

*High adventure*

$\frac{R^2}{A} \rightarrow V^+$

# Assessment Methods for Well Integrity during the Hydraulic Fracturing Cycle

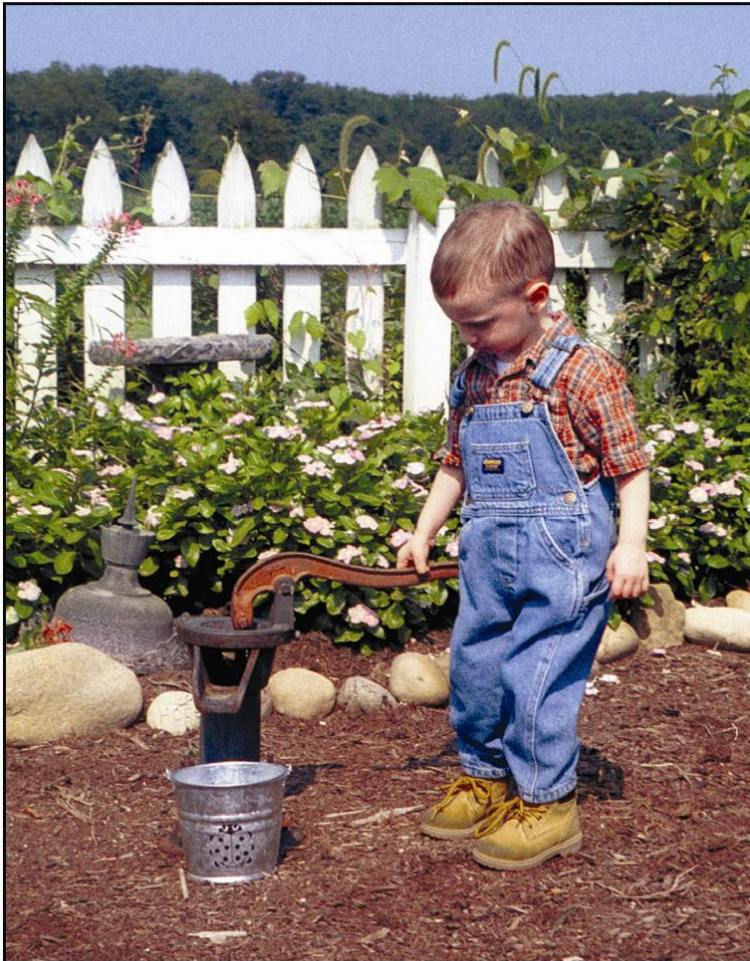
Washington, D.C.  
March 11, 2011

James Bolander  
Vice President – HS&E  
Southwestern Energy

**swn**  
Southwestern Energy®



## Drinking Water From Household Wells



Cover photo courtesy of Charlene E. Shaw, U.S. Environmental Protection Agency

