# Well Integrity – Basics, Prevention, Monitoring, Red Flags & Repair Options

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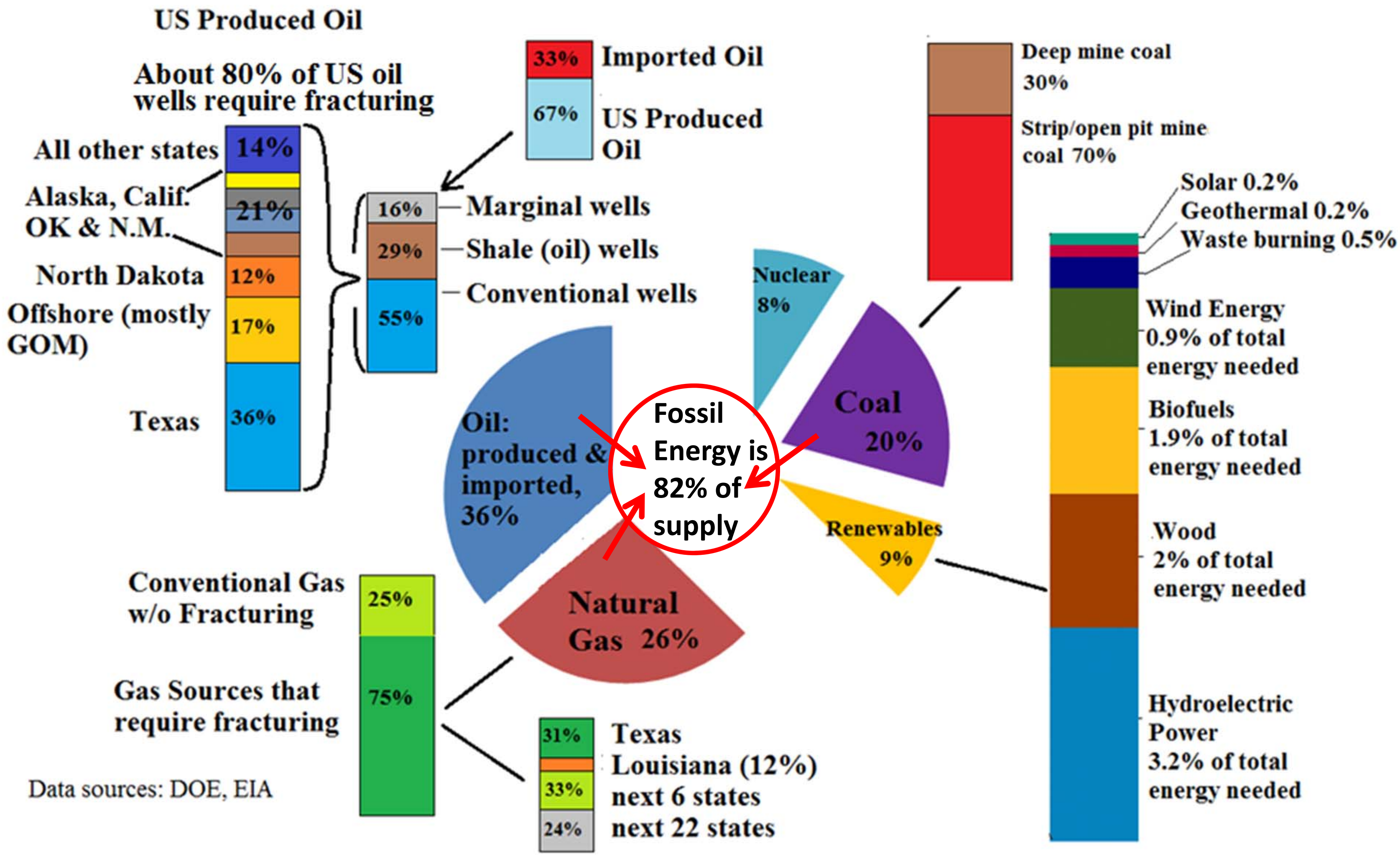
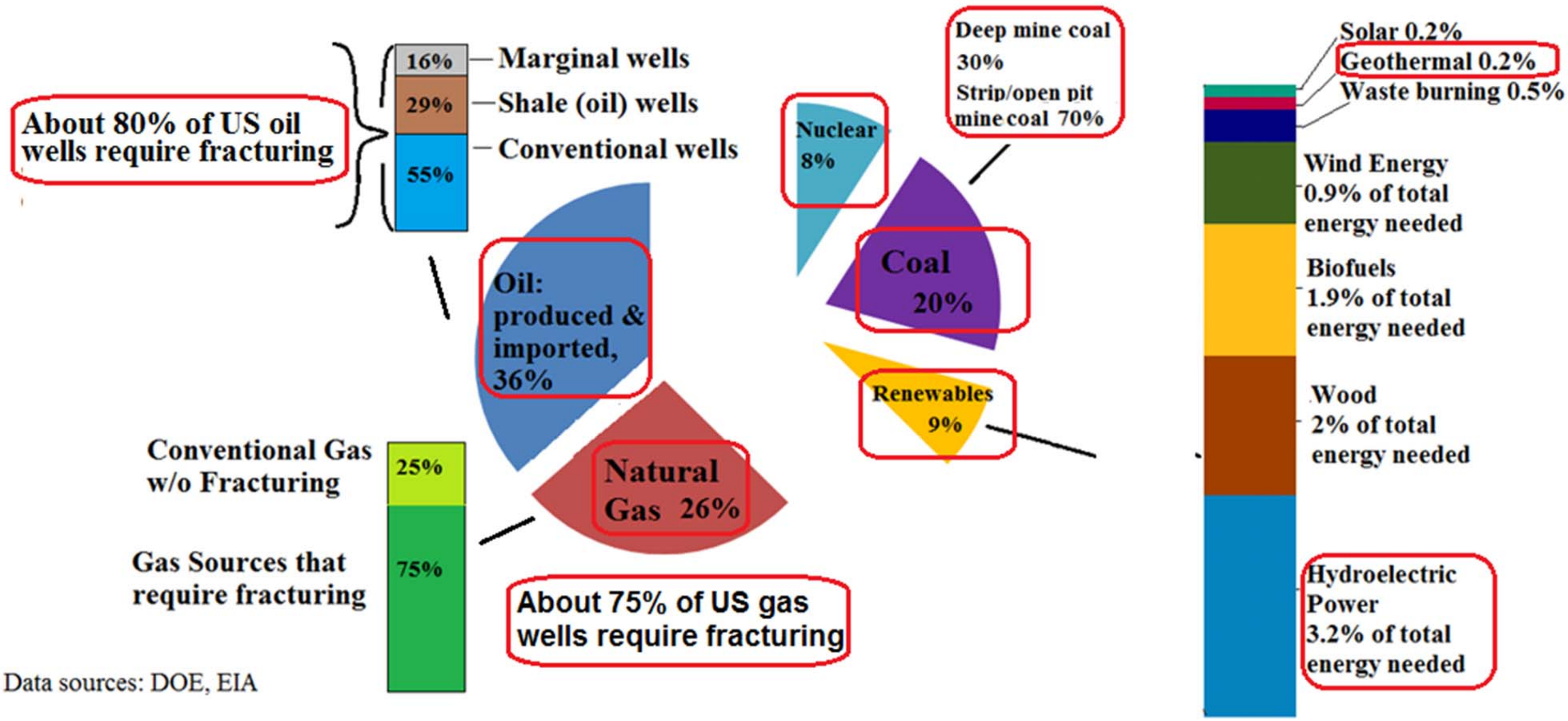
# Sources of US Total Energy Supply



