Challenges in the Testing and Sampling of Aquifers with Dissolved Gases

WaterTech 2014 – April 11, 2014

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Waterline Resources Inc.

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Outline

- Common dissolved gases in aquifers
- Pressure, temperature, bubble point
- Phases in the exsolution of dissolved gas from aquifers and practical problems that arise
- Methods/techniques to manage exsolution of dissolved gas during production
- Health and safety mitigation
- Summary

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Dissolved Gas in Water

- Major: Oxygen, Nitrogen, Argon, Carbon Dioxide
  - i.e. Air!
- Minor Nobel Gases:
  - Helium, Neon, Krypton, Xenon
- Minor Trace Gases:
  - Hydrogen, Methane, Nitrous Oxide
- Solubility in water depends on temperature, salinity and pressure

Free Gas vs Dissolved Gas

- Free Gas: gas that readily comes out of solution at atmospheric pressure (Coleman et al., 1988)
- Concentration > Saturation Point = Exsolution
- Saturation point of methane at atm pressure:
  - 22 mg/L to 28 mg/L

Dissolved Gas in Water

- Solubility also depends (mostly) on pressure!
- Henry's Law:
  - "At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid.“
- i.e. the solubility of a gas in a liquid is <u>directly proportional to the partial pressure of the gas above the liquid</u>.
- Increase pressure = increase solubility
- Decrease temperature = increase solubility

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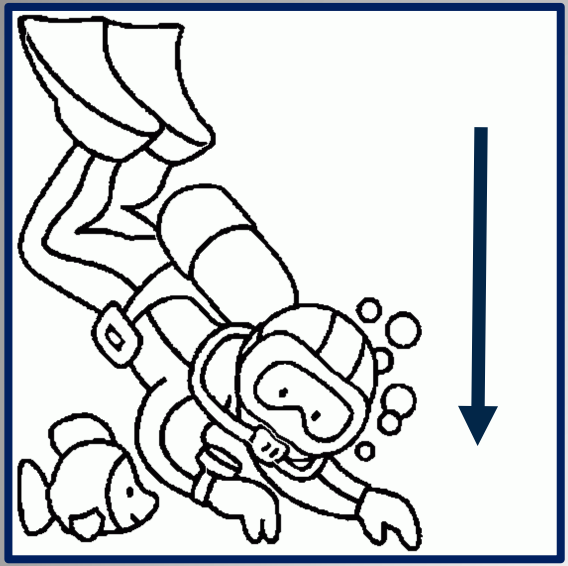
Pressure is Everything!

CO_2 gas in bottle > atm pressure

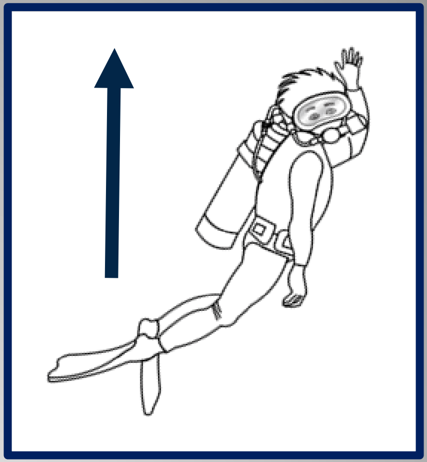
Open the bottle and bubbles exsolve from solution

Solubility vs Pressure



Increase pressure with depth
Tissue can absorb more gases, nitrogen builds up (dissolves) into blood.

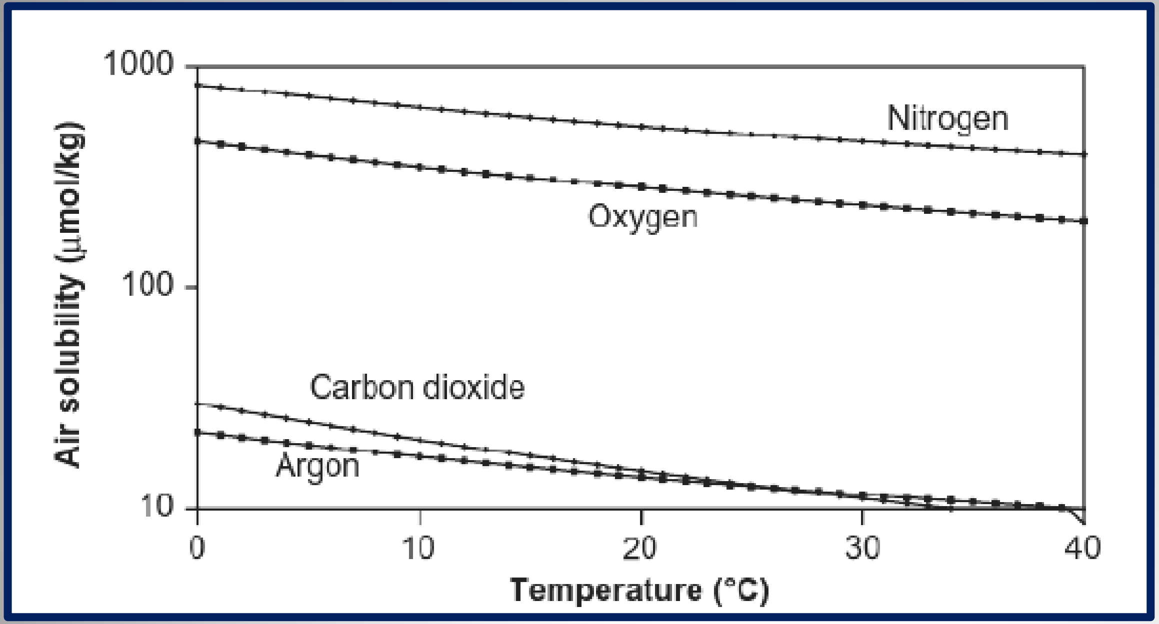
So far so good!



Ascent to surface reduces pressure, nitrogen becomes less soluble.
If come up too fast – nitrogen released in form of bubbles = Decompression Sickness (Bends)

Slow ascent to release pressure – unscrew the pop bottle slowly…

Solubility vs Temperature



Colt, J. (2012), *Dissolved Gas Concentration in Water: Computation as Functions of Temperature, Salinity and Pressure*, Elsevier.

Cold water diving:

Body will on-gas faster!

Shorter dive or shallower dive than warm water.

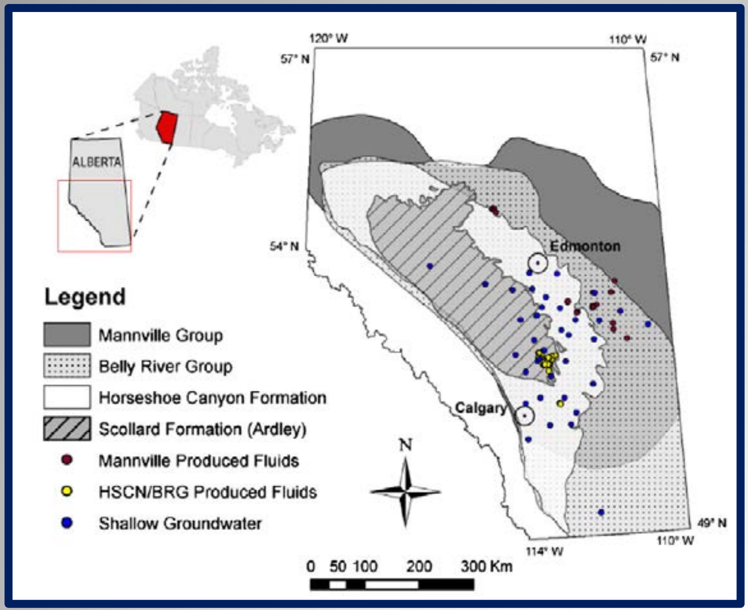
Dissolved Gas in Groundwater

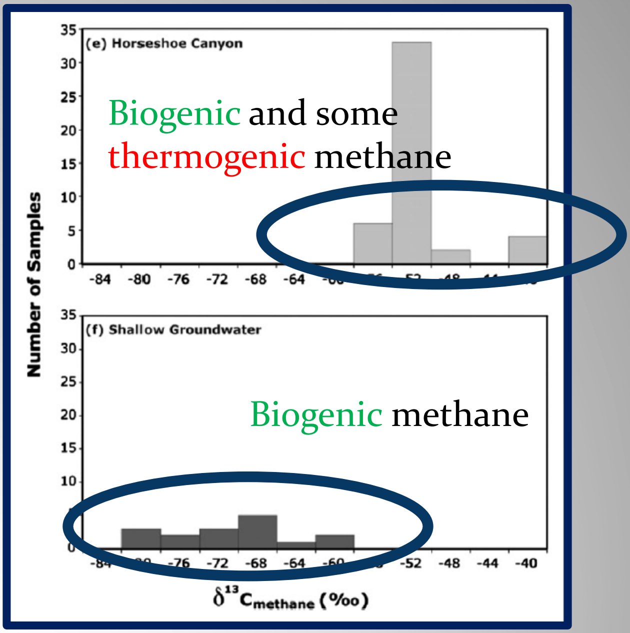
- Groundwater contains a number of dissolved gases
  - Methane (CH_4) low solubility, most common
  - CO_2 almost always present
  - H_2S highly soluble, rare in shallow groundwater
  - Total dissolved gas pressure (TDGP) = sum of partial pressures
    - If TDGP > water pressure + atm pressure → bubbles
- Shallow wells commonly have gas, usually not observable
- Issues practically start when reach the <u>bubble point</u>

Dissolved Gas Sampling

- Flow through cell gas separation
- ***A necessary tool for hydrogeologists***
- Good for identifying gas dissolved **composition**
- Difficult to obtain true gas-water ratio

Methane in Shallow Groundwater





Anaerobic production of methane:
$CH_3COOH \rightarrow CH_4 + CO_2$

Anaerobic production of methane:
$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O$

Cheung et al. (2010)

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Who cares?