# Well Integrity Is the Key!

## 1 Evaluating Stratigraphic Confinement



## 2 Well Construction Standards

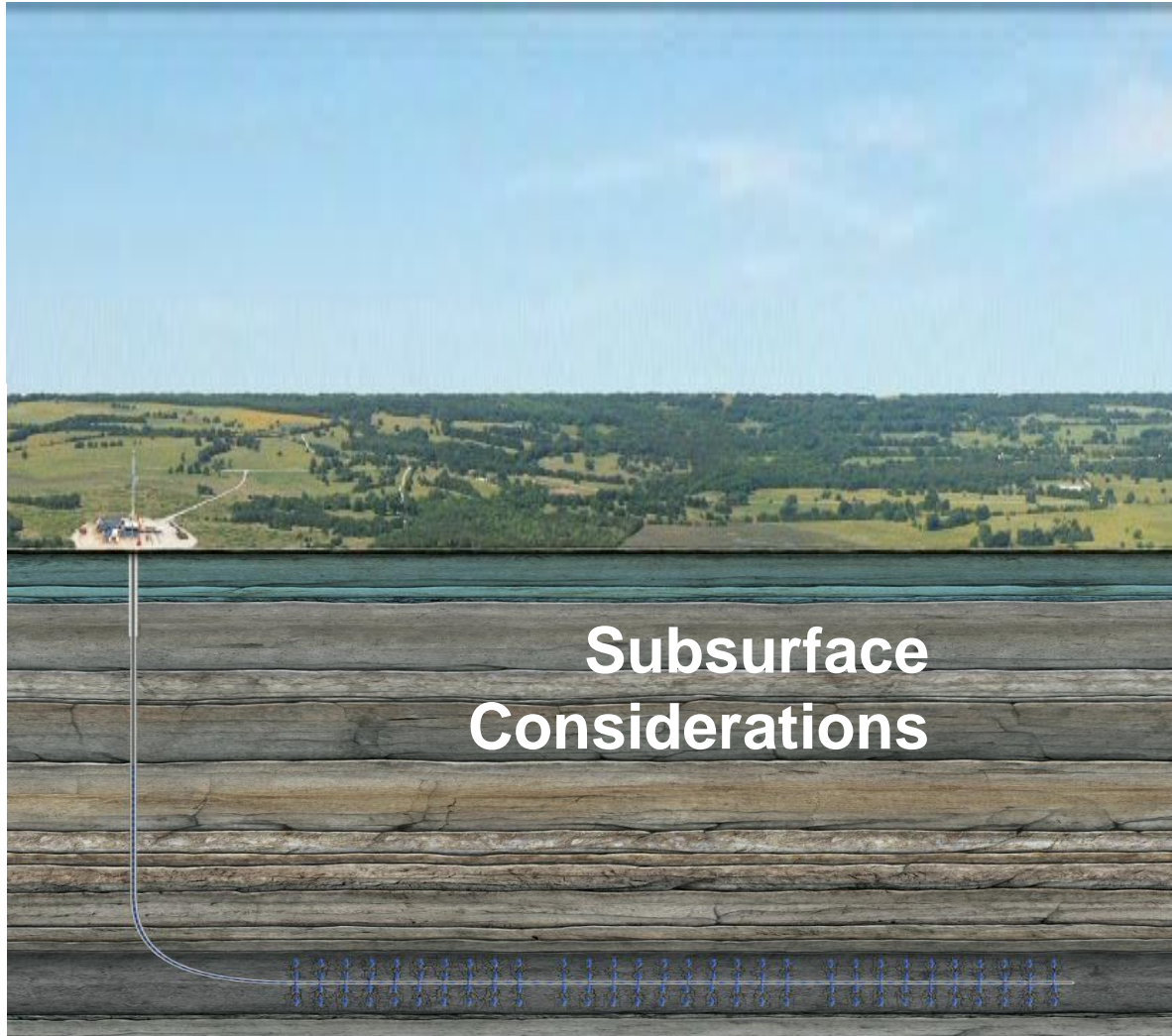


## 3 Evaluating Mechanical Integrity of Well



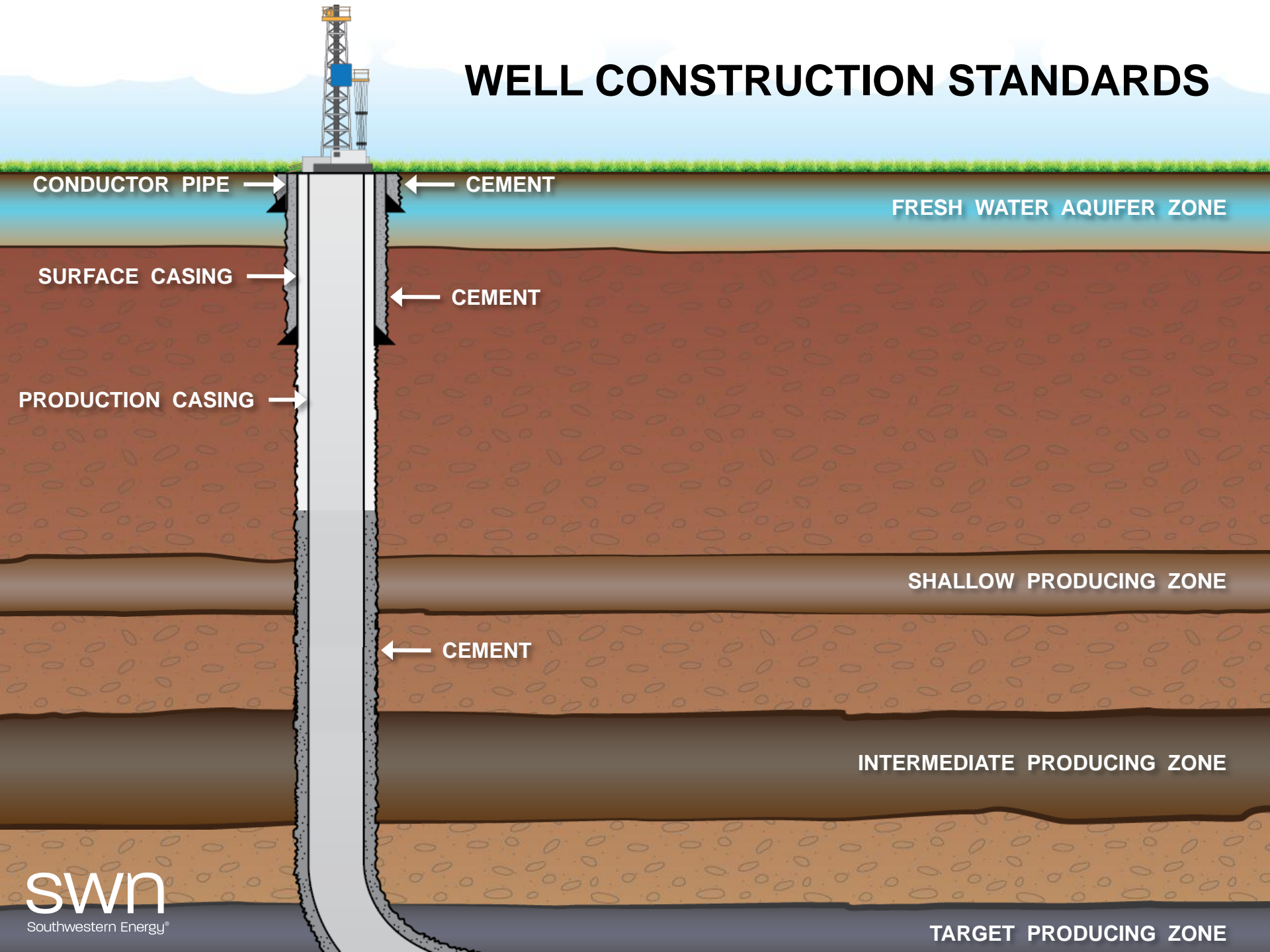
## 4 Monitoring Frac Job & Producing Well





- **Assessment Methods for Well Integrity during the frac life cycle**
- Pre-frac Evaluation
  - Understanding casing and cement integrity
- Frac Monitoring
  - Monitor & record your pressures!!
- Post-frac Evaluation
  - Maintaining well integrity through production