# Energy Sources with Ground Disturbance Impacts or Dependencies

**93% of US total energy supply is dependent on ground penetration and/or substantial subsurface stability**

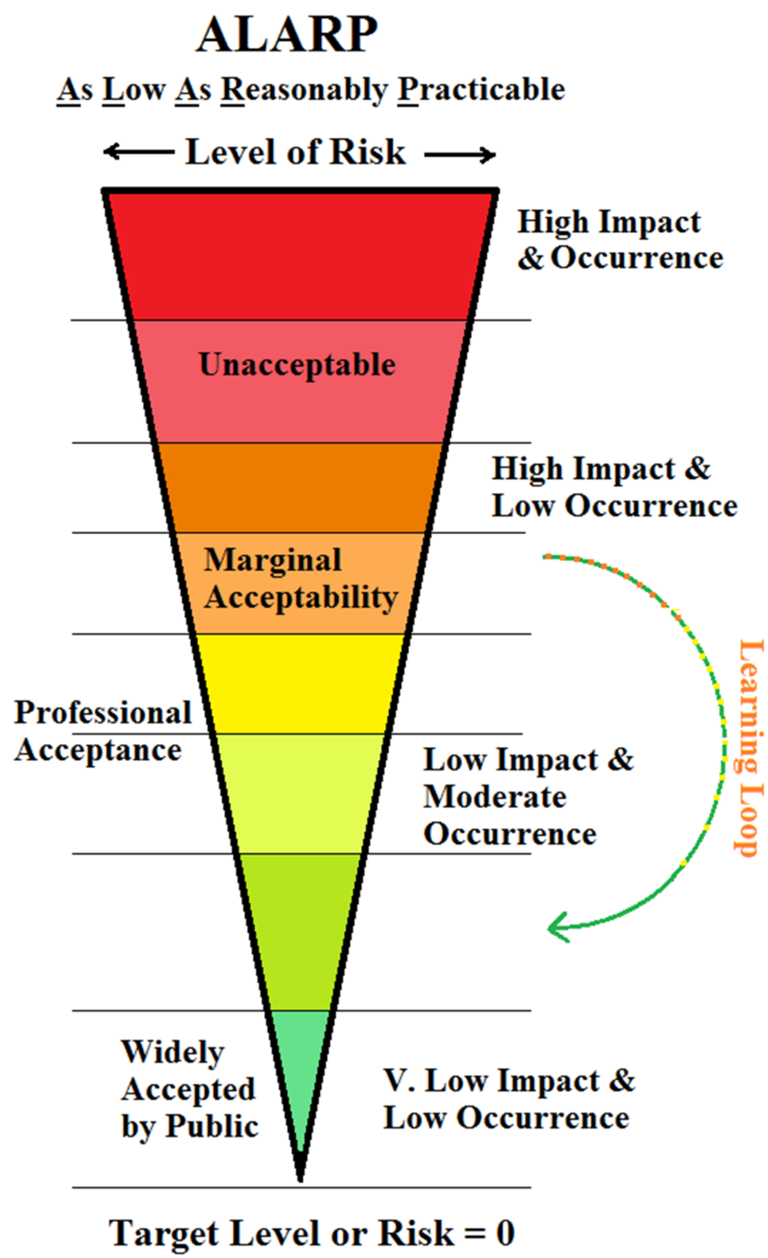


# Risk = Frequency of Occurrence vs. Impact

**Risk exists in every action.**

**What is operationally safe?**

**Occurrence & impact create a threat level that we can understand & accept or reject based on what we believe: hopefully on assessment of facts.**

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# Basics of Well Integrity

- NORSOK Definition:
  - "Application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well".
- Maximum challenge in stimulation?
- Maximum challenge in production?
- Plug & Abandonment – Life?

# Status of the Well Integrity Issue

- How many wells leak?
- Where, why and what?
- How much do they pollute?
- What is special about leaking wells?
- What are the pathways? – route of spills?
  - 15.2 million US residential water wells (integrity?)
  - 1 million Class V injection wells (?)
  - Old wells in Northeast (no location & no records)

# Review of Well Studies: >650,000 wells

(Sources of data in SPE 166142)

| Area | # Wells | Type Wells | Barrier Failure Freq. Range (w/contain) | Well Integ Freq. w/ leak path | Leaks to GW by sampling |
|---|---|---|---|---|---|
| OH | 64,830 | D&C shoe test fail (74)* Take worst case - Prod. 39 | 0.035% in (34,000 wells 1983-2007), 0.1% old wells worst | ~0.06% (total) | |
| TX | 253,090 | D&C Failures, shoe test fail* (10) **Prod (56) fail assumed | 0.02% | 0.02% old era wells, 0.004% new era wells | 0.005% to 0.01% producers 0.03% - 0.07% injector |
| Texas | 16,000 | Horizontal Multi-frac wells | 0 | 0 | |
| Mn Cedar Creek | 671 | Vertical | 5.5% | Unk | |
| Alberta | 316,000 | All well types used in the study. | (4.6%) – unk if active leaks or single barrier fail. | (4.6%) – unk if active leaks or single barrier fail. | |

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# Sustained Casing Pressure

| Area | Number of Wells | Type of Wells | Barrier Failure Freq. Range (w/ containment) | Integrity Failure (leak path – in or out) |
|---|---|---|---|---|
| US Gulf of Mexico | 11,498 (3542 active | Platform based wells | 30% overall with first annulus SCP of 50% of cases. 90% of strings w/ SCP have less than 1000 psi. 10% are more serious form of SCP (Wojtanowicz, 2012) | 0.01% to 0.05% of wells leaked - 0.00005% to 0.0003% of prod oil spilled 1980 thru 2009. |
| US Gulf of Mexico | 4,099 | Shoe Test failures during drilling* | 12% to 18% require cement repair to continue drilling | 0 (all repaired before resuming drilling) |
| Norway | 406 | offshore | 18% | 0 |
| GOM /Trinidad | 2,120 | Sand Control | 0.5 to 1% | 0% subterranean ~0.0001% via surface erosion potential |
| Matagorda Island 623 | 17 | Compaction failures; casing shear & sand fail | 80% to 100% - the high number is due to high pressure and formation compaction. | Wells routinely shut-in and repaired prior to restart. |
| Sumatera | 175 | without maintenance | 43% | 1 to 4% |

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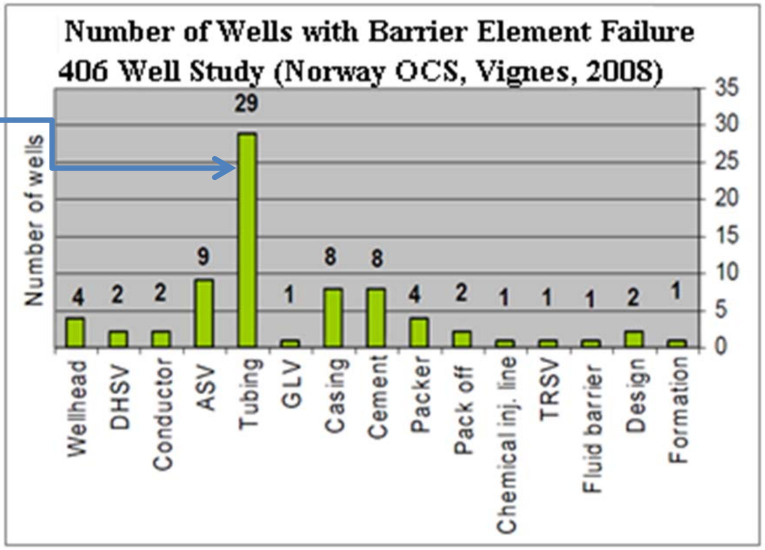
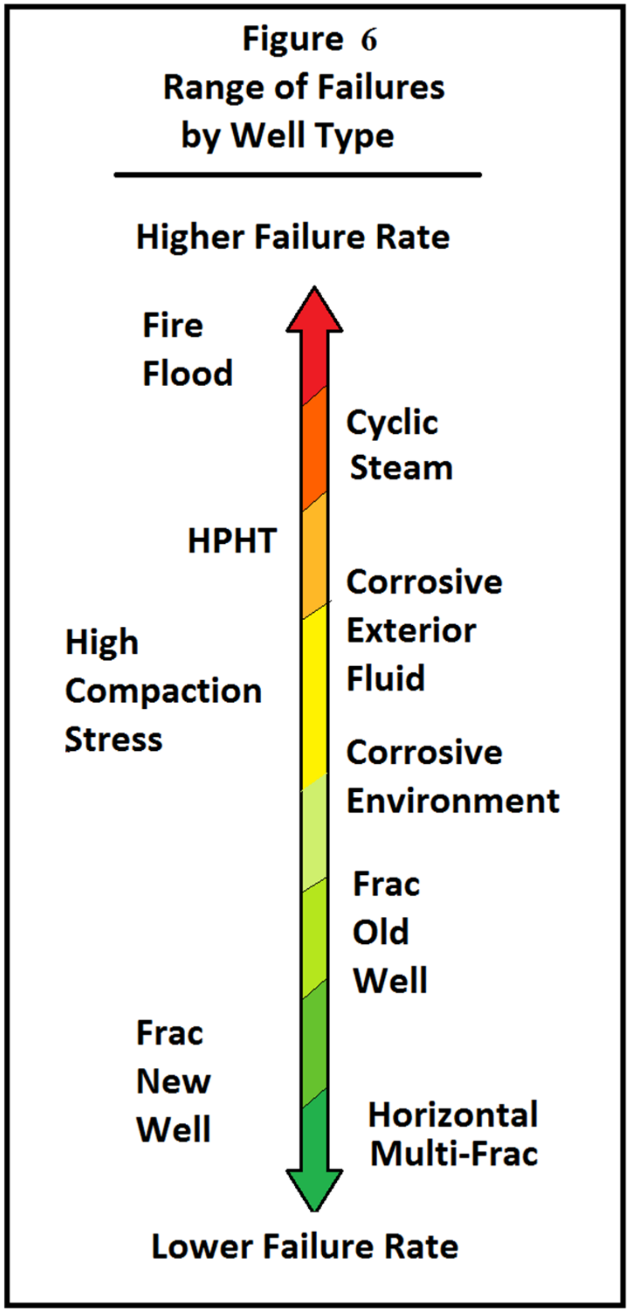
# Well Study Review >650,000 wells

