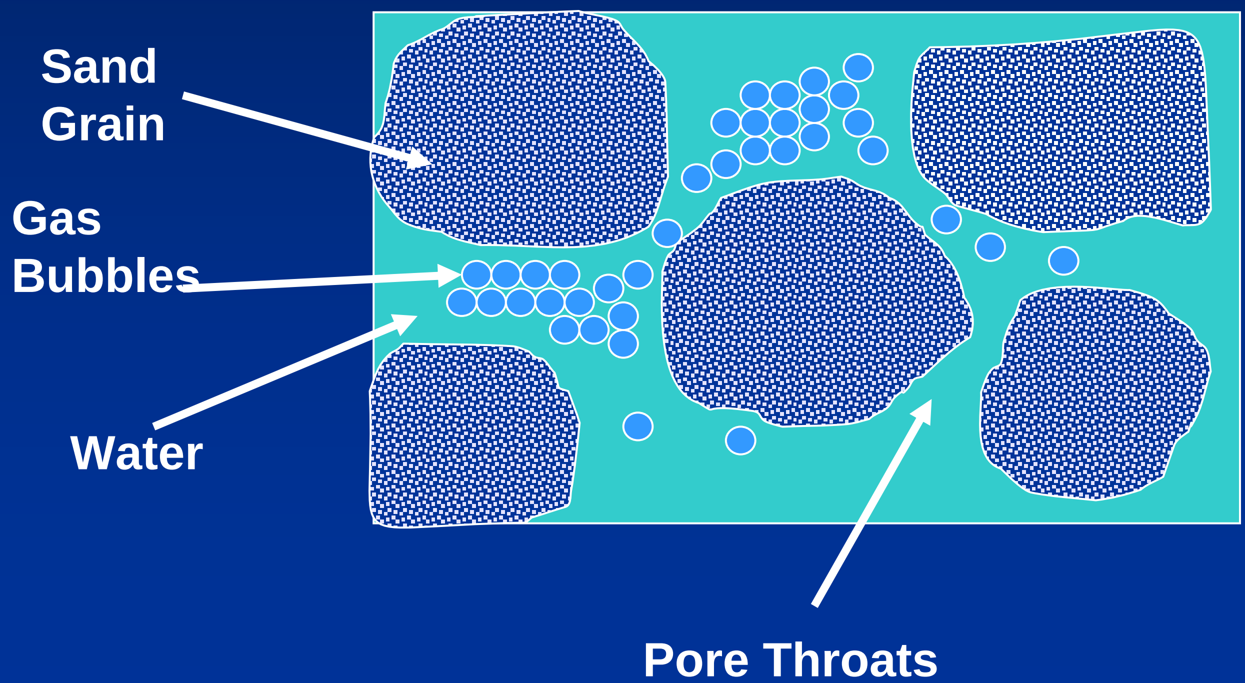
$$Fe^{3+} + 0.5H_2O_2 = Fe^{2+} + H^+ + 0.5O_2 \uparrow$$

Free Phase Oxygen

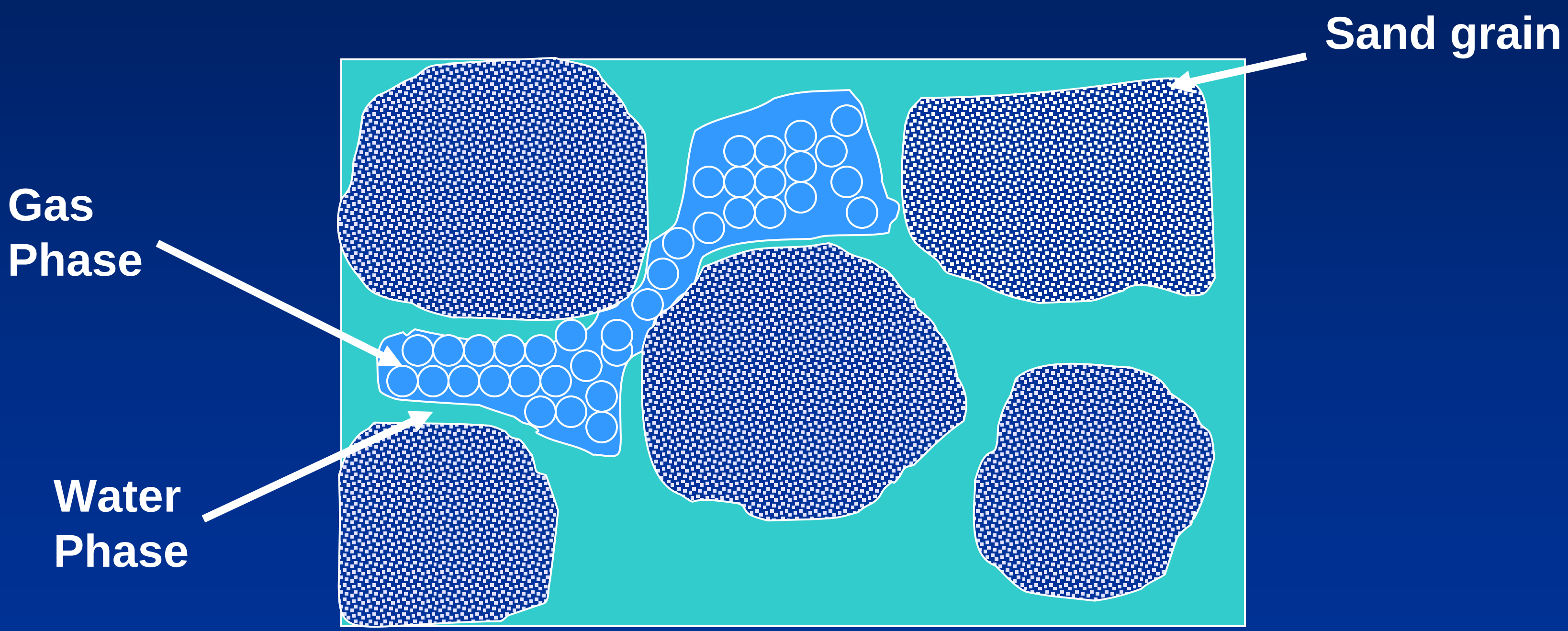
Chirita, P., " A kinetic study of hydrogen peroxide decomposition in presence of pyrite," Chemical and Biochemical Engr Quarterly, Vol. 21, No. 3, pp. 257-264, 2007