# WELL CONSTRUCTION STANDARDS



CONDUCTOR PIPE

CEMENT

FRESH WATER AQUIFER ZONE

SURFACE CASING

CEMENT

PRODUCTION CASING

CEMENT

SHALLOW PRODUCING ZONE

INTERMEDIATE PRODUCING ZONE

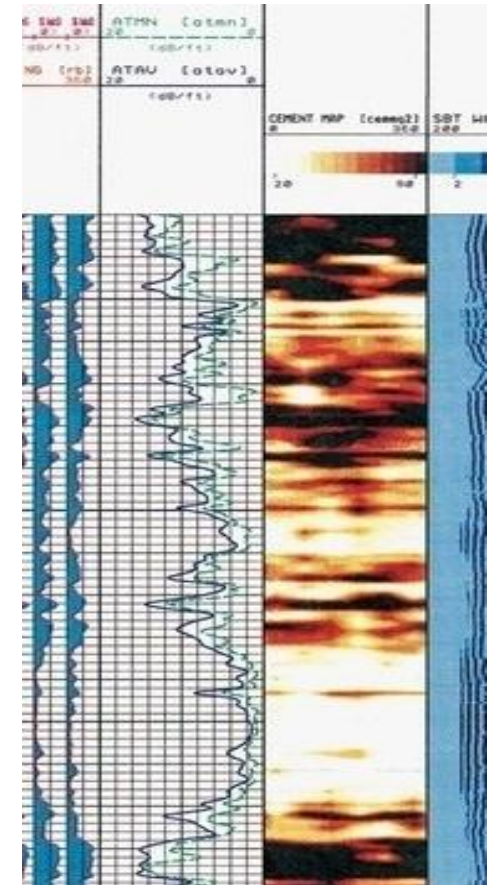
TARGET PRODUCING ZONE

- Internal Mechanical Integrity
  - Verify appropriateness of proposed casing program (e.g., size, grade, minimum internal yield pressure, etc.)
  - Test casing string to ensure it can withstand maximum stimulation pressure