## Failure Factors Recognized:

- Type of Well
- Maintenance Culture
- Era of Construction
- Geographical Location
- Age of Well
- Specifics of Design & Construction
- Usage Change

Single barrier compromised by tubing leaks.

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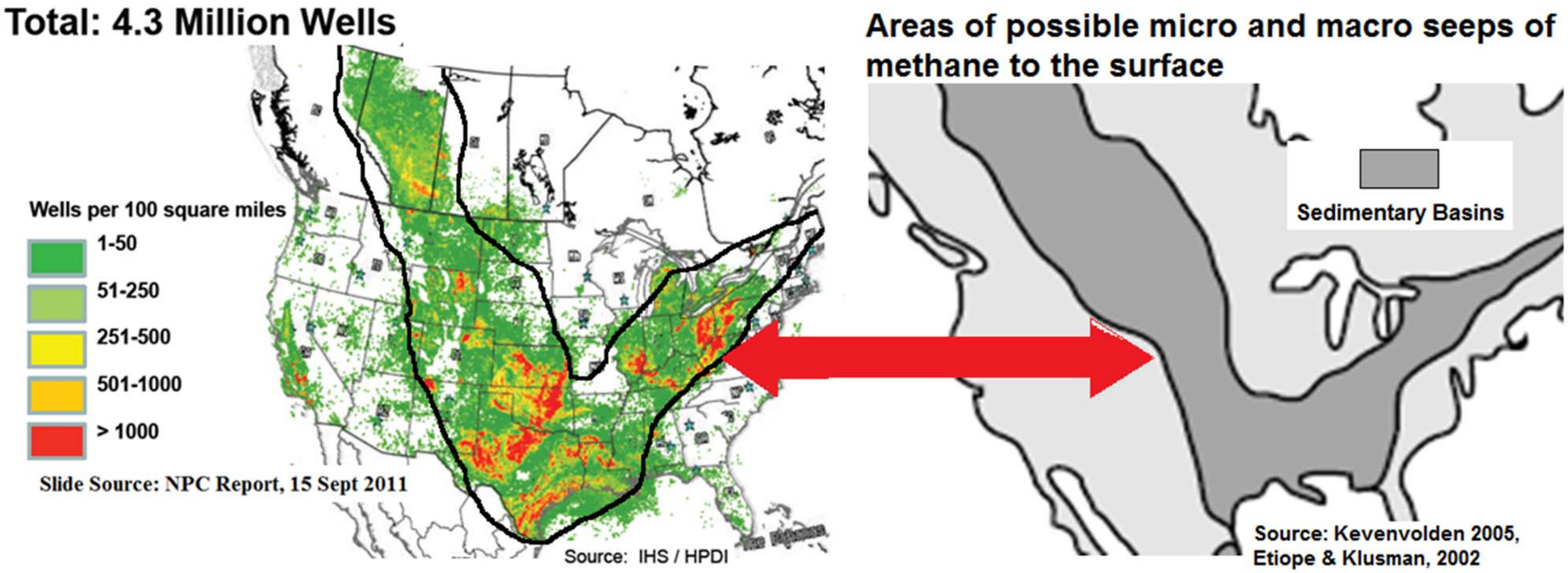
# Background Context –
# Methane Seepage from Soils

**Oil & Gas Seeps are indicators of oil & gas beneath the surface**

**Many natural seep flows diminished as wells were drilled & produced.**




Well Density in US & Canada

Sedimentary Basins in US & Canada

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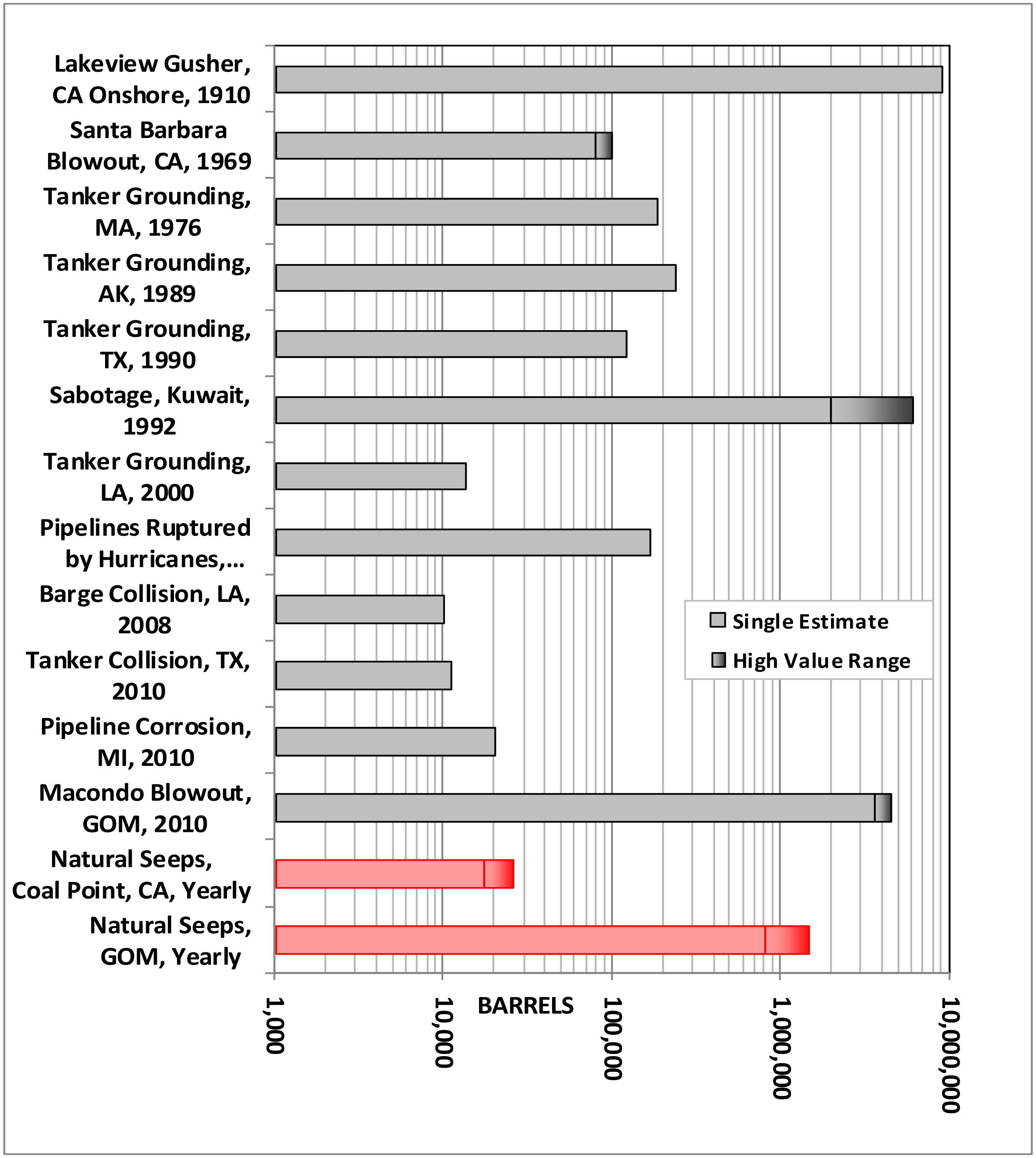
# Other Context - Comparing Spills and Seeps