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Dissolved oxygen bubbles out of lixiviant when hydrostatic head reduced (unconfined or shallow confined aquifer) or hydrogen peroxide interacts with pyrite

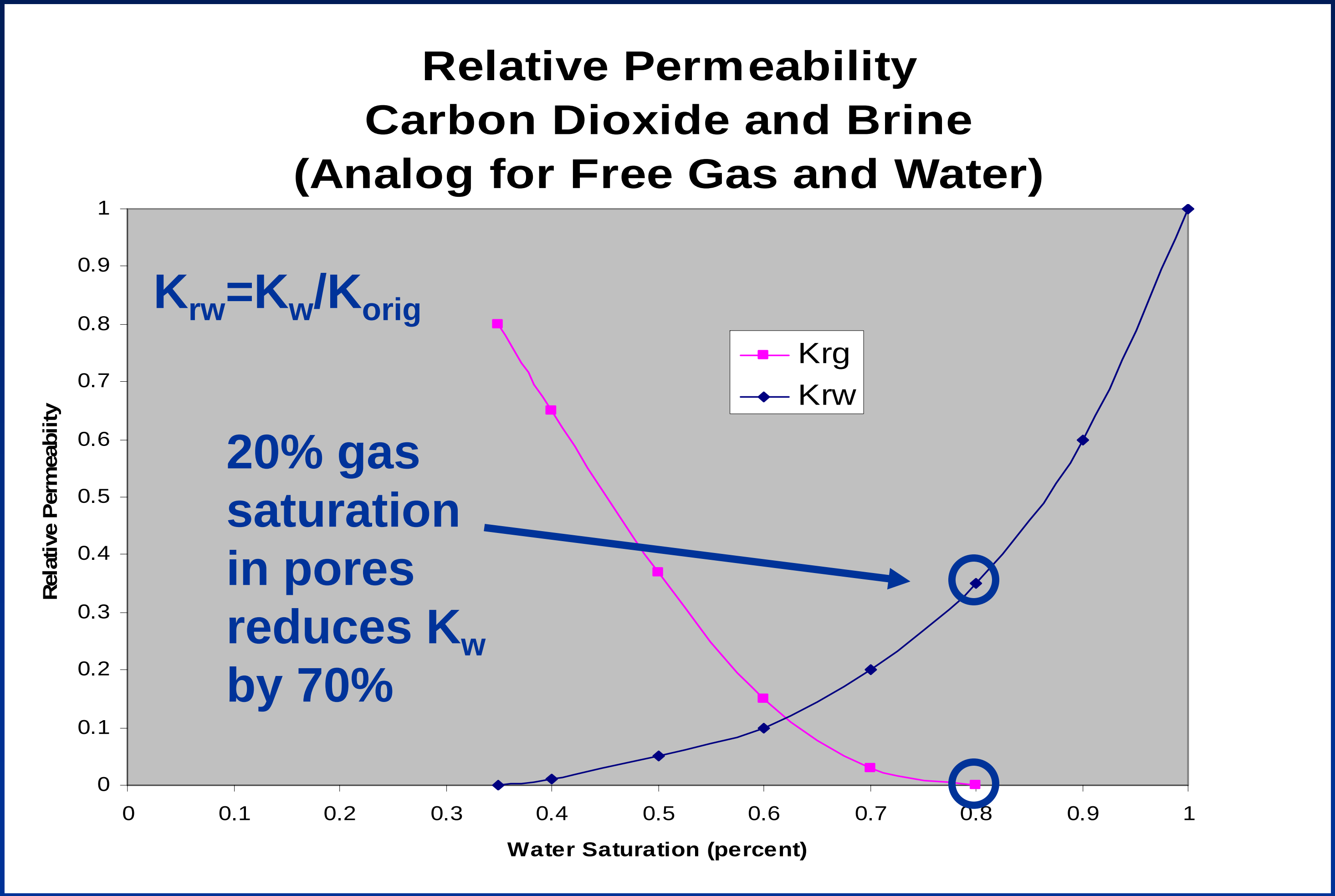


As gas bubbles continue to come out of solution, they combine to block pore throats or separate the water phase into smaller channels.



This creates a reduction in conductivity, known as “Gas Lock,” which is dependent on saturation of the water and gas phases

How much is the conductivity reduced?



From Benson et al, Lawrence Berkley National Lab, 2005

Gas Lock

Why is it a Safety Issue ?

- If free gas is released at the injection well, it can reduce injectivity and create back pressure which can quickly damage well if not detected.
- Gas produced at production well can cause simultaneous gas and water two phase flow that can damage piping, cause cavitation in pumps and affect pressure/flow measurements.
- Reductions in conductivity of ore zone can change flow system in an unpredictable manner which can influence flow control and may lead to excursions or bypassed zones.