- Presence of gas can:
  - Change bubble point pressure
  - Gas lock the pump
  - Affect flow meter function
  - Lead well surging
  - Effectively compromise the aquifer
  - Create unsafe conditions
  - Delay operations

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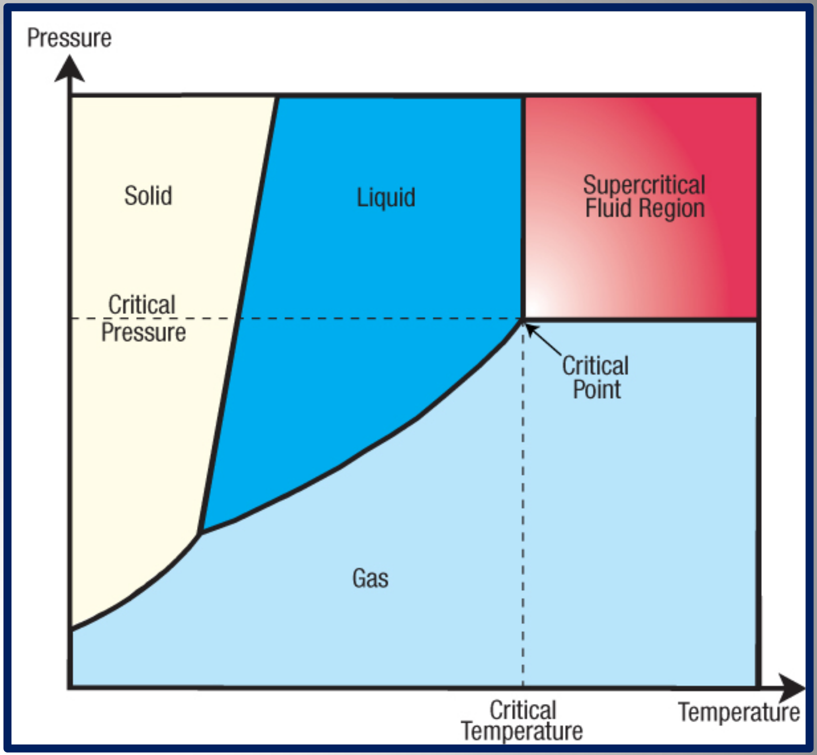
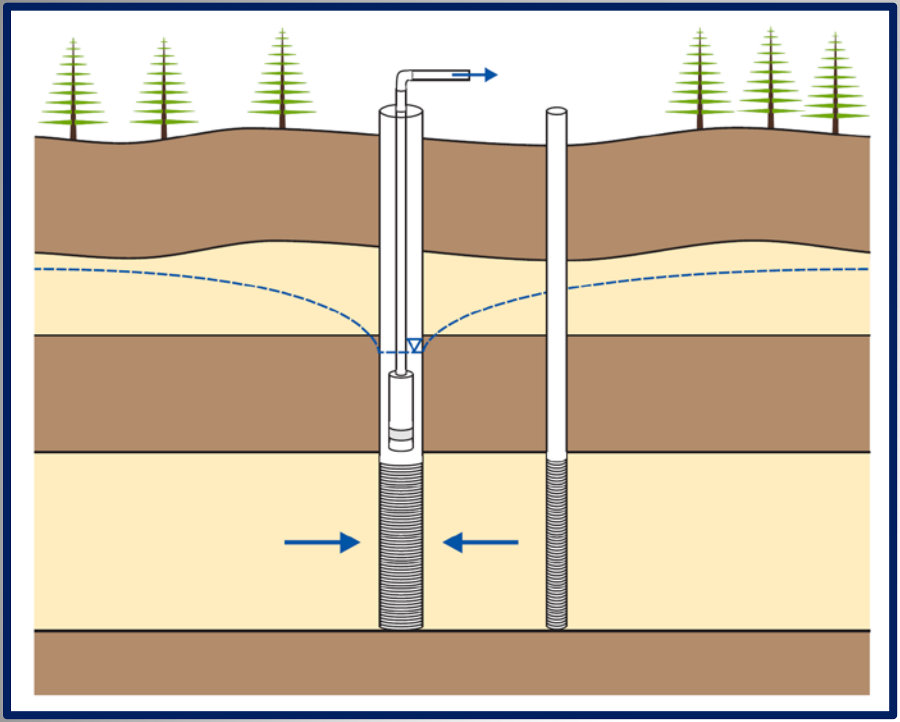
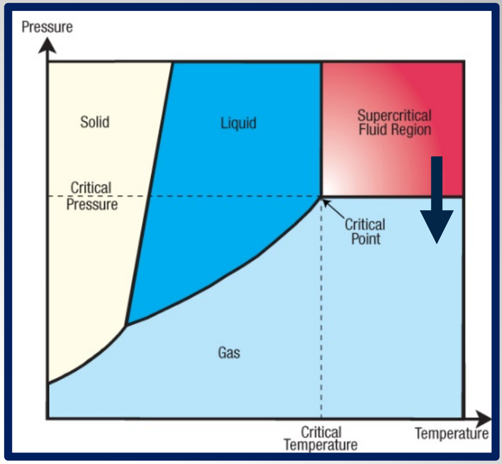
Bubble Point

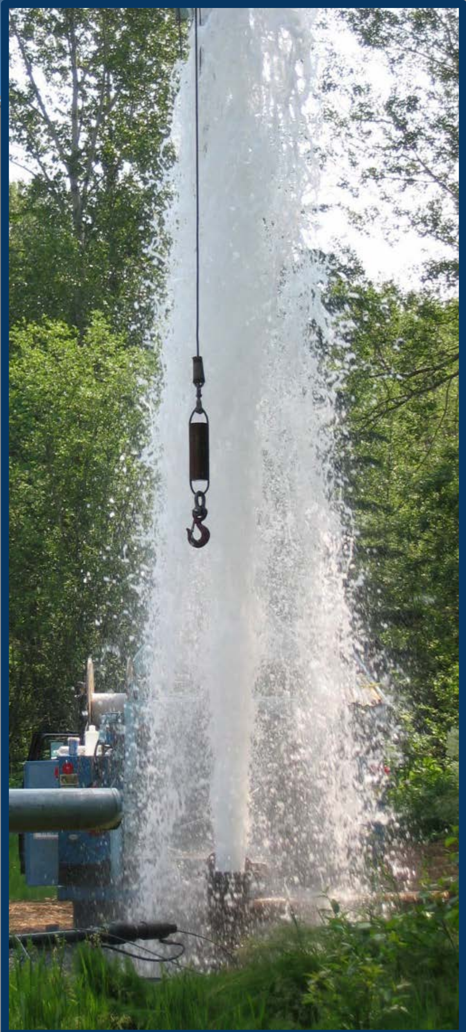
- **Definition**: The pressure and temperature conditions at which the first bubble of vapor comes out of solution
- In an aquifer, when pressure falls below a critical point → exsolution of dissolved gas from groundwater