**History –**

- **Drake's 1859 well hit flowing oil at 69.5 ft.**
- **Hart's 1821 Shale gas well found flowing gas at 28 ft.**
- **Water, Oil & Gas commonly cohabitate shallow formations in oil producing areas.**



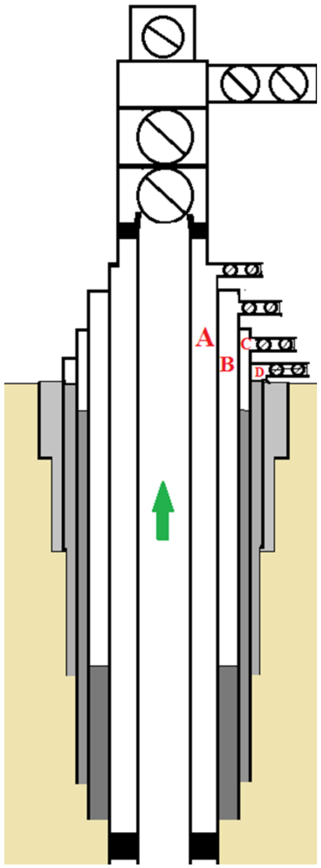
# Prevention of Well Integrity Problems

- Initial planning and creating effective barriers - goal of first well construction effort - lowest cost opportunity for problem prevention.
- Adding/modifying barriers later is expensive.
- Fracturing and acidizing – What is required in well construction?
  - A place for temporary barriers.
  - Barriers that stand up to cyclic pressure.

# Well Barrier Failure vs. Well Integrity Failure

- Barriers are containment elements - Can individually isolate design loads. **<u>If one barrier fails, the next barrier accepts the load</u>**.
- Multiple, nested barriers = redundant barrier system. <u>No Leak Path</u>
- Well integrity failure = if all barriers fail in series = leak path <u>Is</u> formed

| Barrier | Number | Press | Durability |
|---|---|---|---|
| Casing + Cmnt | 2 to 7 | Very High | Very High |
| Hanger + Seal | 2 to 4 | High | High –replace easy. |
| Pipe body | 1 to 3 | High | Very High w/ corros. maintenance |
| Packer, Plug | 1 to 2 | Mod. | Mod. |
| Safety Valve | 1 | Mod. to High | Mod. |
| Valves, Spools in Prod. Tree | 4 to 20+, tandem? | Mod. to High | Mod- easy repair |

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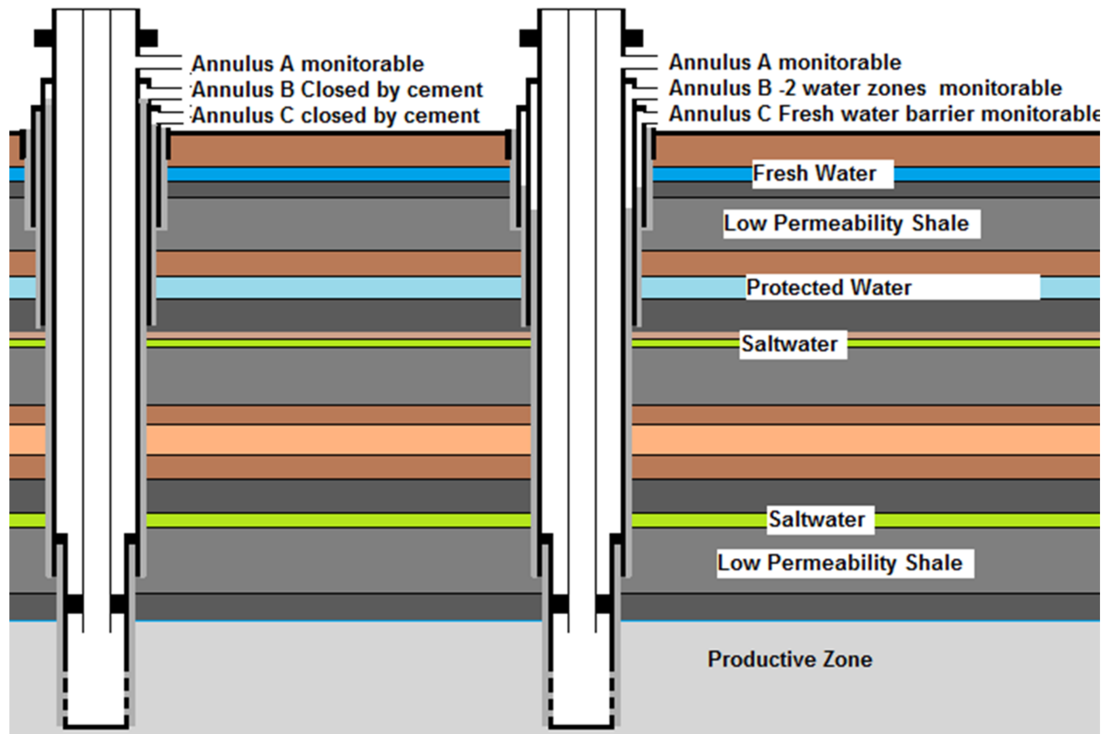
# Cement Every Annulus to Surface? May NOT be the best plan.

**Full Annulus Cementing?**

- **Most full cement columns require a two-stage cement job – requires perforating or DV tool – may decrease well integrity.**
- **Careful positioning of cement top in inner annulus allows monitoring of pressure build-up or monitoring type of fluid flow if leaks are seen.**
- **Repair options increase when open annulus exists including down-squeezes & inner pipe removal.**