Addressing gas lock

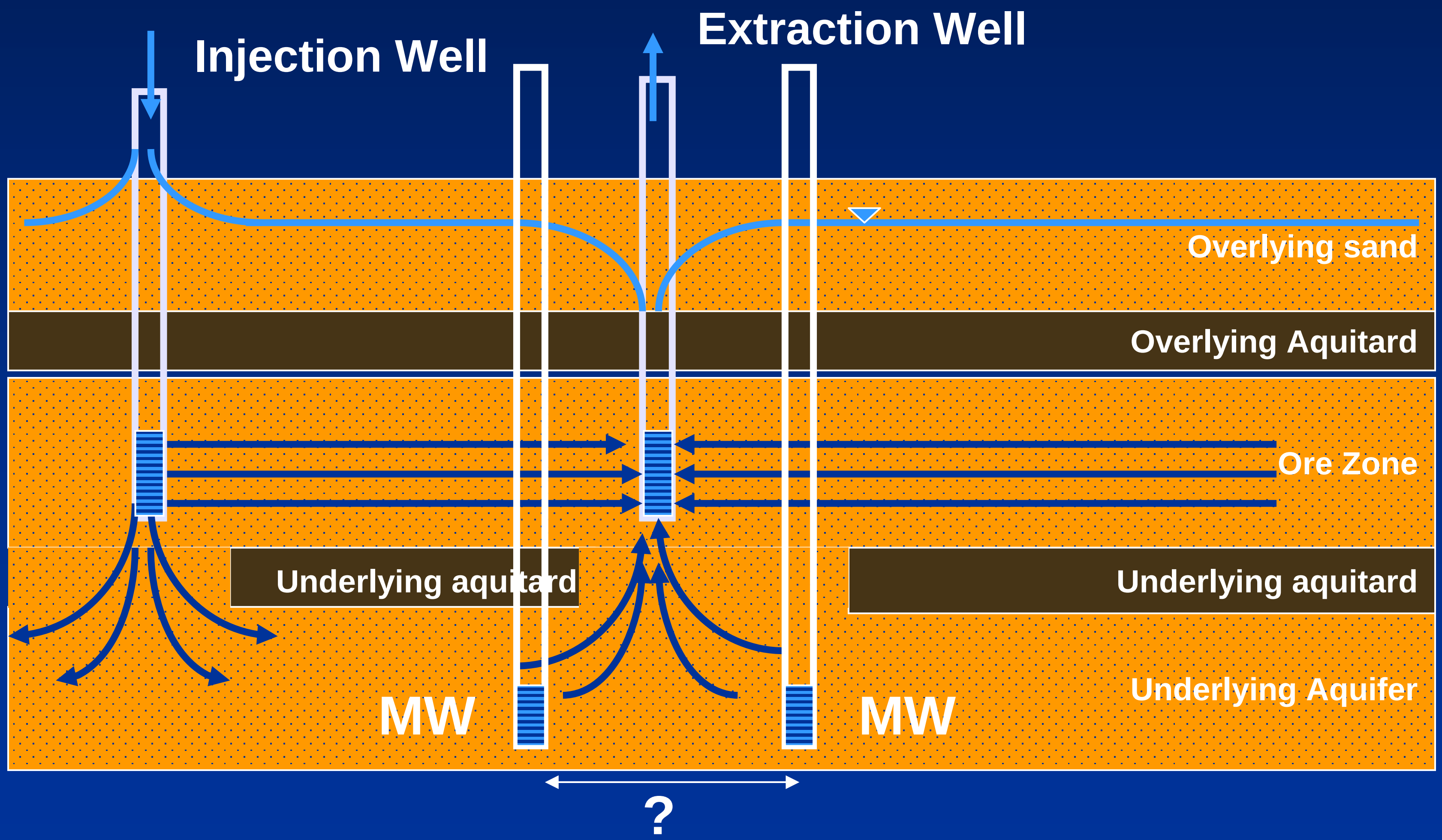
- Assess solubility limits of dissolved oxygen in lixiviant and use oxygen concentrations which prevent gas from being released from solution at injection wells or ore zone
- Avoid use of hydrogen peroxide in low hydrostatic head aquifers with pyrites
- Watch for gas in produced water at extraction wells
- Cycle wells from injection/extraction to change pressure conditions
- Install pressure gauges on each well to detect pressure changes in wells and pipes directly