Bubble Point





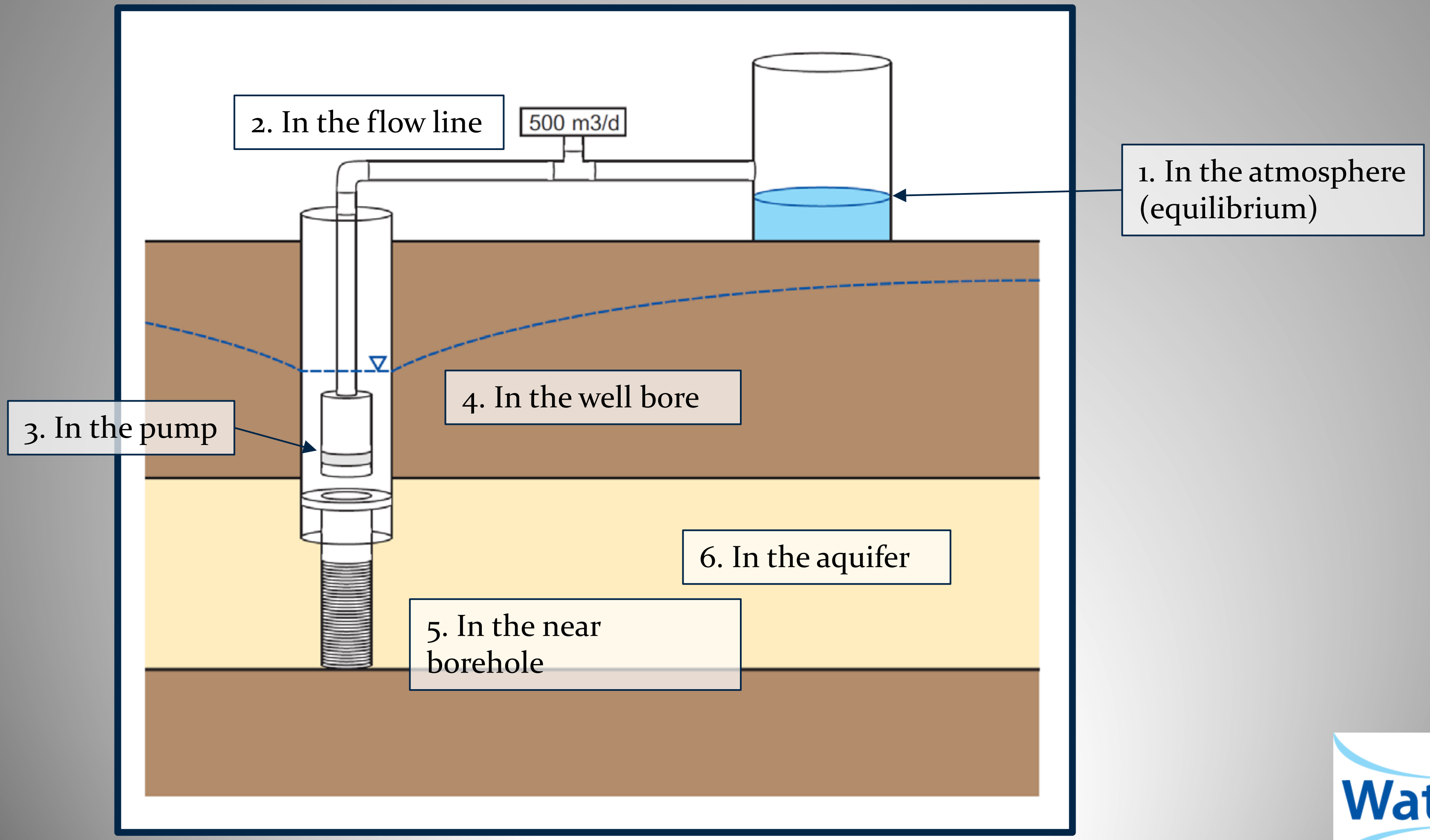


Exsolution of CO_2 in aquifer under high pressure

Exsolution of Dissolved Gas During Pumping Tests

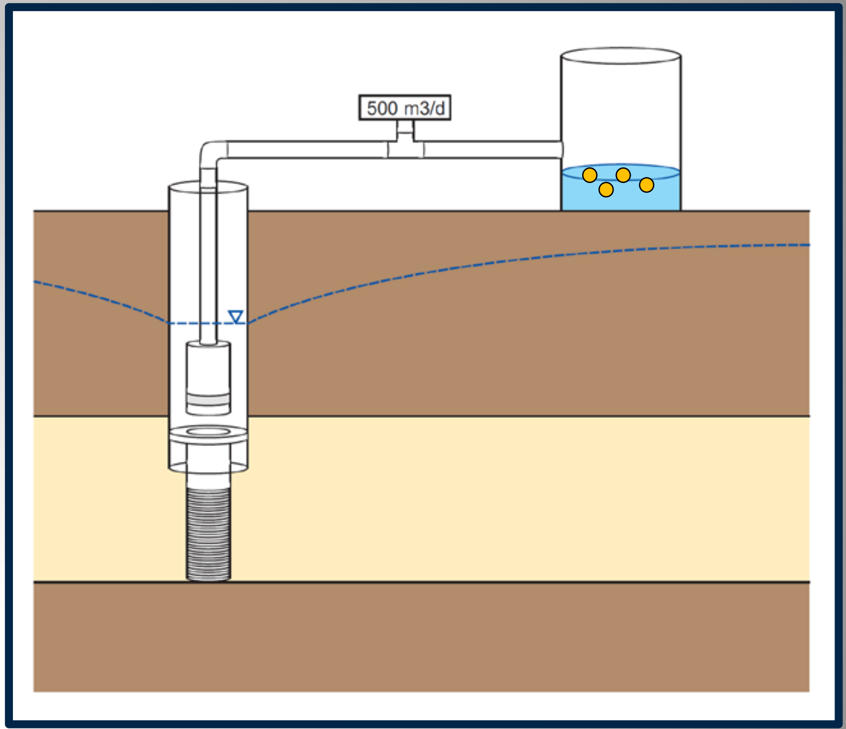
- Gas exsolves as pressure is released in many locations:
  1. When discharged at surface (atmospheric equilibration phase)
  2. In the flow line (flow meter phase)
  3. In the pump (gas locking phase)
  4. In the well bore (borehole exsolution phase)
  5. In the near borehole environment (near borehole phase)
  6. In the aquifer (aquifer phase)

Dissolved Gas Will Exsolve…



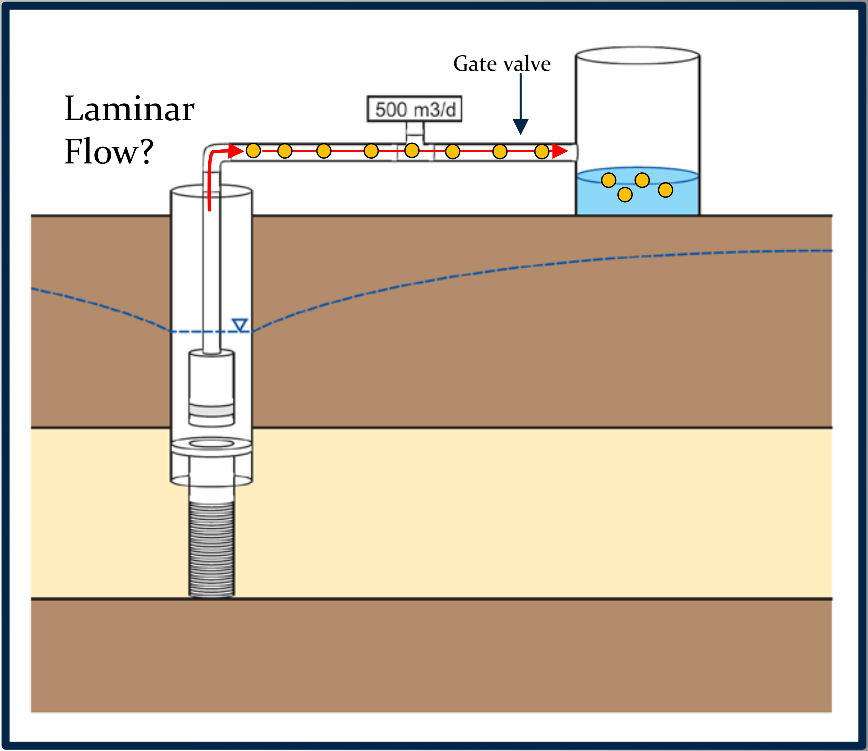
Atmospheric Equilibration Phase

- Gas exsolves from groundwater into the atmosphere
  - Reaches equilibrium with atmosphere
  - Becomes 'free-gas'
  - May observe bubbles in holding tank
  - Typically low concentration and not problematic to groundwater extraction



Flow Meter Phase

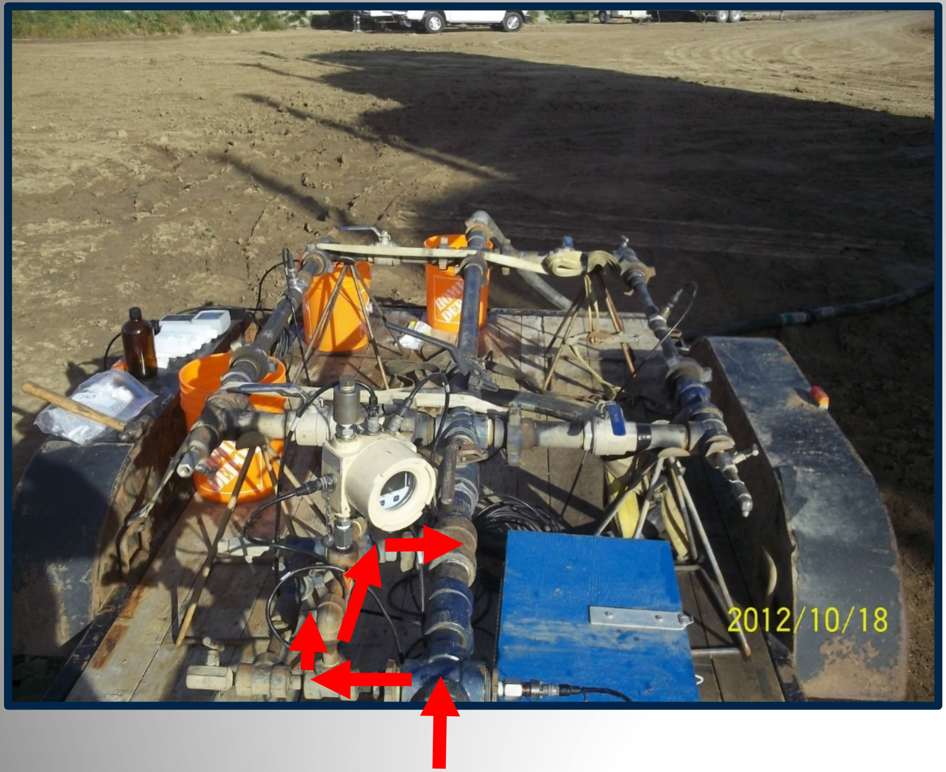
- Gas begins to exsolve in flow line
  - Pressure drop
  - Strive for <u>laminar flow</u>
    - Turbulence in flow line = (shaking the pop bottle)
    - Position gate valve *after* flow meter



Flow Meter Functionality

- Gas exsolving in flow line can affect flow meter
  - Flow meter turbine driven by flowing water i.e. does not account for two-phase flow
  - Results in non-constant flow rate
  - Results in inaccurate totalizer