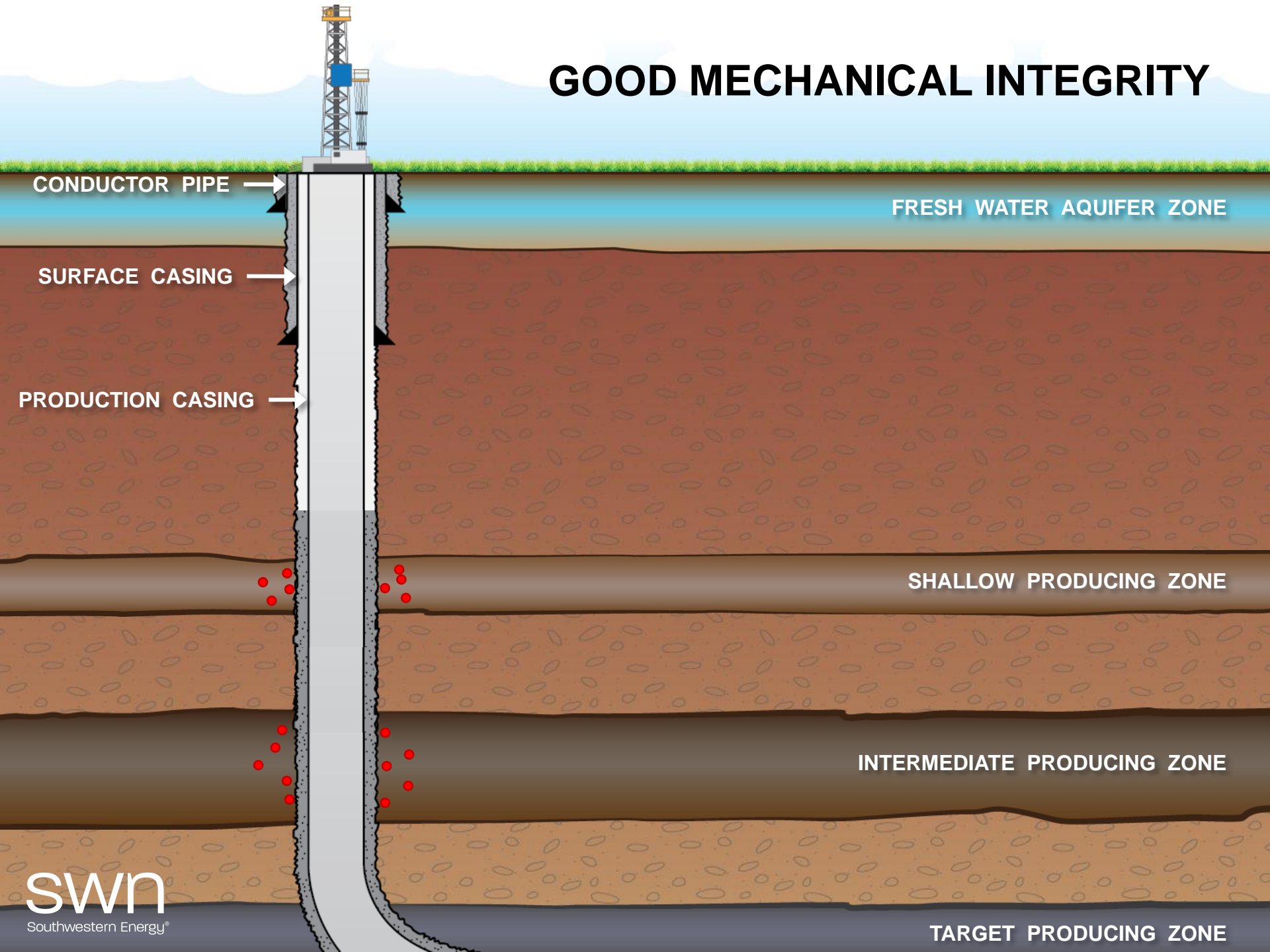


- External Mechanical Integrity
  - Verify quality of cement (field blend samples & slurry density)
  - Monitor cement job (rates, pressures & returns)
  - Identify top of cement
  - Test cement job (FIT, CBL, etc.) when operations indicate inadequate coverage