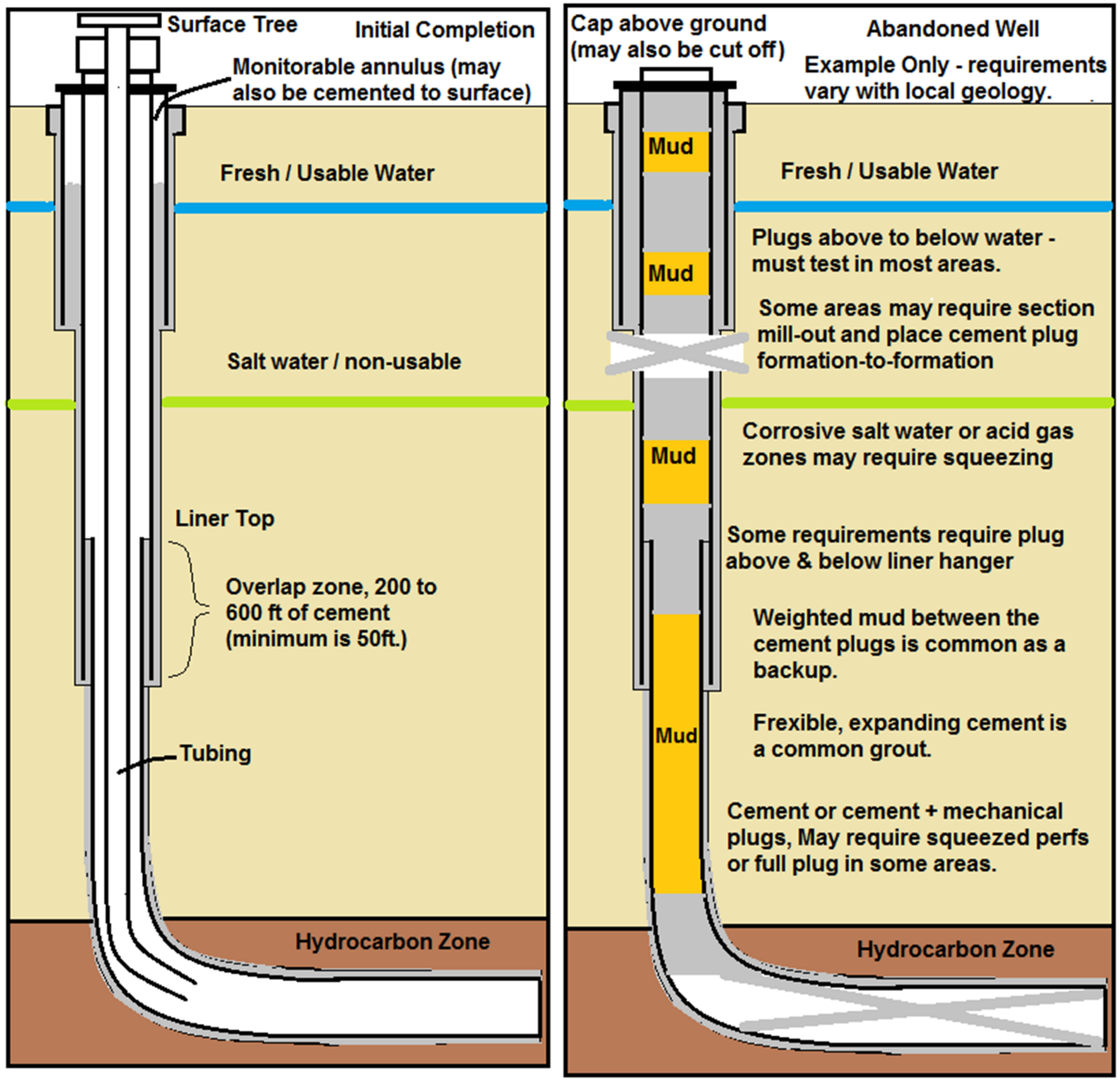



Note: local conditions can dictate fewer casing strings.

- **Placing end of casing in strong, low permeability formations increases isolation success.**
- **Placing salt water and fresh water zones behind different casing strings nearly eliminates potential for salt water intrusions behind the pipe.**

# Example
## Completion & P&A

# The Completion Enables Successful P&A



# How Much Cement is Needed for Isolation? Every inch of cement is NOT required to be perfect.

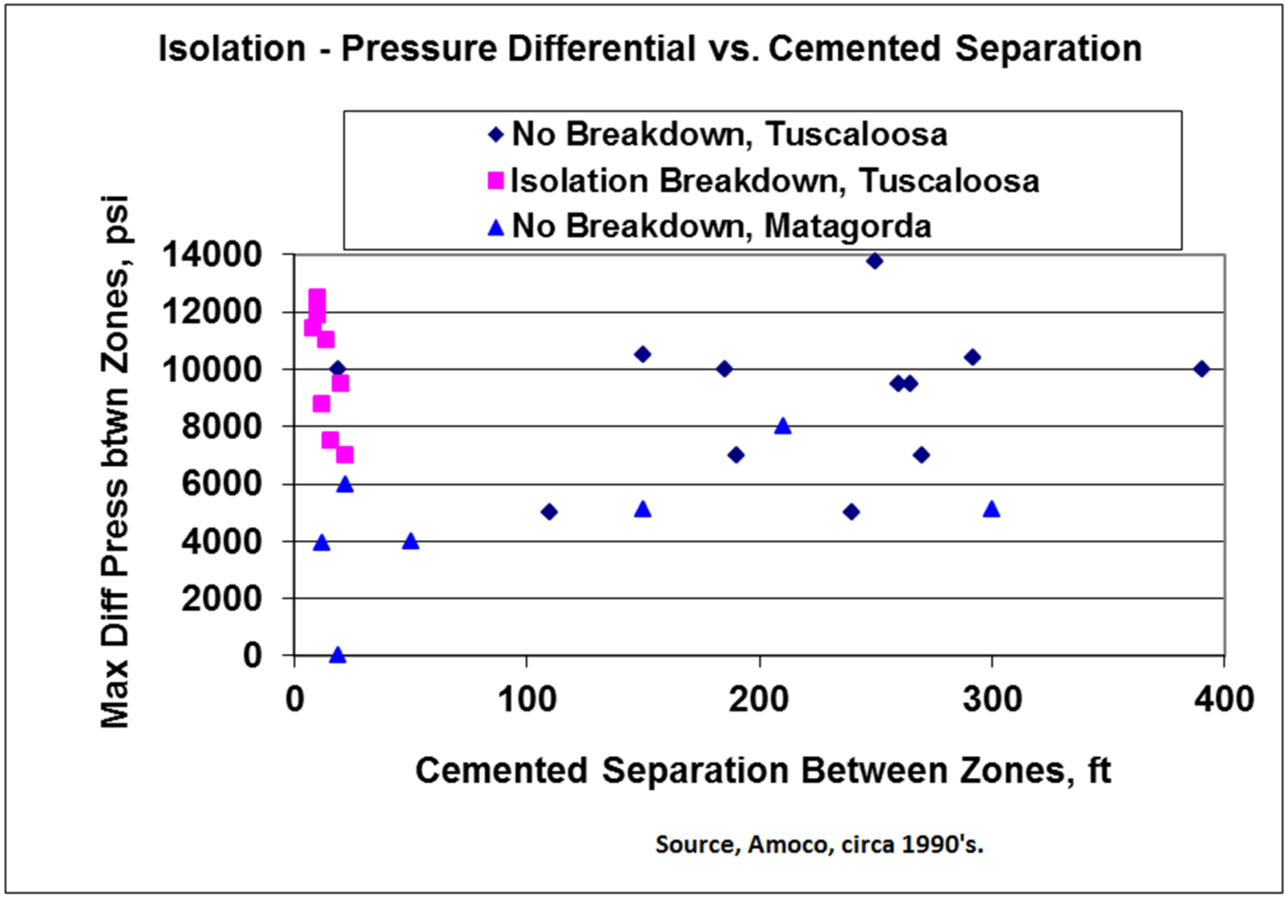
**Quality of cement is more important than the volume.**