Monitoring and Excursions

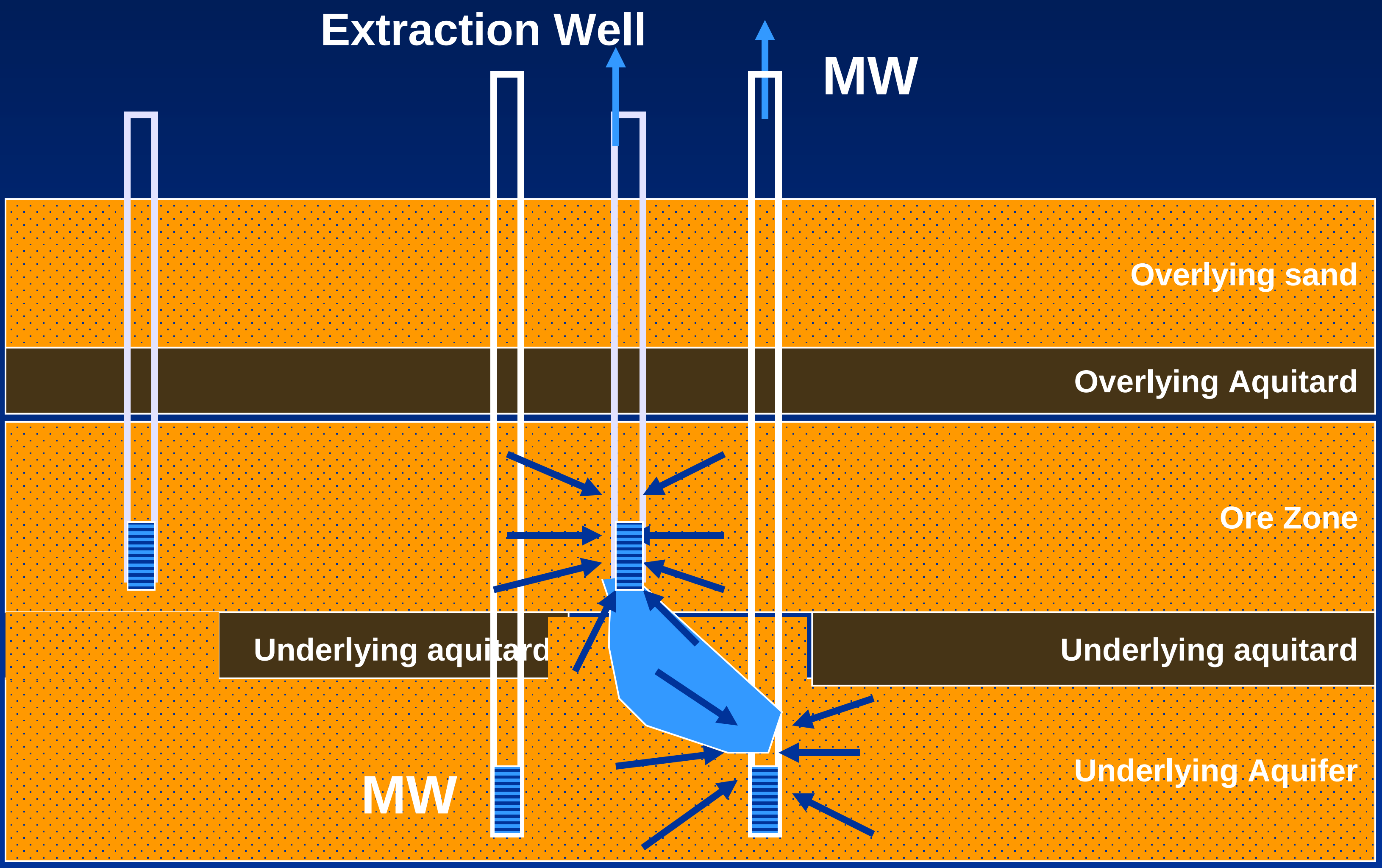
Issues

- Lack of confining layers
- Faults

Where do you place the monitoring wells with lack of vertical barrier?



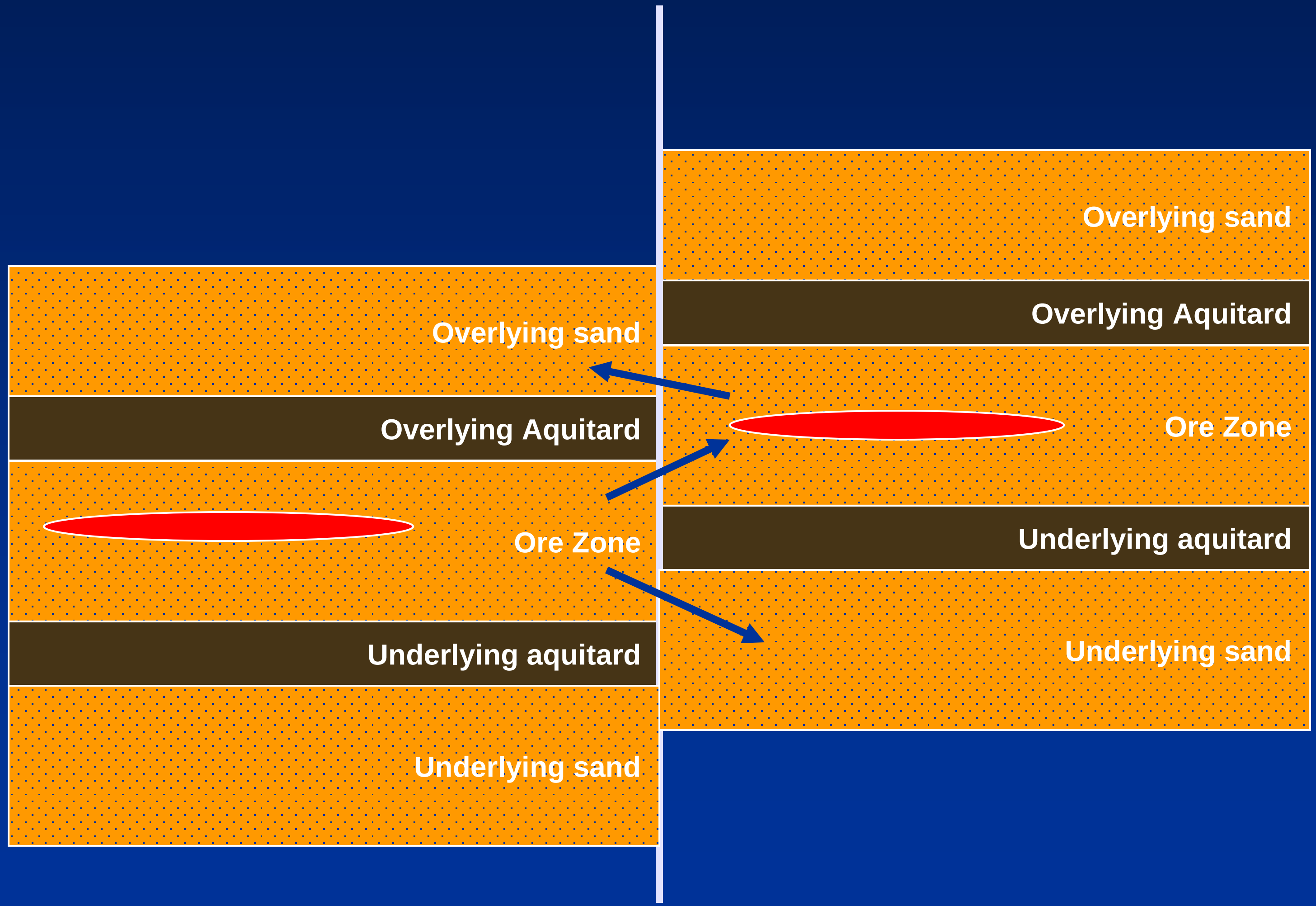
How do you capture an excursion?