Flow Meter Functionality Compromised



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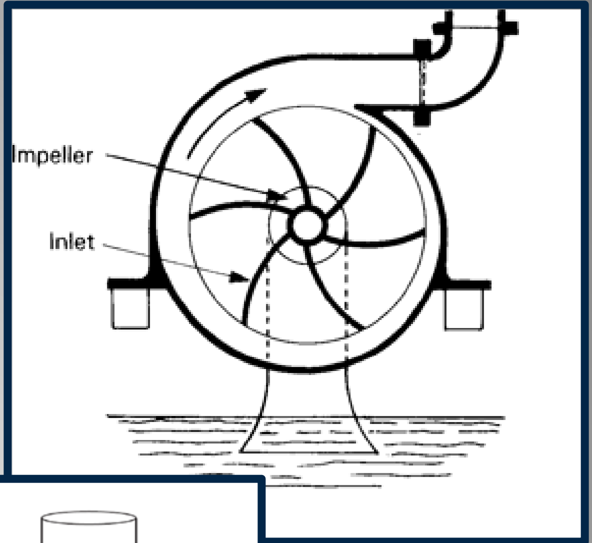
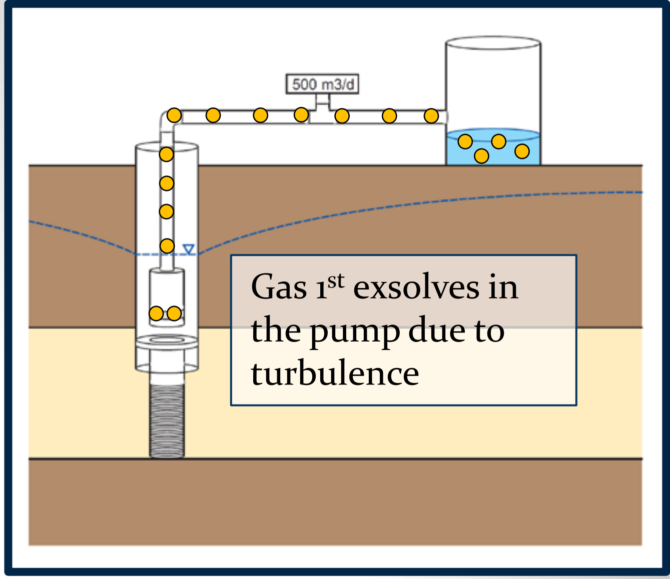
Flow Meter Functionality

Gas Locking Phase

- Gas exsolves in the pump due to turbulence
- Gas bubbles collect in the spinning impellers - cavitation
- Pressures up and 'locks' into the impellers
- Impellers spin in gas until water surges back in
- Can burn out pump motor

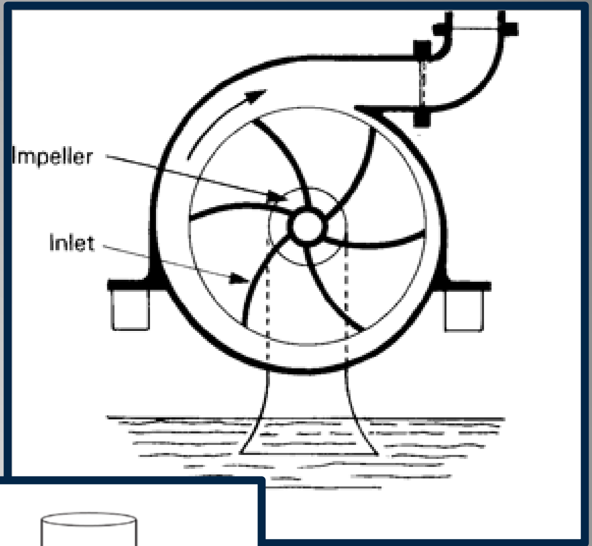
Cavitation: formation of vapour cavities in liquid due to changes in pressure.

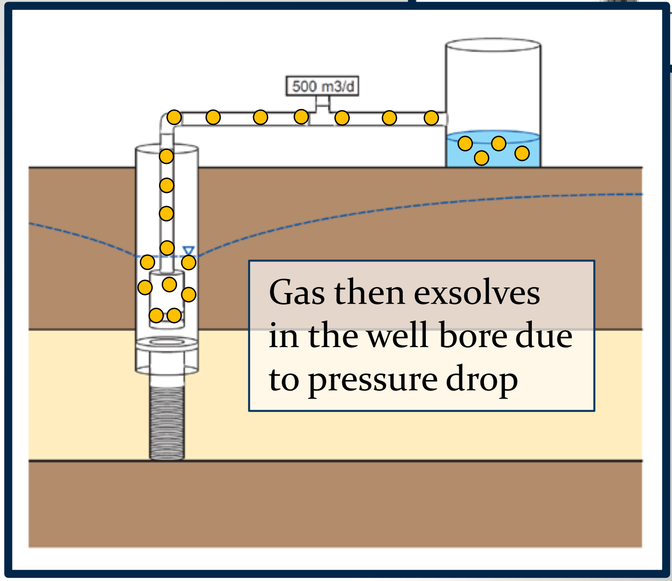




Well Bore Phase

- Gas exsolves in the pump due to turbulence
- Gas bubbles collect in the spinning impellers - cavitation
- Pressures up and 'locks' into the impellers
- Impellers spin in gas until water surges back in
- Can burn out pump motor





Cavitation: formation of vapour cavities in liquid due to changes in pressure.

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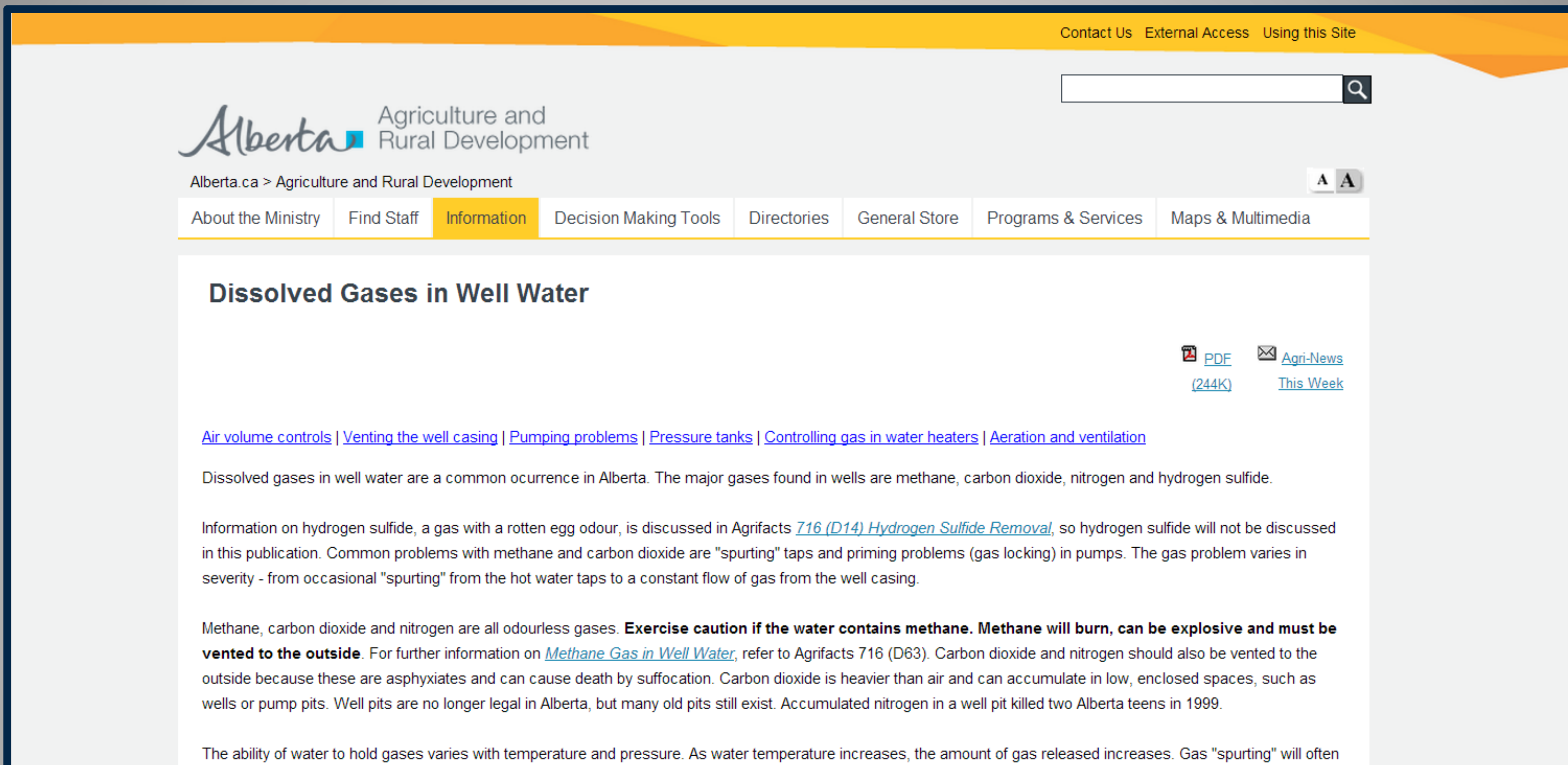
Gas Locking – A well known issue in AB



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Dissolved Gases in Well Water

PDF (244K) Agri-News This Week

Air volume controls | Venting the well casing | Pumping problems | Pressure tanks | Controlling gas in water heaters | Aeration and ventilation

Dissolved gases in well water are a common ocurrence in Alberta. The major gases found in wells are methane, carbon dioxide, nitrogen and hydrogen sulfide.

Information on hydrogen sulfide, a gas with a rotten egg odour, is discussed in Agrifacts *716 (D14) Hydrogen Sulfide Removal*, so hydrogen sulfide will not be discussed in this publication. Common problems with methane and carbon dioxide are "spurting" taps and priming problems (gas locking) in pumps. The gas problem varies in severity - from occasional "spurting" from the hot water taps to a constant flow of gas from the well casing.

Methane, carbon dioxide and nitrogen are all odourless gases. **Exercise caution if the water contains methane. Methane will burn, can be explosive and must be vented to the outside**. For further information on *Methane Gas in Well Water*, refer to Agrifacts 716 (D63). Carbon dioxide and nitrogen should also be vented to the outside because these are asphyxiates and can cause death by suffocation. Carbon dioxide is heavier than air and can accumulate in low, enclosed spaces, such as wells or pump pits. Well pits are no longer legal in Alberta, but many old pits still exist. Accumulated nitrogen in a well pit killed two Alberta teens in 1999.