- Confirming top of cement (TOC) and quality are keys to protecting drinking water sources
  - Monitoring rate and fluid volumes are the first step in evaluating the effectiveness of a cement job
  - Mechanical test methods include the following:
    - Temperature surveys which can determine the top of cement
    - Cement evaluation tools, such as the Segmented Bond Tool (SBT) which can determine TOC and quality of cement job to confirm zonal isolation



# GOOD MECHANICAL INTEGRITY



CONDUCTOR PIPE

FRESH WATER AQUIFER ZONE

SURFACE CASING

PRODUCTION CASING

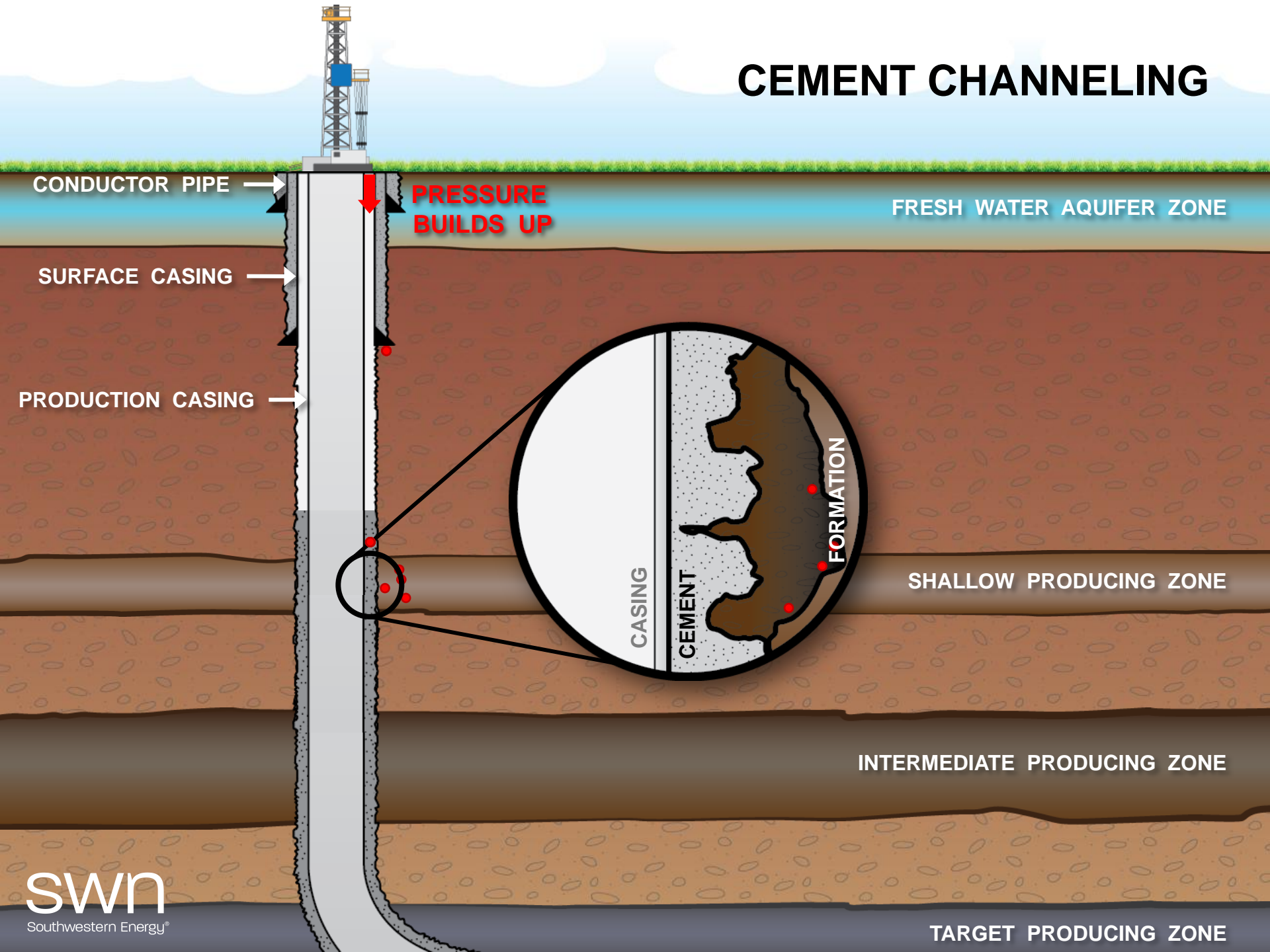
SHALLOW PRODUCING ZONE

INTERMEDIATE PRODUCING ZONE

TARGET PRODUCING ZONE

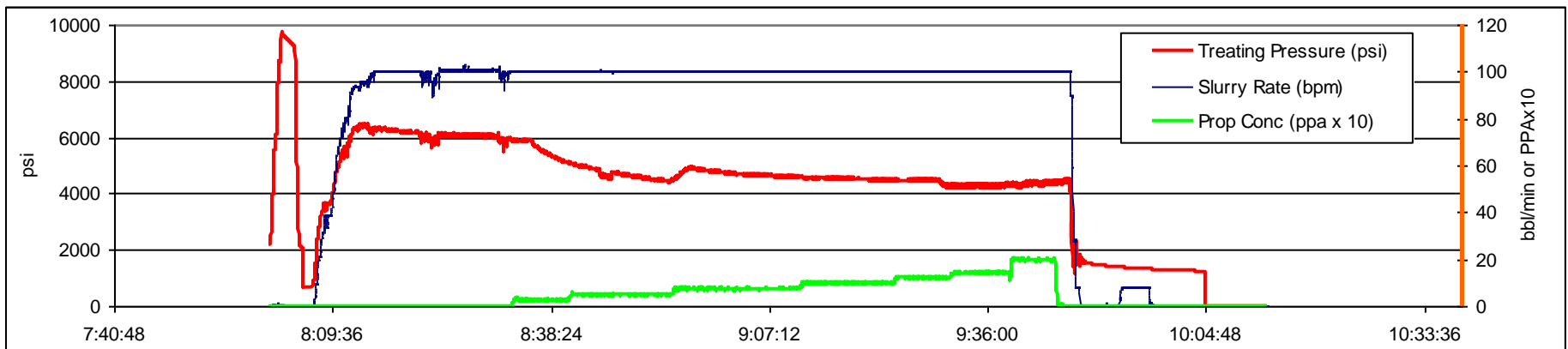
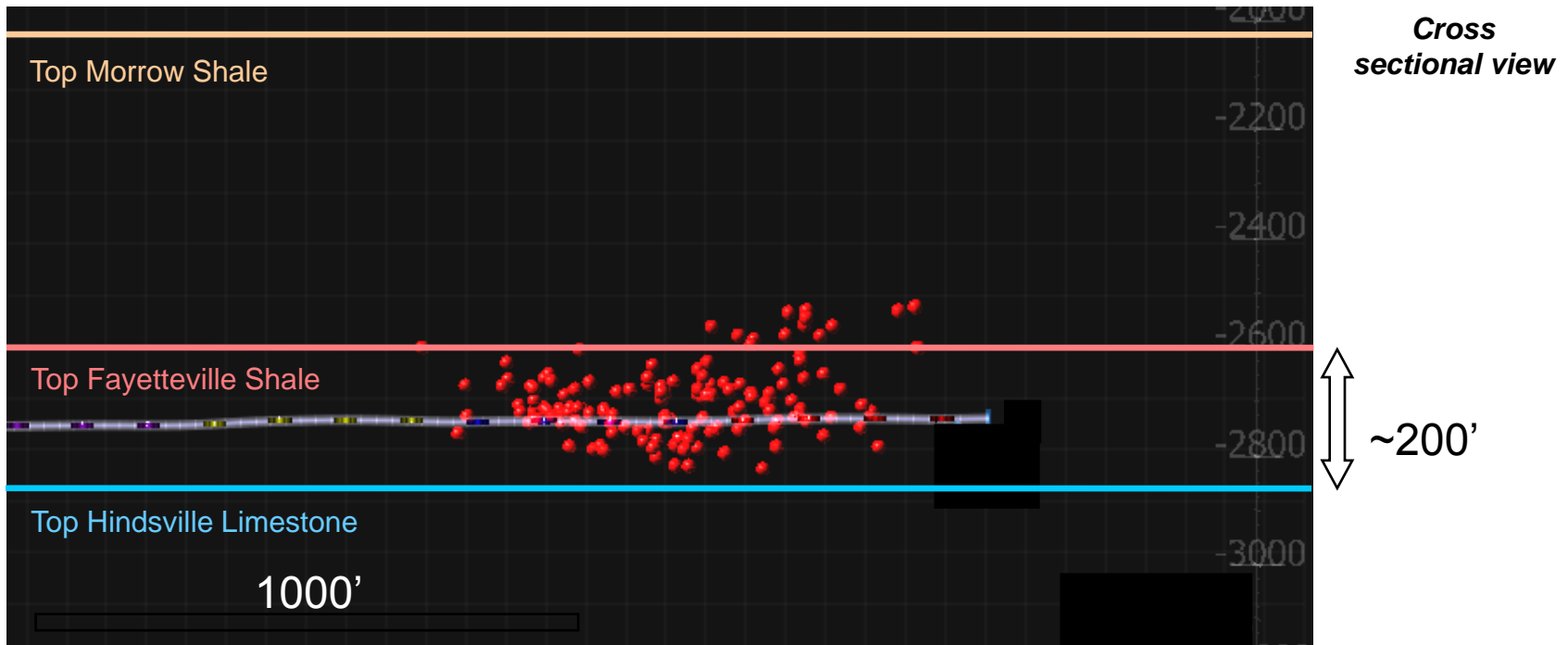