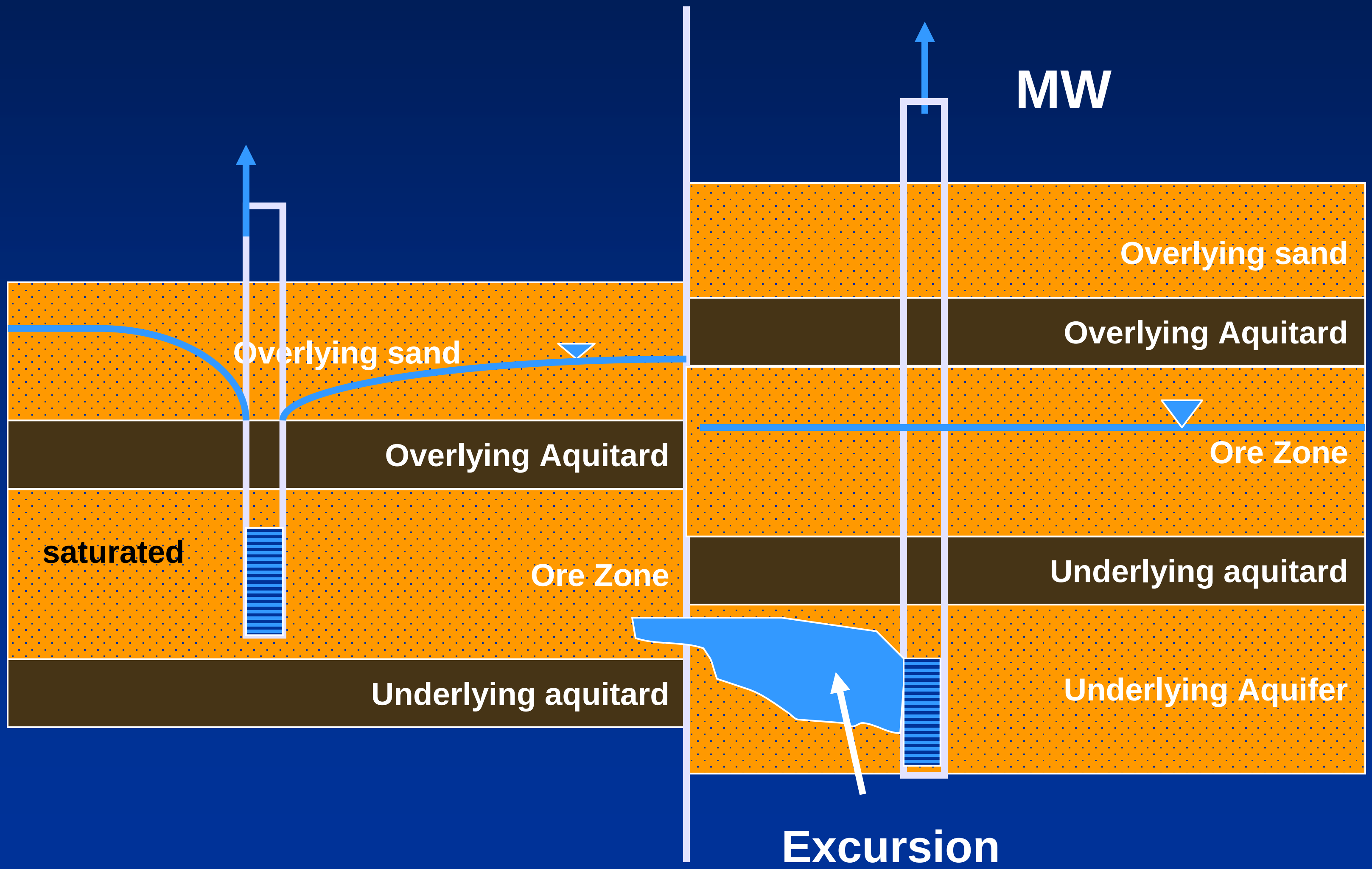
Monitoring and excursion capture with missing confining layers

- Assess how to place monitoring wells to detect vertical excursions in the absence of barrier (analogous to MW ring for horizontal excursions)
- Address how a vertical excursion to underlying aquifer would be captured
- Include underlying aquifer as part of production zone
- Consider groundwater flow modeling to demonstrate monitoring and capture

Issue- Faults: Sealing or Leaking



Where do you place a MW and how do you capture an excursion near a fault?



Monitoring and excursion capture near a fault

- Assess how to place monitoring wells to detect excursions across fault to offset overlying and underlying aquifers
- Address how excursions across faults would be captured
- Consider groundwater flow modeling to demonstrate monitoring and capture