The ability of water to hold gases varies with temperature and pressure. As water temperature increases, the amount of gas released increases. Gas "spurting" will often

http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex637

Gas Locking – A well known issue in AB

Pumping Problems

Severe gas problems may cause the gas locking (loss of prime) of submersible and jet pumps. Gas locking can sometimes be remedied by modifying the pump in consultation with representatives of pump companies, water well drillers or an agricultural water specialist.

When groundwater contains significant amounts of methane gas, it sometimes causes gas-locking problems in submersible water pumps. In a typical gas-lock situation, the pump will be operating normally, then quit pumping for no apparent reason, but the pump keeps running. Gas bubbles collect in the impellers of the pump and prevent water from moving through the pump. If the pump is shut off for a while and then re-started, it will usually start pumping water again. In the past, solutions to this problem included:

1. drilling holes in the submersible pump impellers to release the air bubbles
2. moving the pump check valve from the top of the pump to 5 or 10 feet above the pump
3. installing a shroud around the pump to divert gas bubbles past the pump intake

These solutions have had less than a 50 percent success rate. However, a fourth method has proven to work well in many situations. It involves diverting some of the water back down the water well, while the remaining water is pumped to the pressure tank.

http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex637

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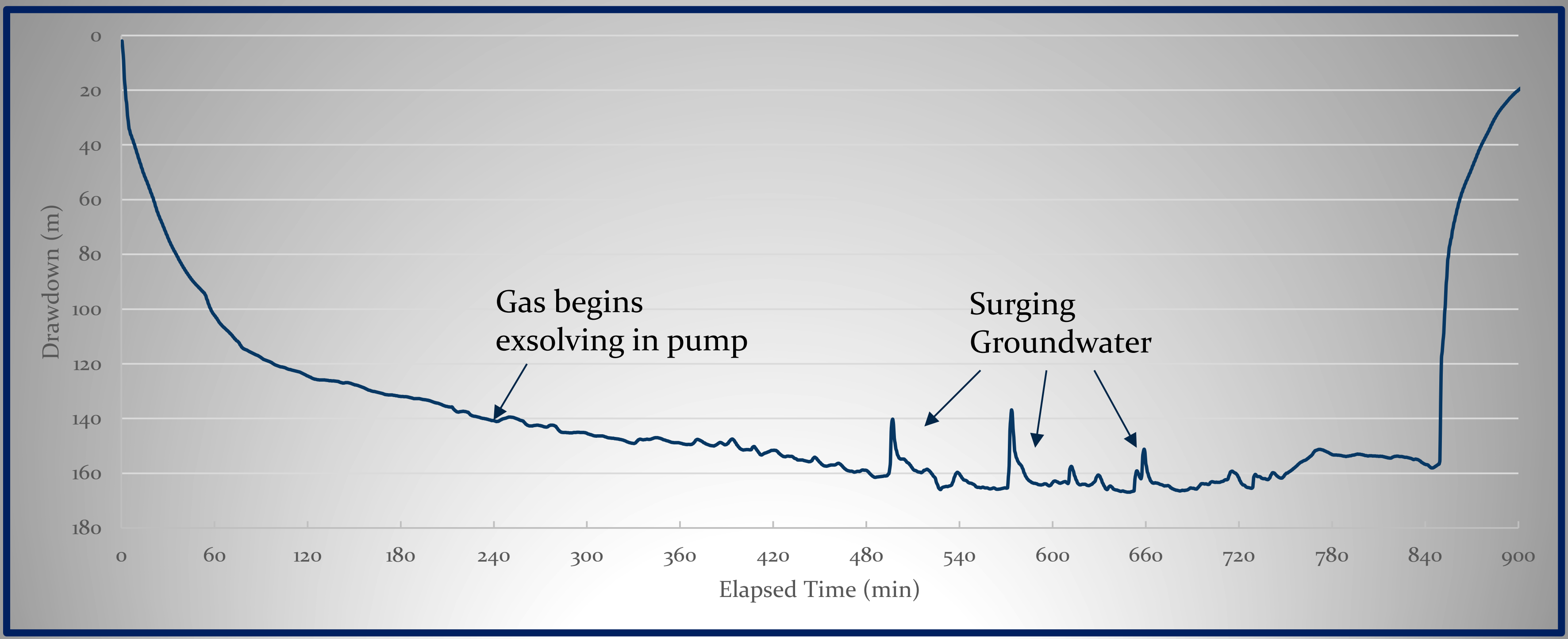
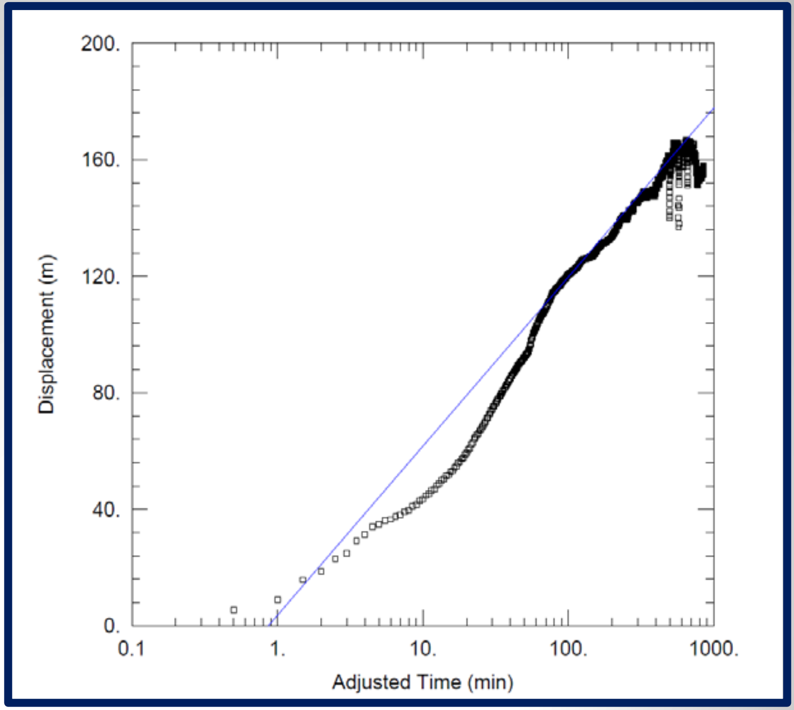
Bubble Point, Gas Locking and Surging



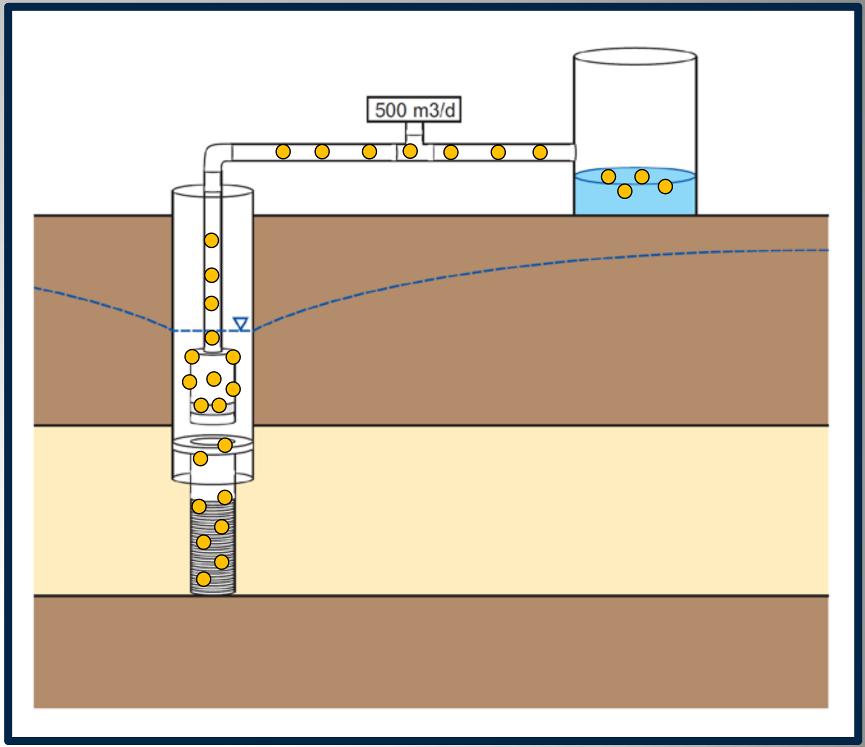
Surging and Curve Matching

- Aquifer analysis (e.g. Theis, 1935) is based on single phase flow equations
- *Water Act* Licence test objective in Alberta: **Constant-Rate**
  - Surging well
  - Flow meter reading
  - Tank reading