**Isolation can only be measured with a pressure test.**

**Bond logs are not always best tool**

- **~10% channels missed.**
- **Instances of false negatives.**

**Over 10,000 psi can be held with less than 50 ft of cement, but 200 to 300 ft is routinely used.**

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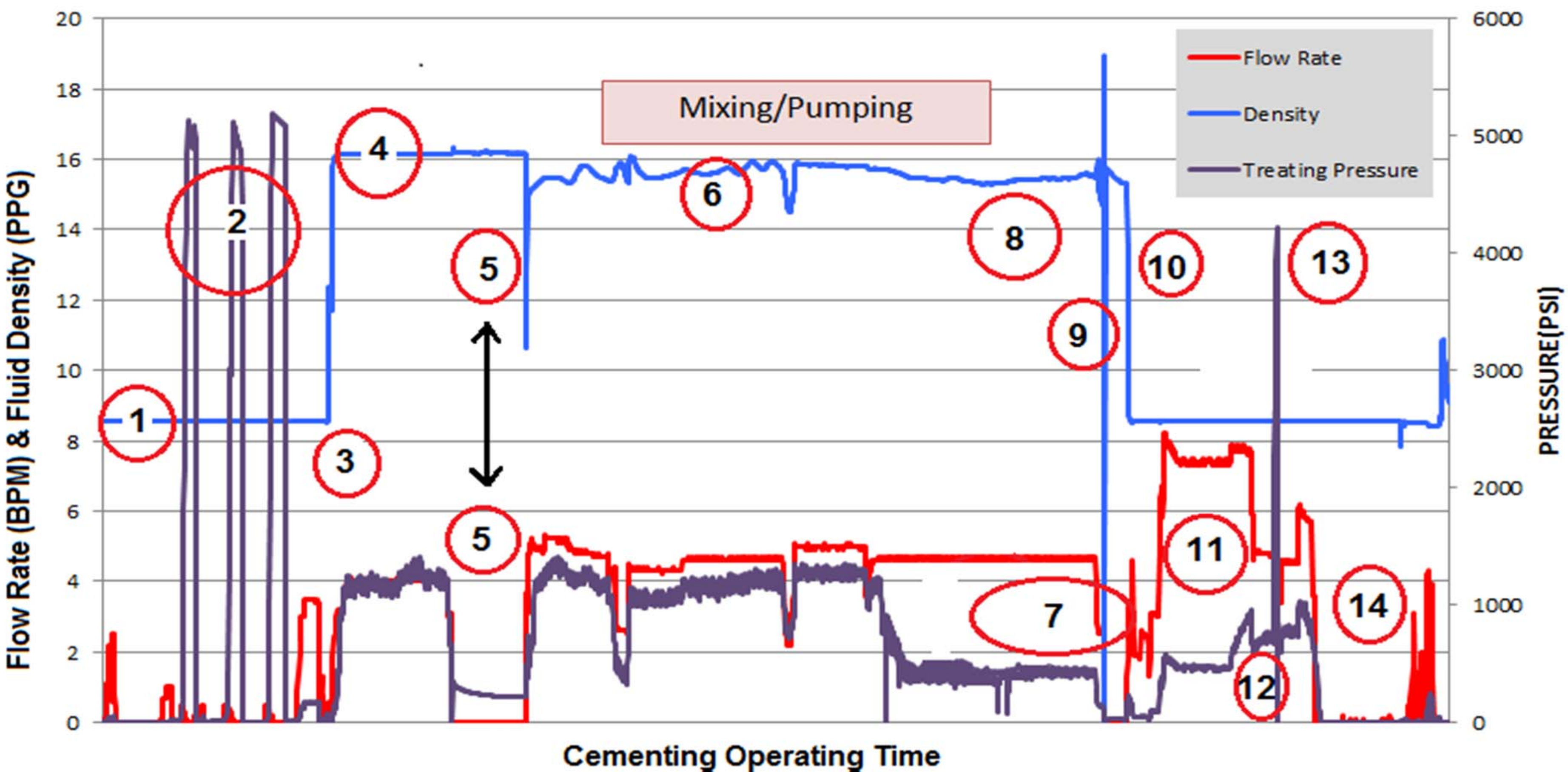
# The Best "Tool" for Evaluating Cement Quality is the Pump Chart

| | | | |
|---|---|---|---|
| 1 | **Filling surface equipment w/ fresh water** | 8 | **Cement density variance – was a special tail-in slurry used?** |
| 2 | Pressure test – two leaks in surface connection & a successful test | 9 | Shut-down to flush surface lines and drop the solid top plug. |
| 3 | Pump spacer to separate mud from cement | 10 | Bottom plug lands, diaphragm ruptures & cement into annulus. |
| 4 | Constant density spacer between mud in the well and cement | 11 | Free-fall make up – more flow in than out - pressures equalizing |
| 5 | Shut down to drop bottom plug & switch to on-the-fly cement | 12 | Cement lift pressure too low – check return volumes and timing. |
| 6 | Pumping cement – within density guidelines, but barely. | 13 | Top plug "bumps" (lands in the shoe track) – placement complete. |
| 7 | Cement free-fall – heavy cement pushes mud faster than vol. inj. | 14 | Hold back pressure on casing if float valve fails. (not in this case). |



# Cement Evaluation Tool – Value & Limits

Amplitude

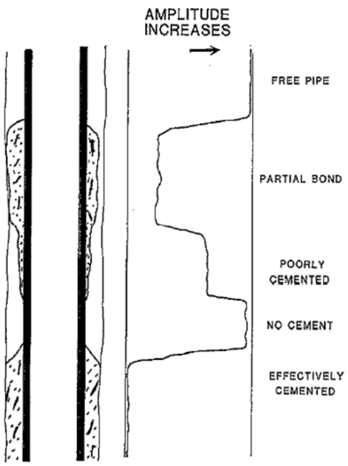
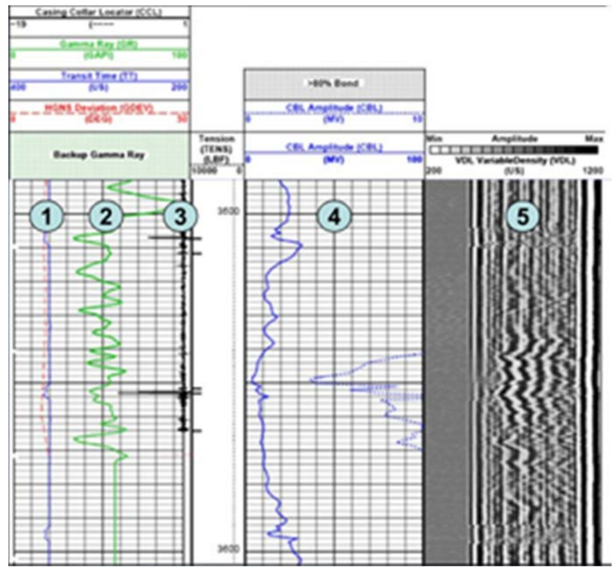
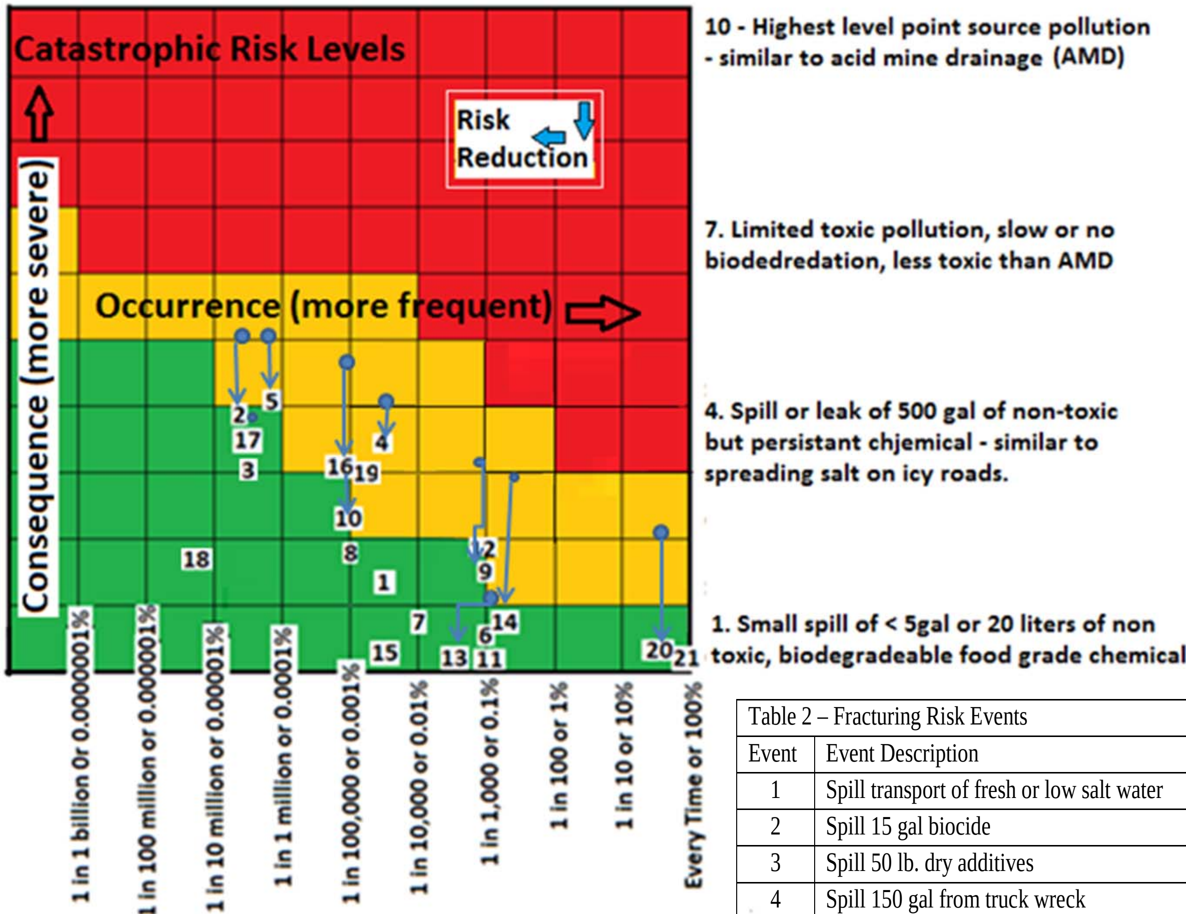