Restoration

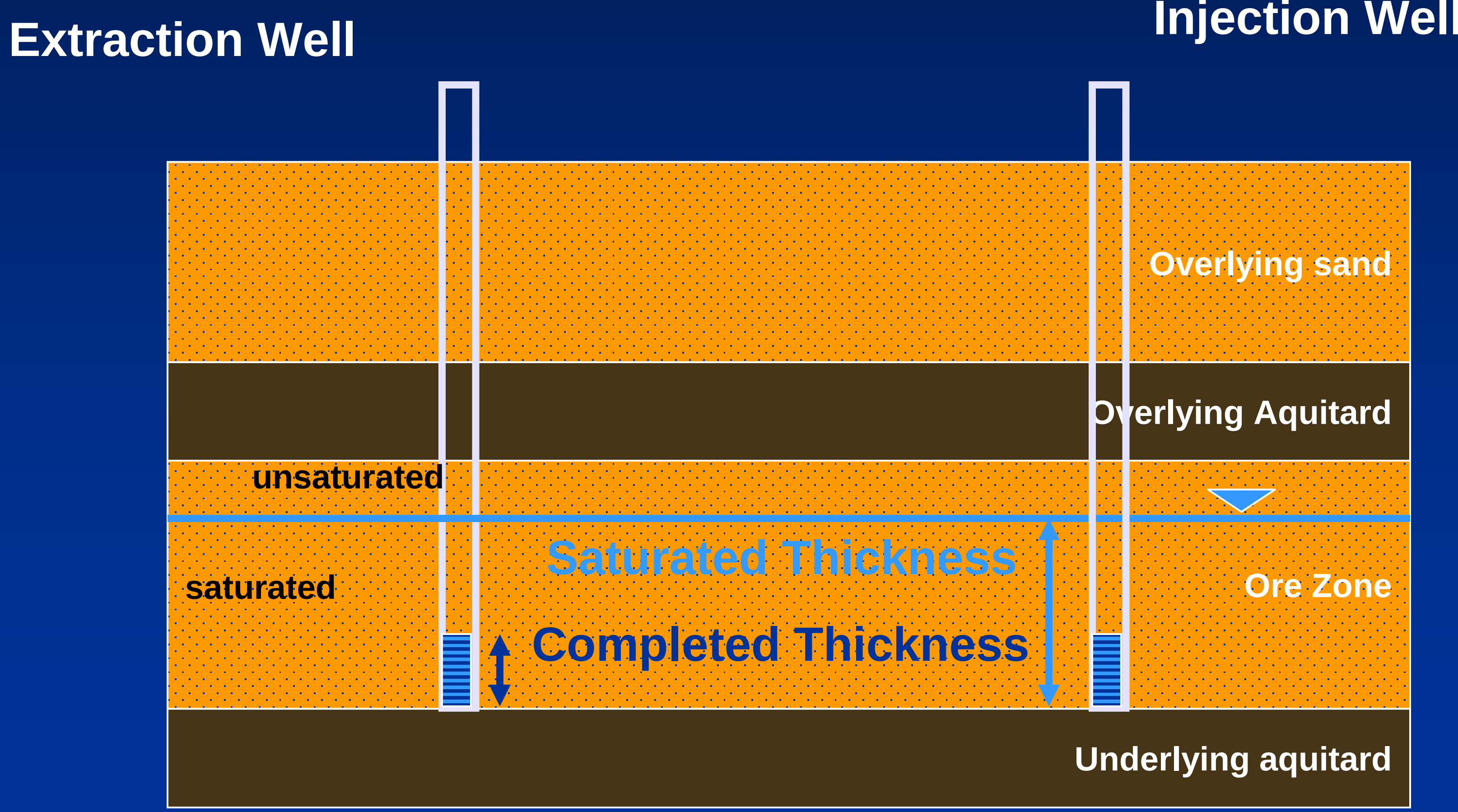
Issues

- Pore volume calculation using saturated thickness vs. average completed thickness in unconfined aquifers

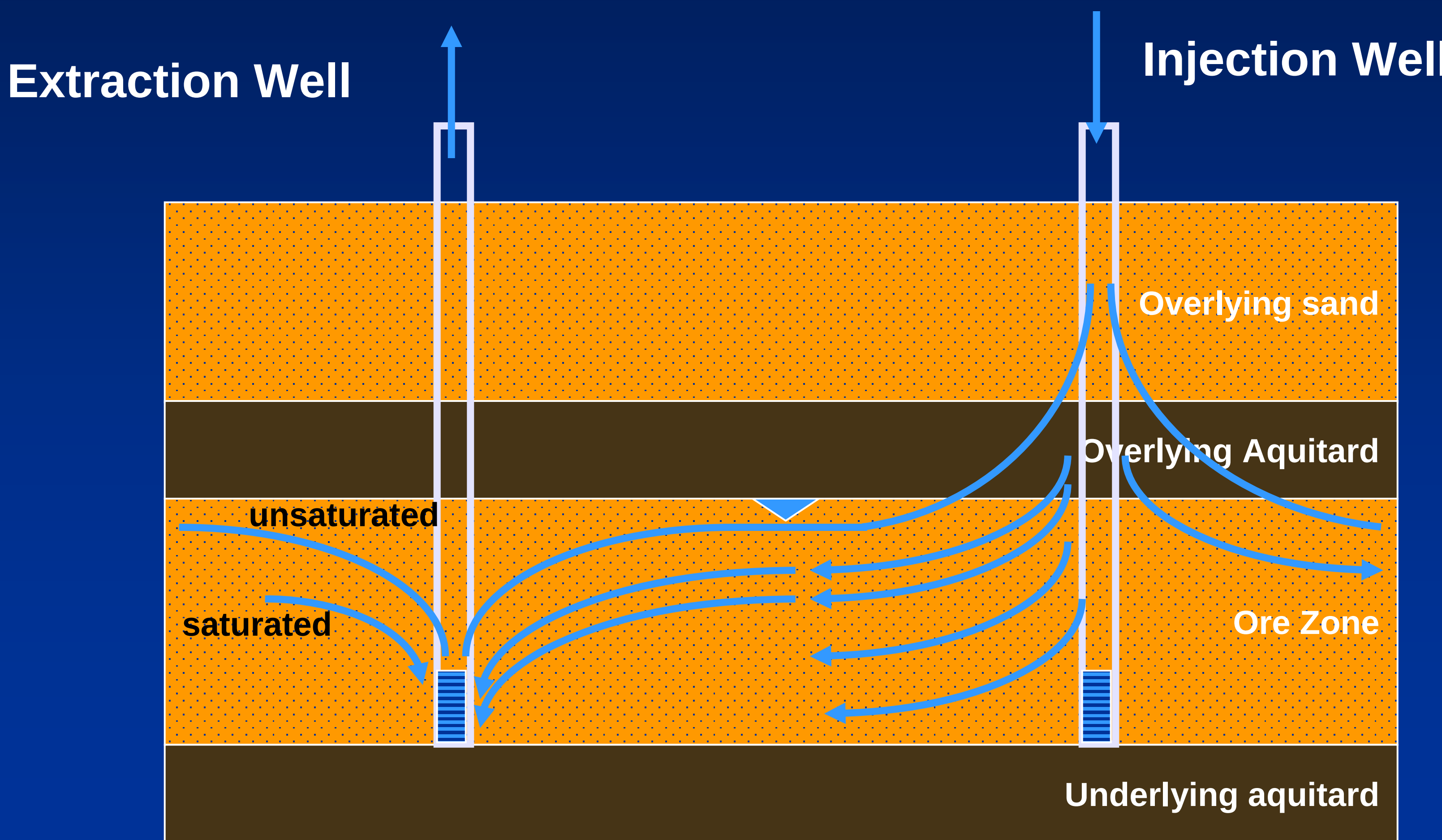
- Dewatering/mounding effects on saturation and contact of ore zone in unconfined aquifers