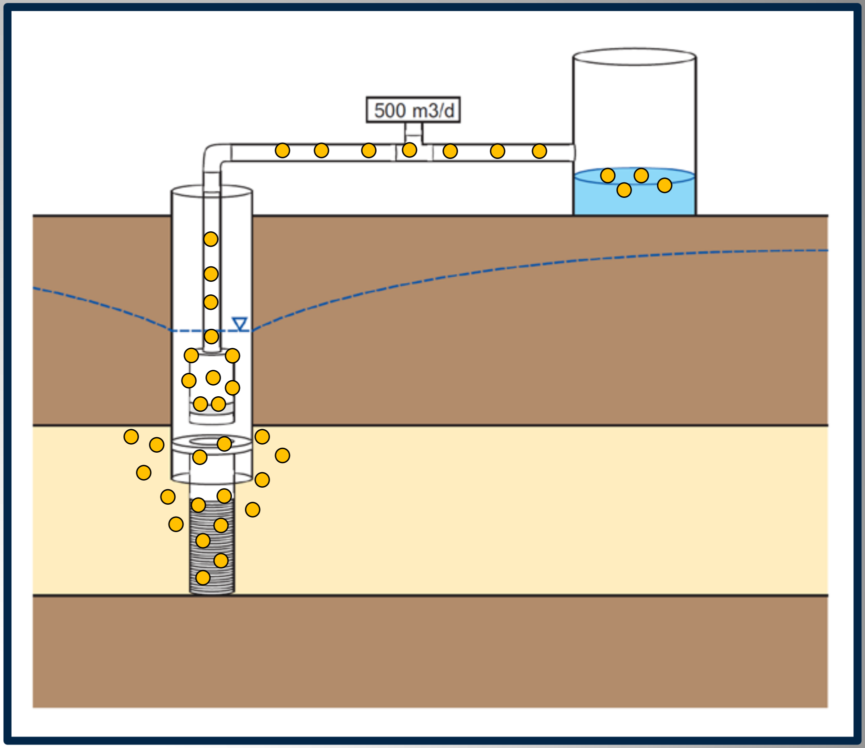
Near Borehole Phase

- Gas exsolves in the near borehole environment
- Gas bubbles form near the well screen, along the well skin and cross the well screen into the wellbore
- Drastically reduced well efficiency
- Can mimic partial penetration effects
- Blinding of pre-packed screens



Aquifer Phase

- Exsolution of groundwater in the aquifer
  - Gas reaches critical saturation in the aquifer
  - Bubbles form in the pore space
  - Gas phase flows more rapidly than groundwater
  - Groundwater must flow around the gas bubbles
    - Slows production
    - Damages the aquifer



Methods to Manage Gas Production

- Find and avoid the bubble point!
  - Build an efficient well to avoid the bubble point
  - Step-Rate well performance testing to find the bubble point
  - In-situ gas sampling to find the bubble point
  - Drill a horizontal well to avoid the bubble
- Use specialized equipment for gas/water separation

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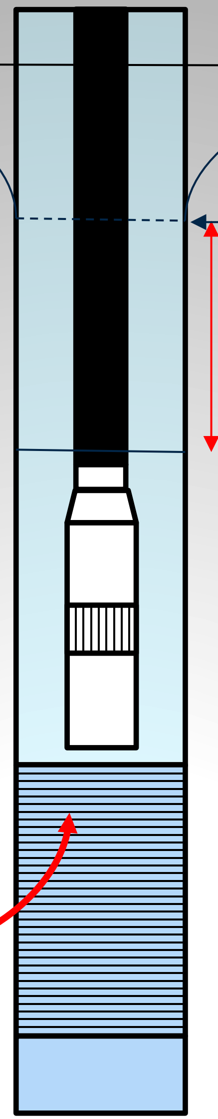
Well Efficiency

Potentiometric surface outside the well rarely equals water level in the well

Inefficient well = Greater drawdown

Greater drawdown → Hit bubble point sooner!



Potentiometric surface
Water level with no well loss:
Drawdown in aquifer = drawdown in well
→perfectly efficient well

Water level in the well
Difference = well loss due to inefficiencies

Build the most efficient well to avoid the bubble point!

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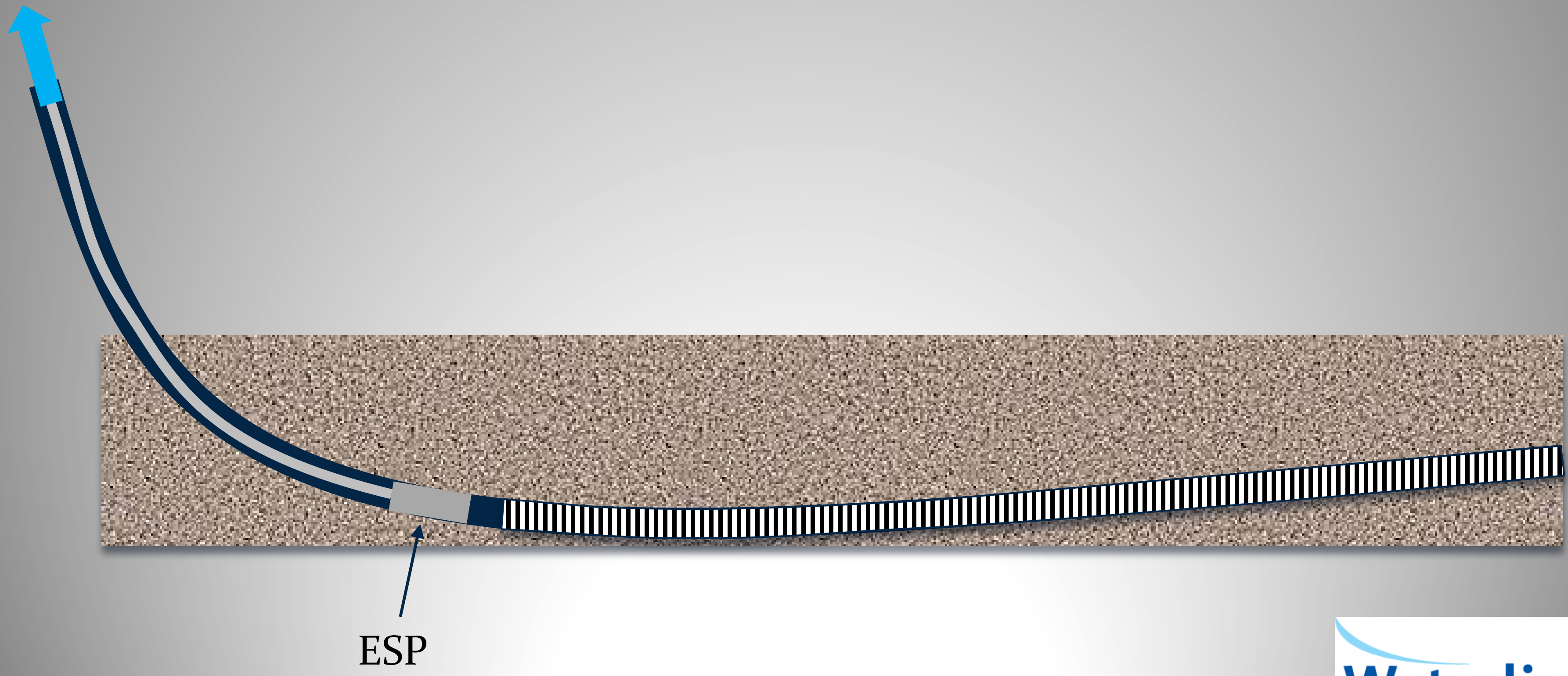
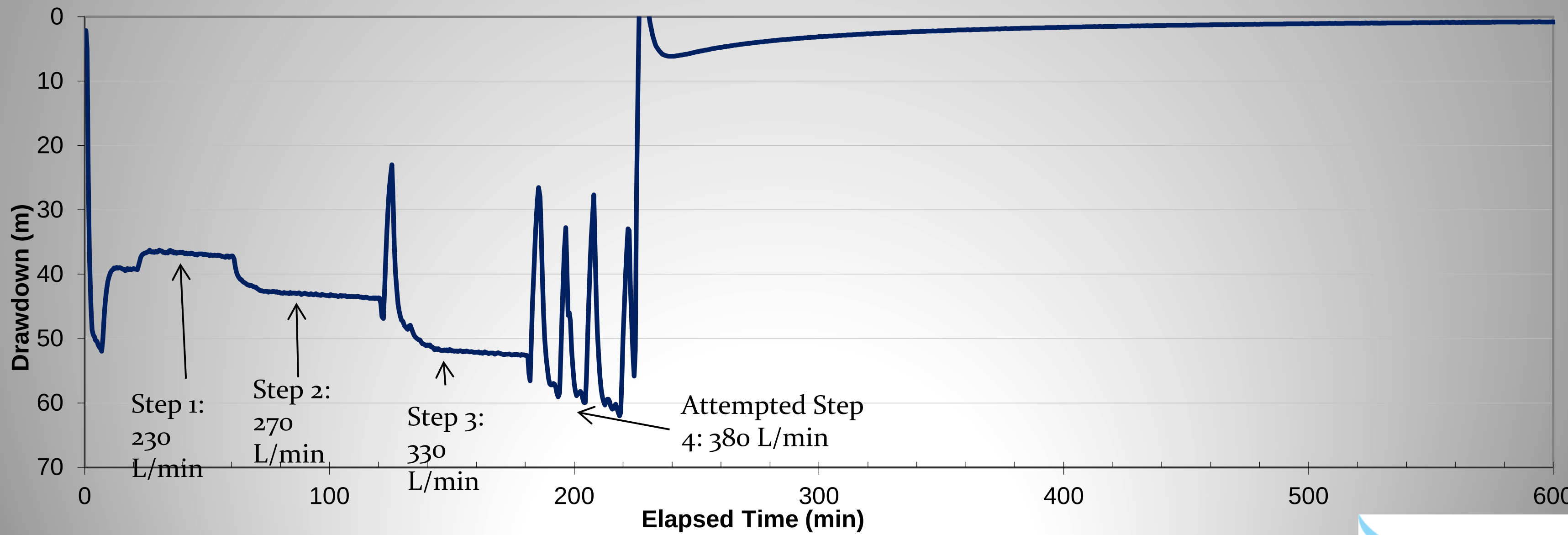
Well Efficiency

- Can overcome well inefficiencies with a horizontal well



Finding the Bubble Point

- Step-rate well performance testing
- Find and avoid the bubble point!
- “Gas limited well”