**Fig. 2—Generally accepted qualitative interpretation of the amplitude curve.** Bigelow, SPE JPT, 1985.




1. Transit Time
2. Gamma Ray Log
3. Collar Locator
4. Amplitude
5. Variable Density Log

- Issues:
    - Cement must develop strength before CBL is useful (>72 hours)
    - CBL will not predict or confirm pressure isolation.
    - Properly run CBL – 90% reliable in finding channels of >10% total annular space
    - Many wells show effective isolation, even when CBL shows only 30% to 75% of bond as “good”.
    - CBL utility is determining cement presence & info on bonding across zone of investigation.
    - “Fast” formation may act like free pipe when bonding is good.
    - Cement sheaths less than ½ “ to ¾” may look unbonded even when seal is good.
    - Gas bubbles decrease signal. Void spaces increase amplitude.
    - Pipe thickness changes cause amplitude shift
    - Tool eccentering & microannuli reduce amplitude




# What are documented occurrences and impacts from fracturing?

| Table 2 – Fracturing Risk Events | | | |
|---|---|---|---|
| Event | Event Description | Event | Event Description |
| 1 | Spill transport of fresh or low salt water | 10 | Frac ruptures surface casing |
| 2 | Spill 15 gal biocide | 11 | Cooling pulls tbg string out of packer. |
| 3 | Spill 50 lb. dry additives | 12 | Frac opens mud channel, well < 2000 ft. |
| 4 | Spill 150 gal from truck wreck | 13 | Frac opens mud channel, well > 2000 ft. |
| 5 | Spill 2500 gal from refueler wreck | 14 | Frac intersects another well in pay zone. |
| 6 | Spill frac tank of water, no additives | 15 | Frac intersects properly abandoned wellbore. |
| 7 | Spill frac tank of water with food grade polymer only | 16 | Frac intersects improperly abandoned wellbore. |
| 8 | Spill 10 gal. diesel during refueling | 17 | Frac to surface or groundwater through the rock, well > 2000 ft. deep. |
| 9 | Spill 100 bbls of produced water | 18 | Frac produces earthquake that can be felt at surface. |
| | | 19 | Frac intersects a natural seep. |
| | | 20 | Frac produces emissions in excess of limits. |
| | | 21 | Normal frac operations – no problems |

**Conclusions from actual tests, trials & case studies is the only risk from deep well (>2000 ft) hydraulic fracturing is:**

- **Low risk in transport & produced water storage**
- **Very low risk in well construction.**
- **Virtually no risk in fracturing.**

Source: SPE 152596 – download from www.fracfocus.org or www.www.onepetro.org

# Monitoring Well Integrity

- The Era of construction is the first indicator of the stability of well integrity. => couplings & cement
- Is a base line set and a trend line maintained?
- Simple, regular monitoring can be inexpensive.
- Are the working limits of the asset known and strictly observed?
- Monitoring is more effective when a company has a "culture of proper maintenance".
- Are wells P&A'd when practical value is gone? (does shut-in have a required end point?)

# Well Failures & Improvements in Development Eras

| Time Era | Operation Norms | Era Potential For Pollution |
|---|---|---|
| 1830 to 1916 | Cable Tool drilling, no cement, wells vented | High |
| 1916 to 1970 | Cementing isolation steadily improving. | Moderate |
| 1930's | Rotary drilling replace cable tool, BOPs | Moderate & Lower |
| 1952 → | Fracs reduce # wells. Better pipe & cement | Lower from Frac aspects |
| 1960 → | Gas tight couplings and joint make up | Moderate |
| 1970 → | Cement improving, Horizontal Wells introduced | Lower |
| 1988 → → | Multi-frac, horizontal wells, pad drilling reducing environmental land footprint 90% | Lower |
| 2005 → | Well integrity assessment, premium couplings, adding barriers & cementing full strings. | Lower after 2008 to 2010 (STRONGER Reg Review) |
| 2008 → | Chemical toxicity & endocrine disruptors sharply reduced. Real time well integrity needs studied - early warning & avoidance. | Lowest yet, most states caught up with design and inspection requirements. |

**When evaluating well integrity, ALWAYS look at era of construction.**

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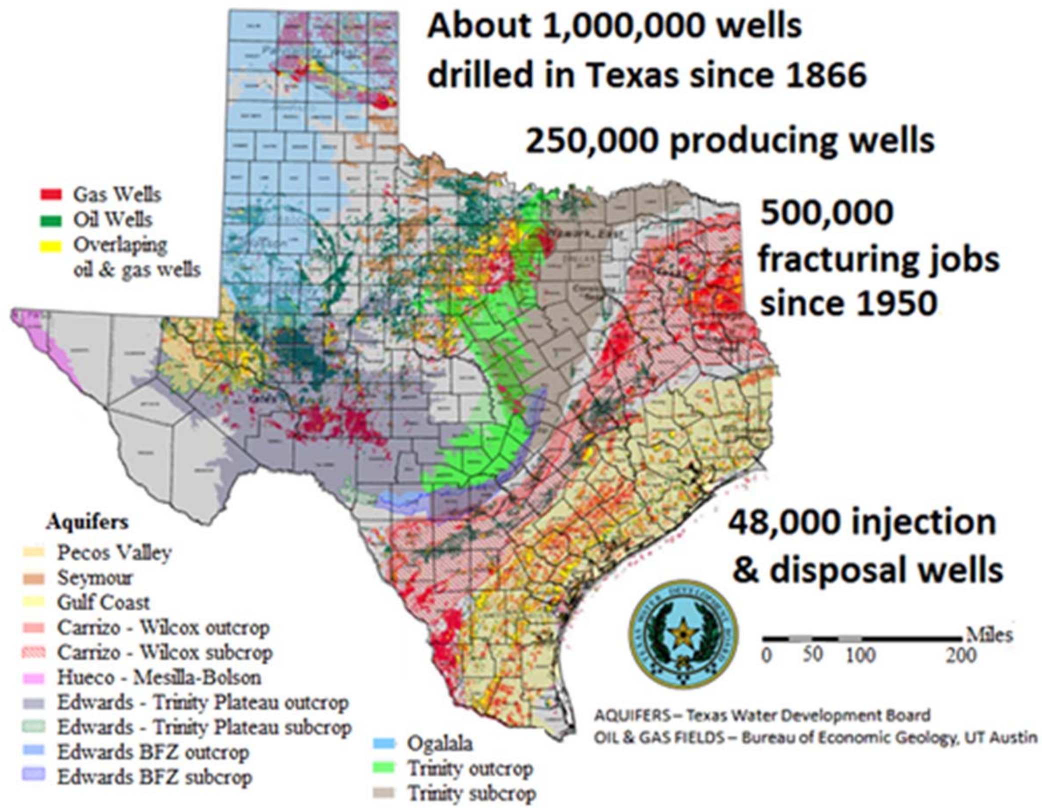
# What are Groundwater Pollutants Today & where do oil & Gas Wells Fit in this Picture?