Issue: Pore Volume in Unconfined Aquifer

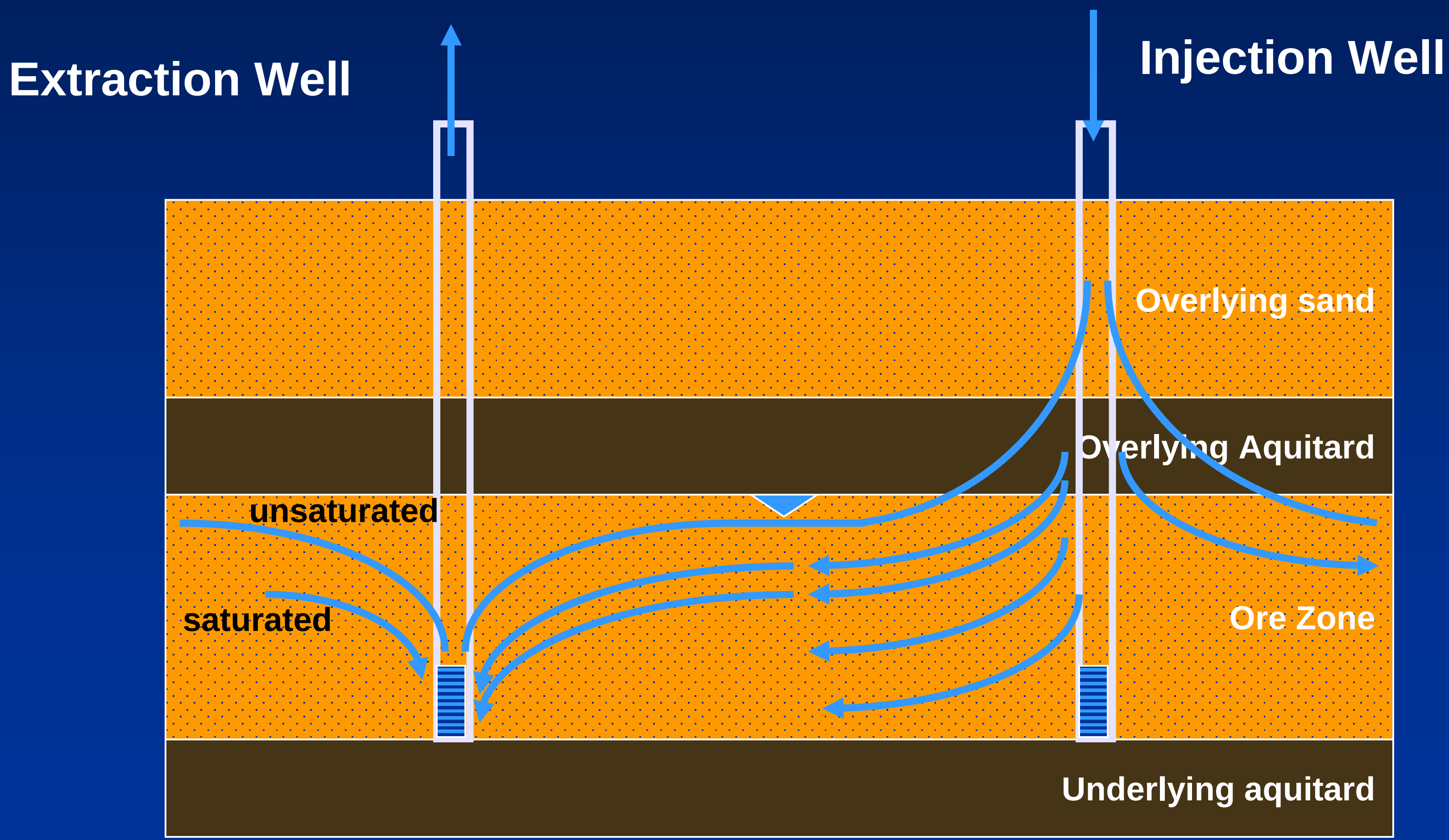
PV= Area * *Average Completed Thickness* * Porosity * Flare



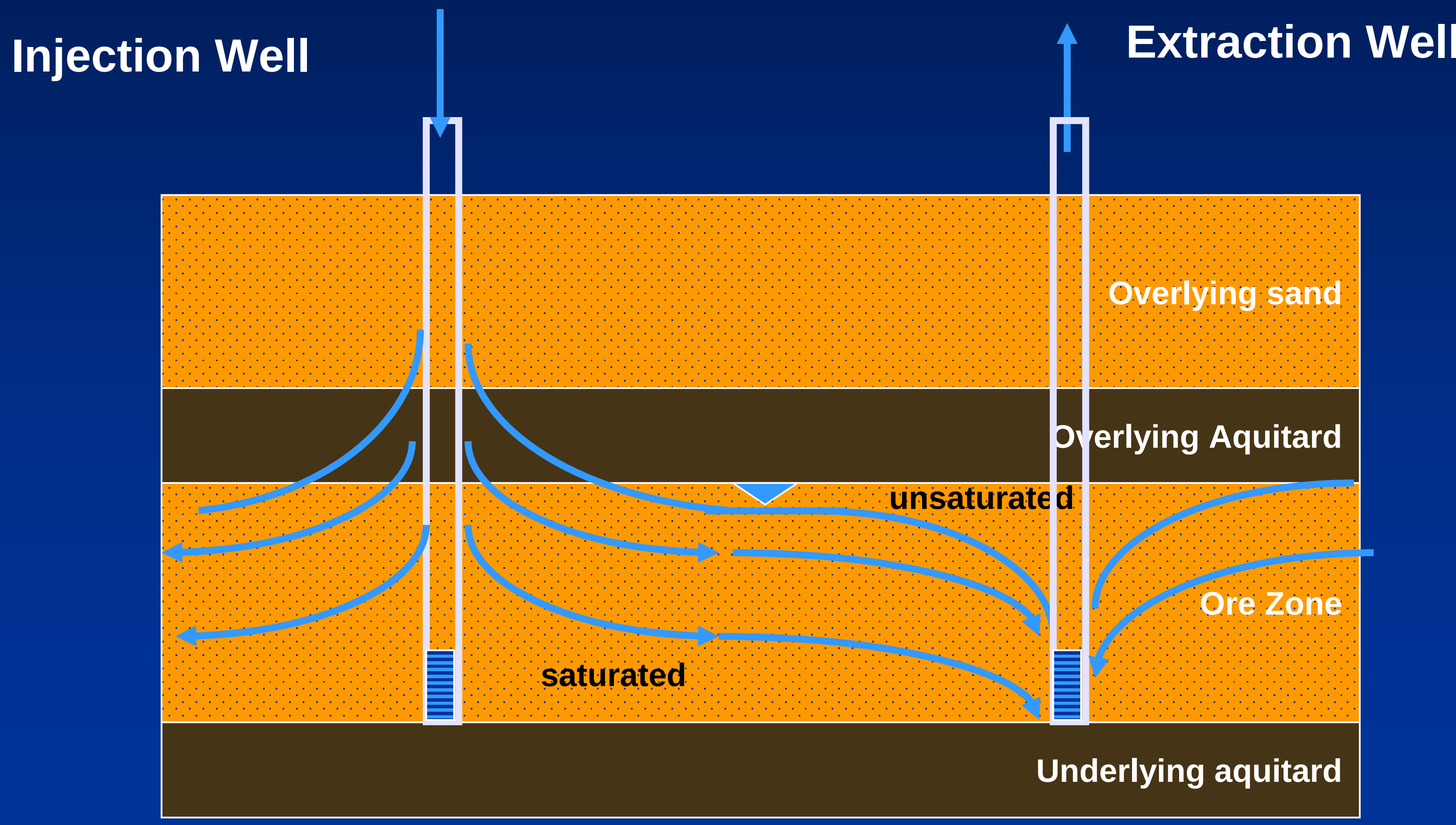
Injection/Extraction in Unconfined Aquifer :
Vertical flow contacts more than completed thickness
PV= Area * *Saturated thickness* * Porosity * Flare