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Finding the Bubble Point

Borehole in-situ sampling

- Evacuated cylinder deployed into well
- Laboratory evaluation of bubble point
- Good for finding gas concentrations
- Good for finding true gas-water ratio

Gas separation at surface

- Gas separated in column
- Sample collected in tedlar bag
- Good for finding gas composition
- Sample prone to de-gassing losses
- Incomplete degassing in column

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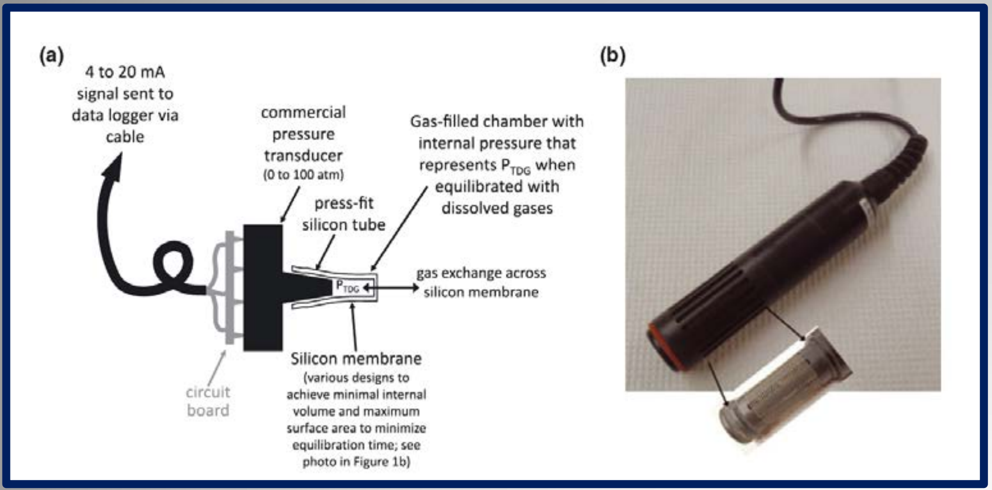
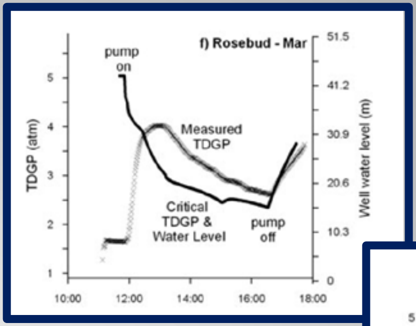
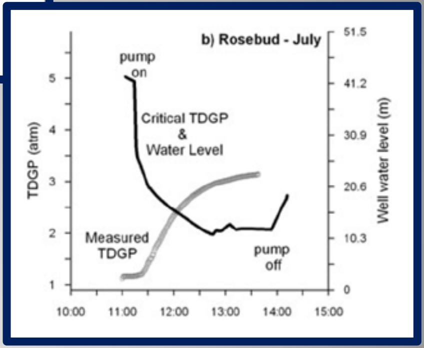
Finding the Bubble Point

- Data logger with TDGP probe







Roy and Ryan (2013)

Methods to Manage Gas Production

- Specialized equipment and techniques
  - Flow meter phase:
    - Apply increased backpressure to avoid breakout of dissolved gas
  - Gas locking and near wellbore phase:
    - Drill holes in the impellor
    - Place pump below top of aquifer → shroud and vent
    - Rotary gas separator
    - Industrial Scale Gas Separator
  - Aquifer phase
    - Decrease pumping rate

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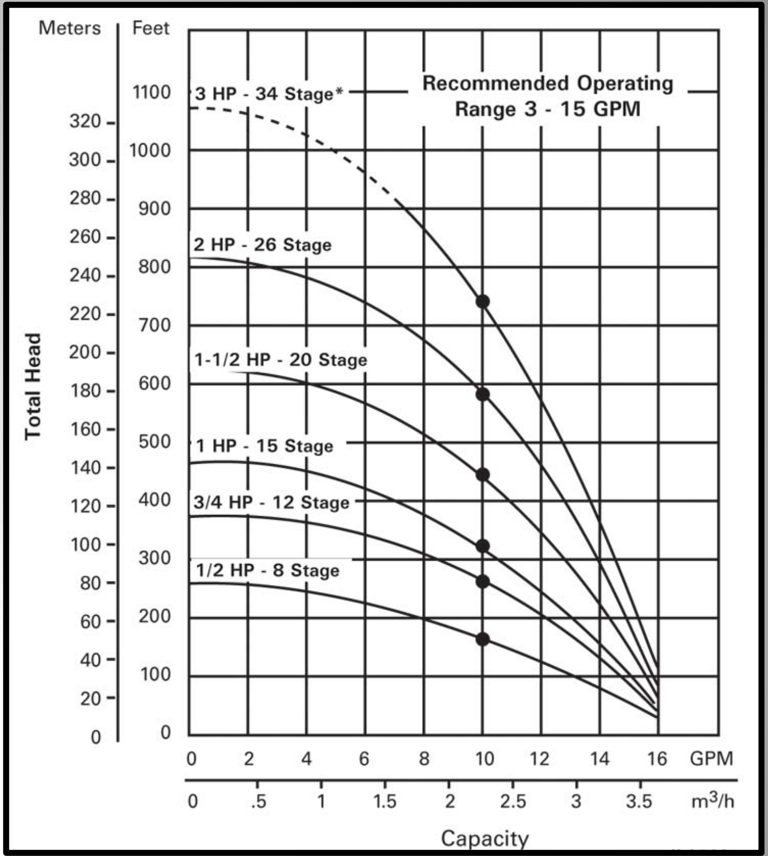
Methods to Manage Gas Production

- Oversize pump + increased backpressure in flow line
- Apply significant backpressure on the flow line at surface
  - Maintains high pressure in flow line to reduce gas breakout
- Works moderately well to improve 'Flow meter phase' exsolution only



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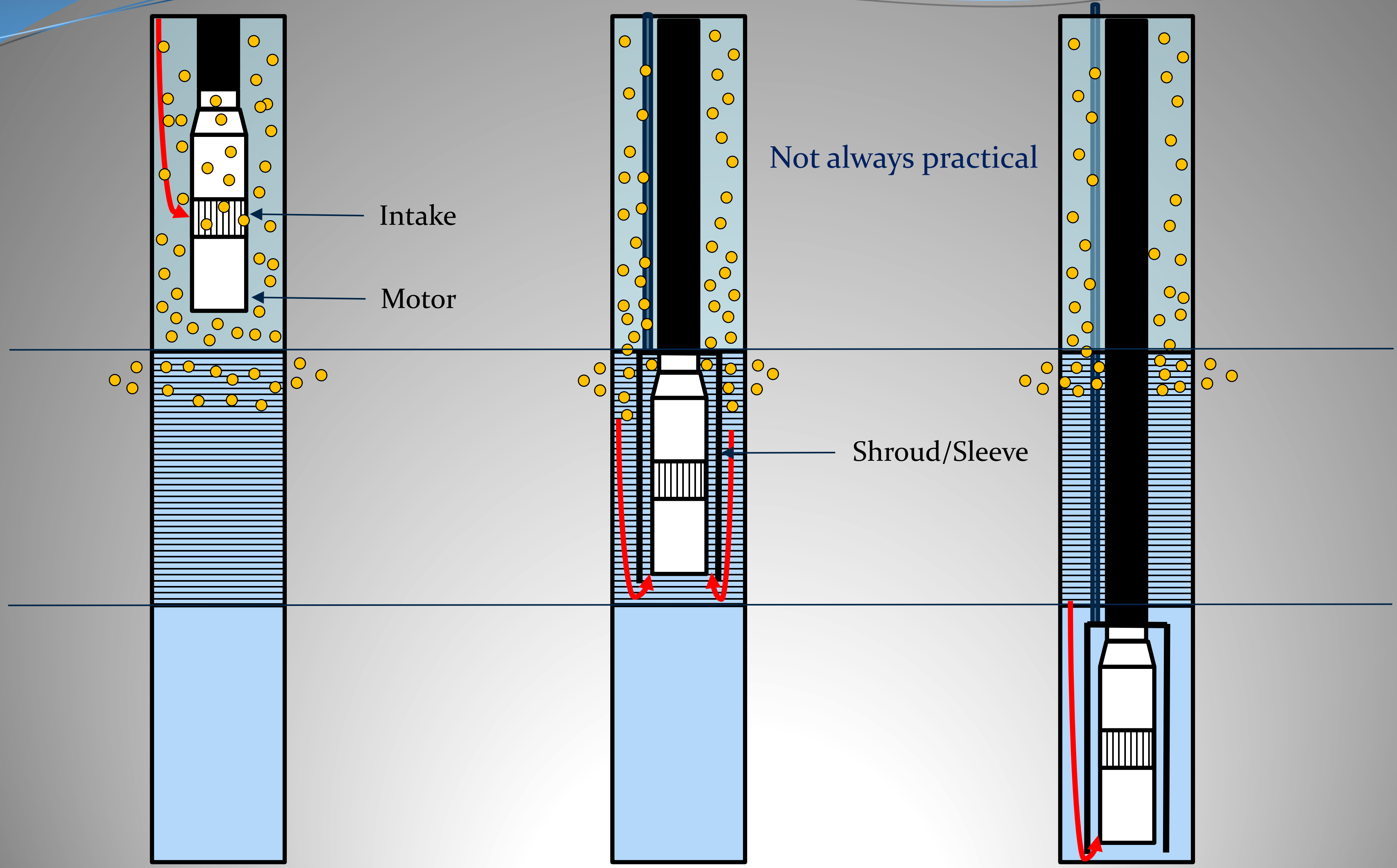
Intake
Motor
Not always practical
Shroud/Sleeve

Rotary Gas Separator

- In well separation of gas due to centrifugal forces
- Separated gas vented to the annulus – fluid enters the pump

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Health and Safety

- H_2S is highly poisonous, but uncommon in shallow aquifers
- Methane is *very* common
  - asphyxiant, extremely flammable and explosive
- Other asphyxiants: nitrogen, argon, helium…
- Pump house construction over water wells??
- Melt ice on flow lines with open flame??