**Used Texas as a Study Case.**

**Over a million penetrations through the 29 major & minor aquifers in Texas.**

**Texas is #2 in total Groundwater withdrawals with ~ 80% going to Agriculture & Municipalities.**

**If the water was really polluted by O&G wells, we'd see it quickly in Municipal & Ag.**

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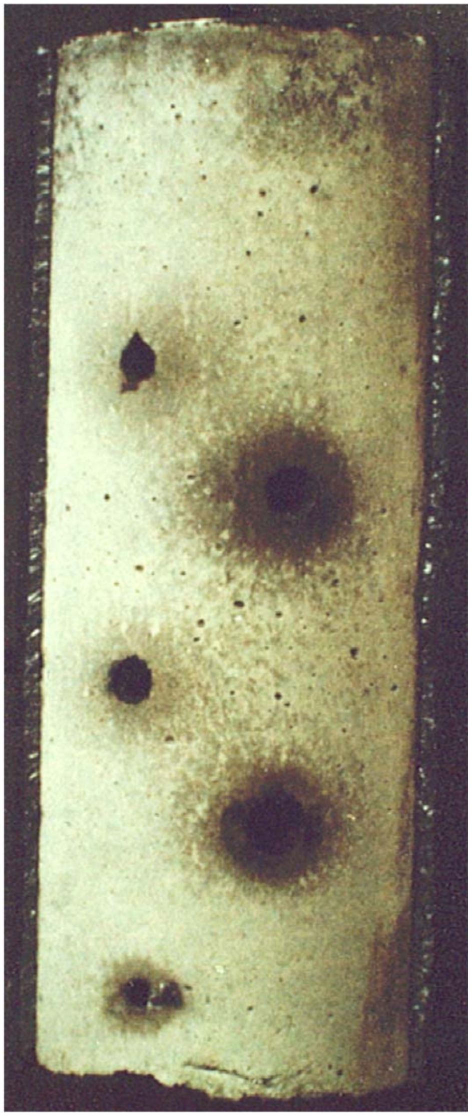
# Red Flags – Looking Into the Future

- There are very few well integrity failures that do not show signs of their approach.
- Major issues
  - Corrosion possibly creates more damage than all other failures combined.
- To predict future problems – look at the past.
  - What era of technology was the well built in?
  - What level of maintenance has the asset received?
  - Who is responsible?

# Repairs

- Sequence of Outcomes:
  - Safety impact
  - Contamination impact
  - Containment issues
  - Remediation potential
  - Retribution and punishment
- Repair – methods – success
  - Convention squeeze (cement & sealer)
  - Pipe removal
  - Better initial design/application



# Gas migration >>200+ yrs. Old - highly regional - many causes - 1000’s of seeps.

Figure 12 Residential water wells may have many points of methane gas entry

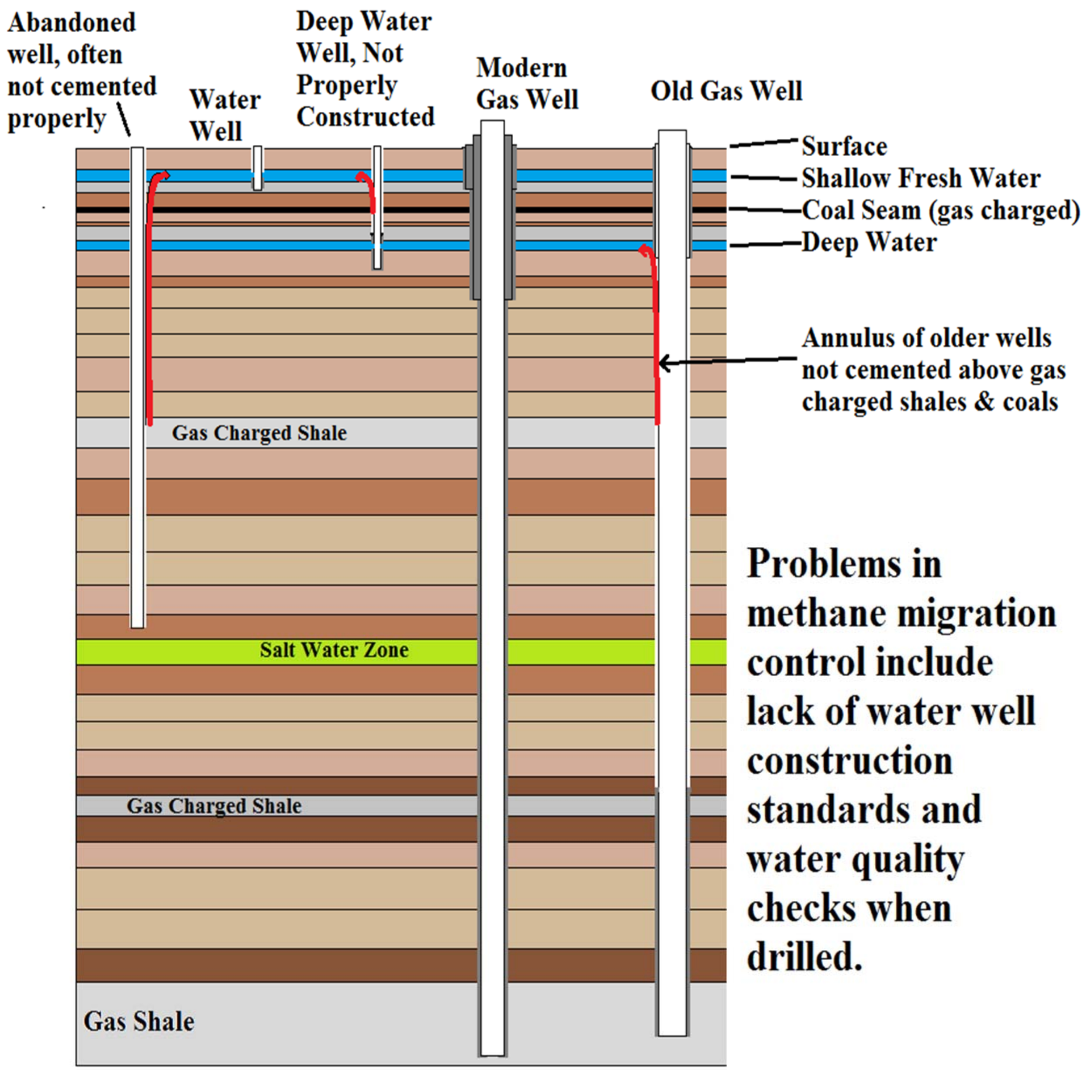
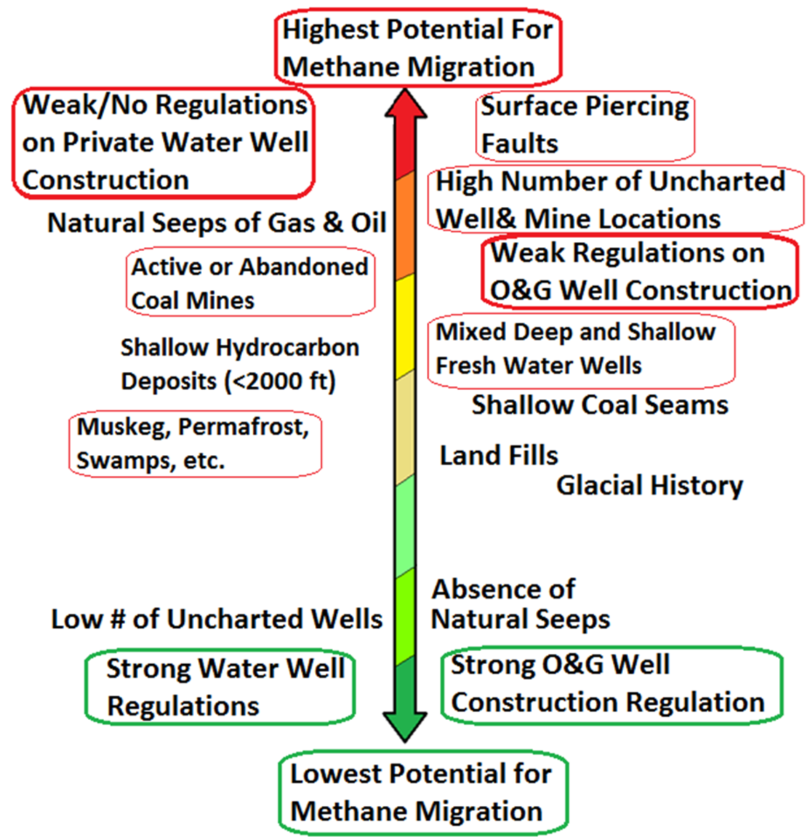



Figure 13 Common Factors in Methane Migration

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# Conclusions

1. Risk of GW pollution from producing well is low.
2. Barrier failure rates and well failure rates vary widely.
3. Barriers may fail without creating a pollution pathway.
4. Failure of wells of a specific time era are artifacts of that era; not reflective of wells completed today.
5. The nation’s 15 million residential water wells may be conduits for methane migration.

## Society of Petroleum Engineers

### Well Integrity Symposium

- 3 potential training courses (June 1)
  - General integrity overview
  - Integrity inspection points
  - Well integrity for stimulations in new & old Wells

- 2 day symposium (June 2 & 3)