Issue: Unconfined aquifer saturation/desaturation impacts sweep/contact of ore zone with restoration fluids.



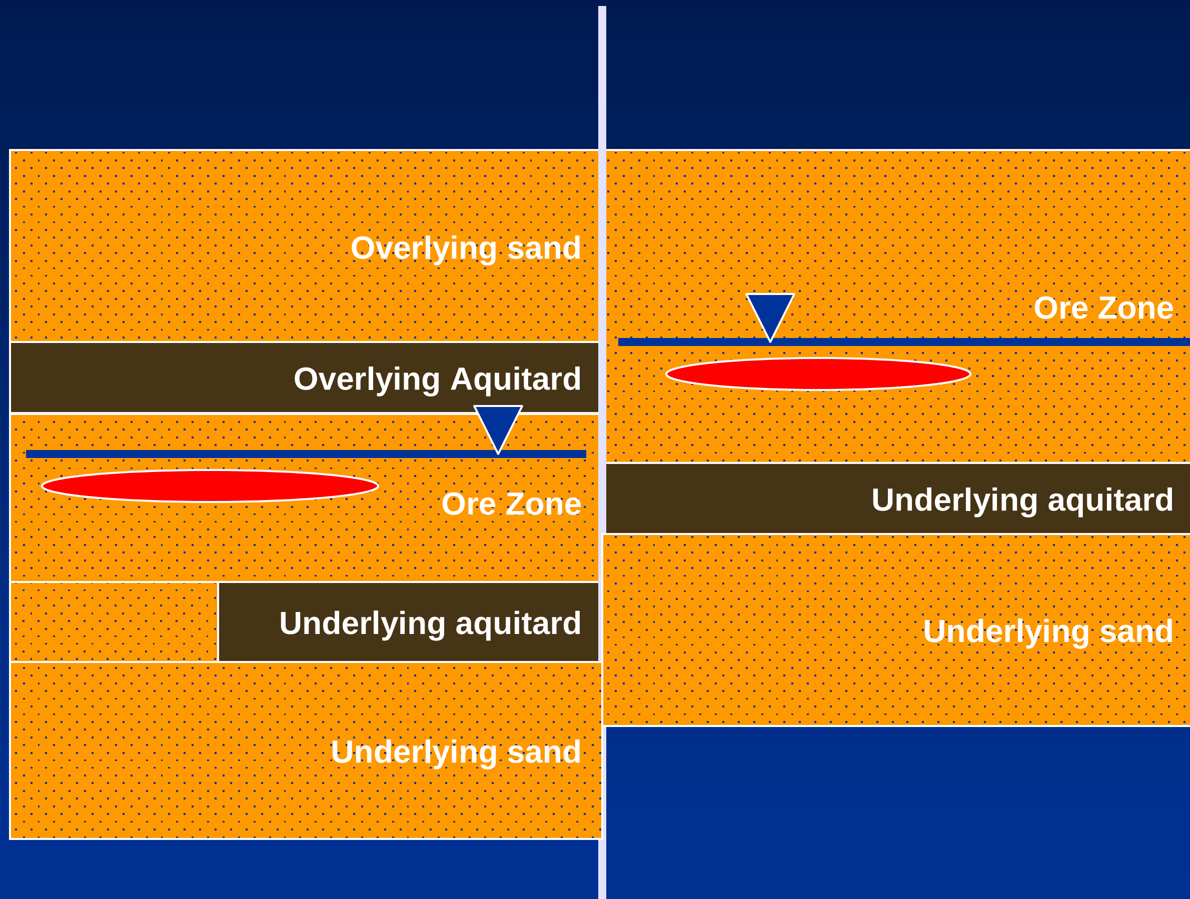
Flip/pulse wells to ensure contact of all portions of aquifer with restoration fluids.



Conclusion - Issues

- Surficial Aquifers
- Unconfined Aquifers
- Faults
- Missing Confining Layers

All four issues at one site



Characterization, Flow Behavior, Monitoring, Excursion Capture, Restoration

Resources

- William Walton, "Groundwater Pumping Tests: Design and Analysis"
- Johnson Controls, "Groundwater and Wells"
- Michael Kasenow, " Aquifer Test Data: Analysis and Evaluation"