Other Considerations

- Shale and other unconventional gas development
- "Systematic and independent data on groundwater quality, including dissolved-gas concentrations and isotopic compositions, should be collected before drilling operations begin in a region" (Osborn, 2011).

Groundwater

Technical Commentary/

Effects of Unconventional Gas Development on Groundwater: A Call for Total Dissolved Gas Pressure Field Measurements

by J.W. Roy[1] and M.C. Ryan[2] August, 2013

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Summary

- Hydrogeologists: Always expect natural gas in aquifers in Alberta until proven otherwise
  - PPE, gas separator, in-situ gas sampling, TDGP monitoring
- Perform suitable tests to identify the bubble point
- Avoid the bubble point if possible
- Consider specialized equipment for "gas limited" wells if necessary
- Appropriately sample dissolved gases to estimate gas to water ratio

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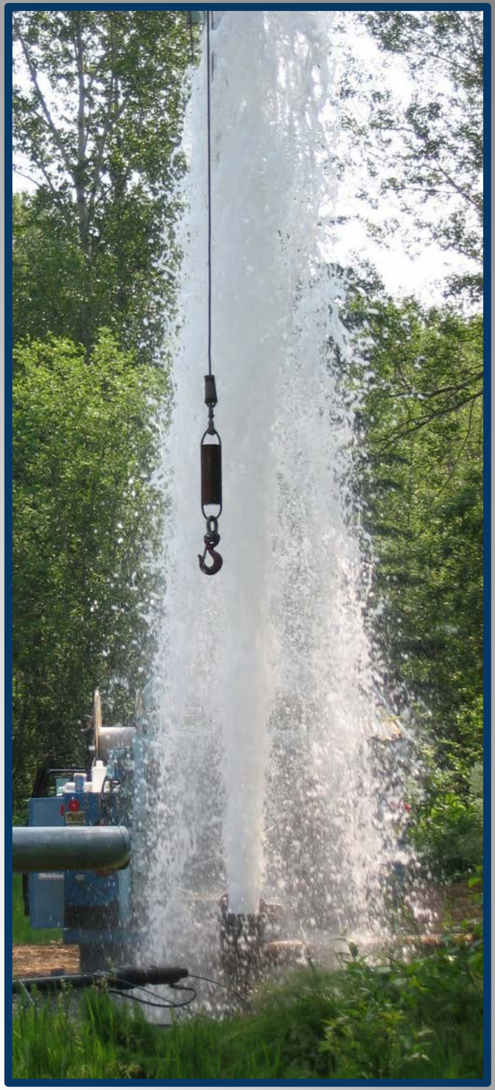
Thank You

- Please direct additional comments and questions to:
  - Steve Sturrock: ssturrock@waterlineresources.com



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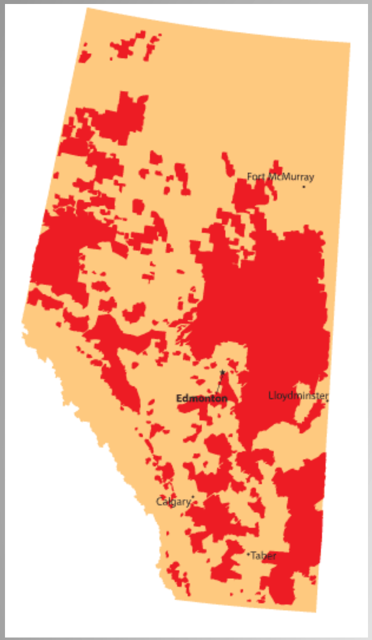
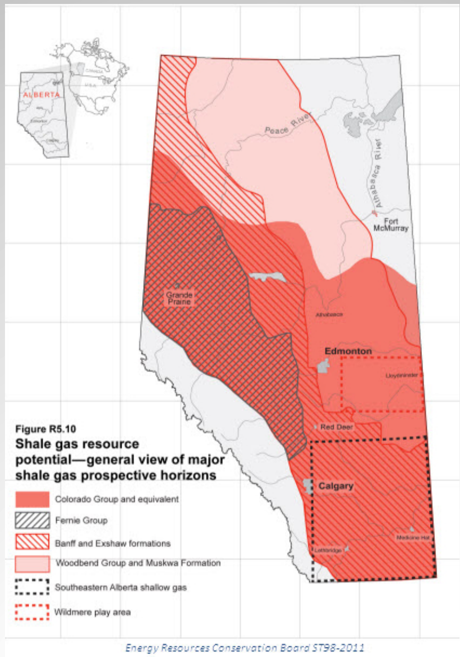
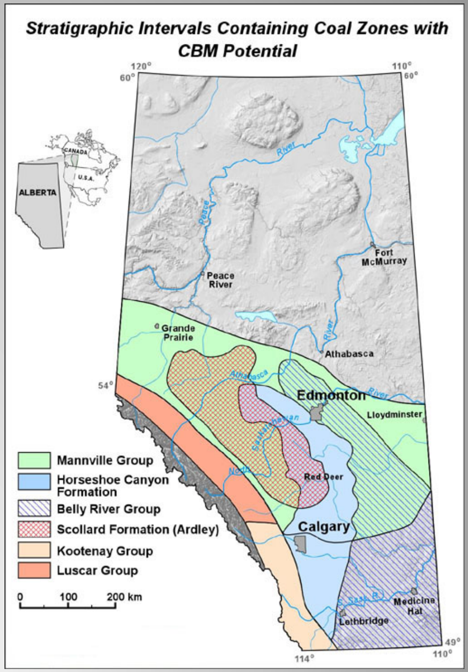
Natural Gas in Alberta



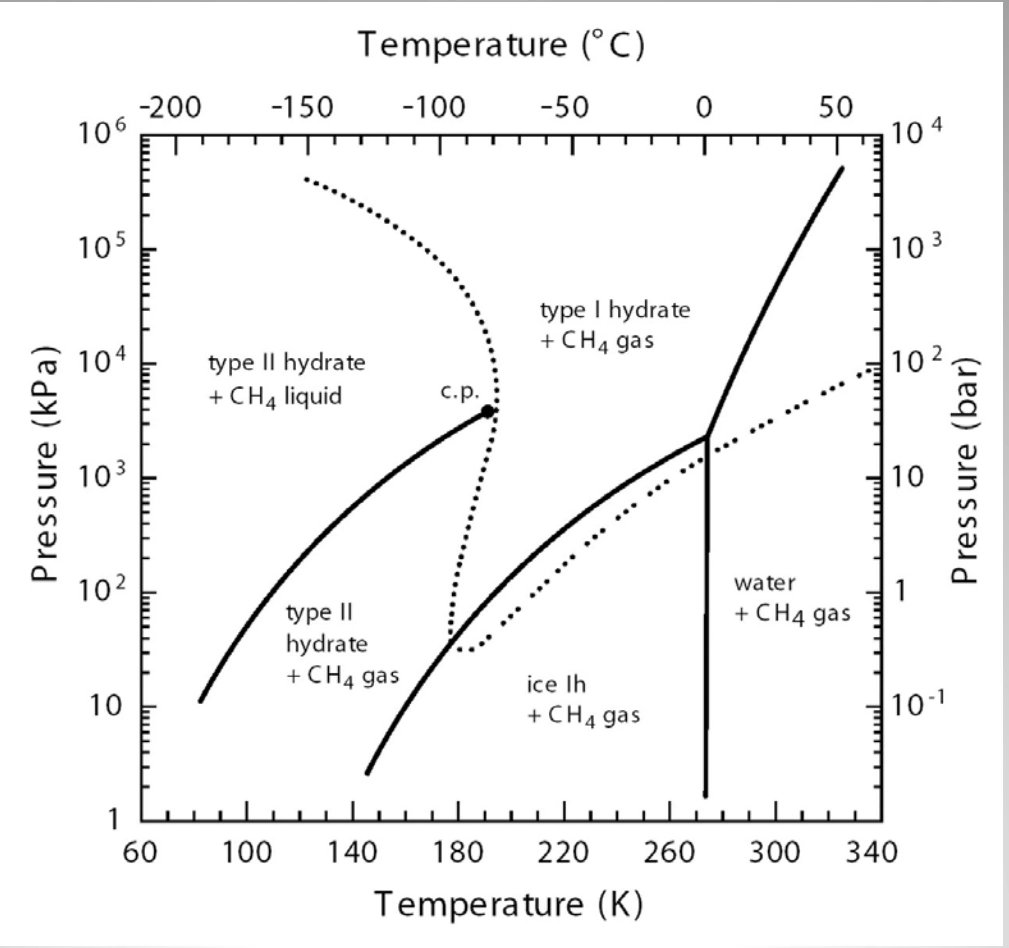
Conventional



Shale Gas



CBM



Temperature (°C)
-200
-150
-100
-50
0
50
10^6
10^5
10^4
10^3
10^2
10
1
10^4
10^3
10^2
10
1
10^{-1}
Pressure (kPa)
Pressure (bar)
type II hydrate
+ CH_4 liquid
c.p.
type I hydrate
+ CH_4 gas
type II
hydrate
+ CH_4 gas
ice Ih
+ CH_4 gas
water
+ CH_4 gas
60
100
140
180
220
260
300
340
Temperature (K)