# CEMENT CHANNELING



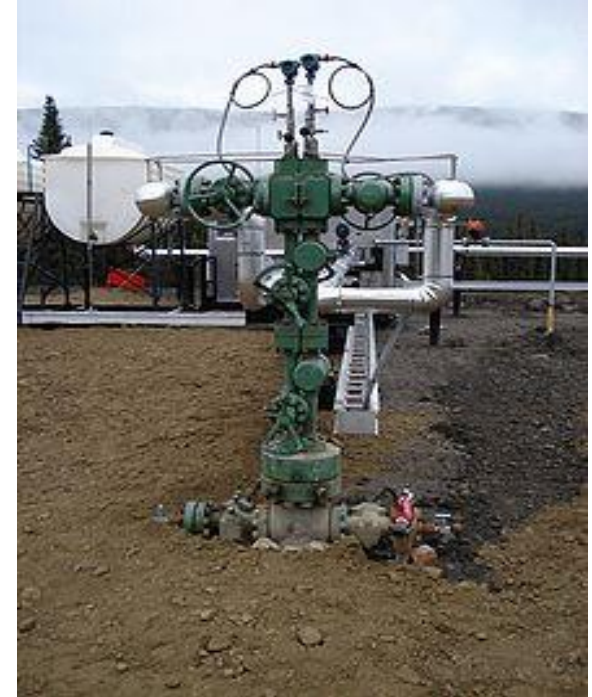
- **Monitor surface injection pressure and rate during frac job**
- **Monitor annular pressures during and after frac job**
- Additional assessment methods include microseismic and use of tracer technology.
- Terminate operations and take corrective action if abnormal pressure responses indicate mechanical integrity failure or fracture growth out of target zone





$$\frac{R^2}{A} \rightarrow V^+$$

- Monitor Flowing and Annular pressures for changes
- Monitor gas and fluid rates which could indicate influx from an external sources
- Monitor gas and fluid composition which could indicate influx from external source and aid in determining scaling and corrosion tendencies
- Perform diagnostic tests to ensure integrity throughout the life of the well:
  - Use of radioactive tracers and logging
  - Use of Chemical tracers
  - Casing Inspection and Production Logging
- Take corrective action to remediate well integrity concerns



# Fracture Stimulation Results Tracer Survey

Southwestern Energy Production Company

Arnold G.U. #1-4

67,000 # of 40/70 sand traced with 27 mCi of Sb-124 ZW (25-1 ppq)

165,000 # of 40/70 sand traced with 70 mCi of Ir-192 ZW (1.25-2.5 ppq)

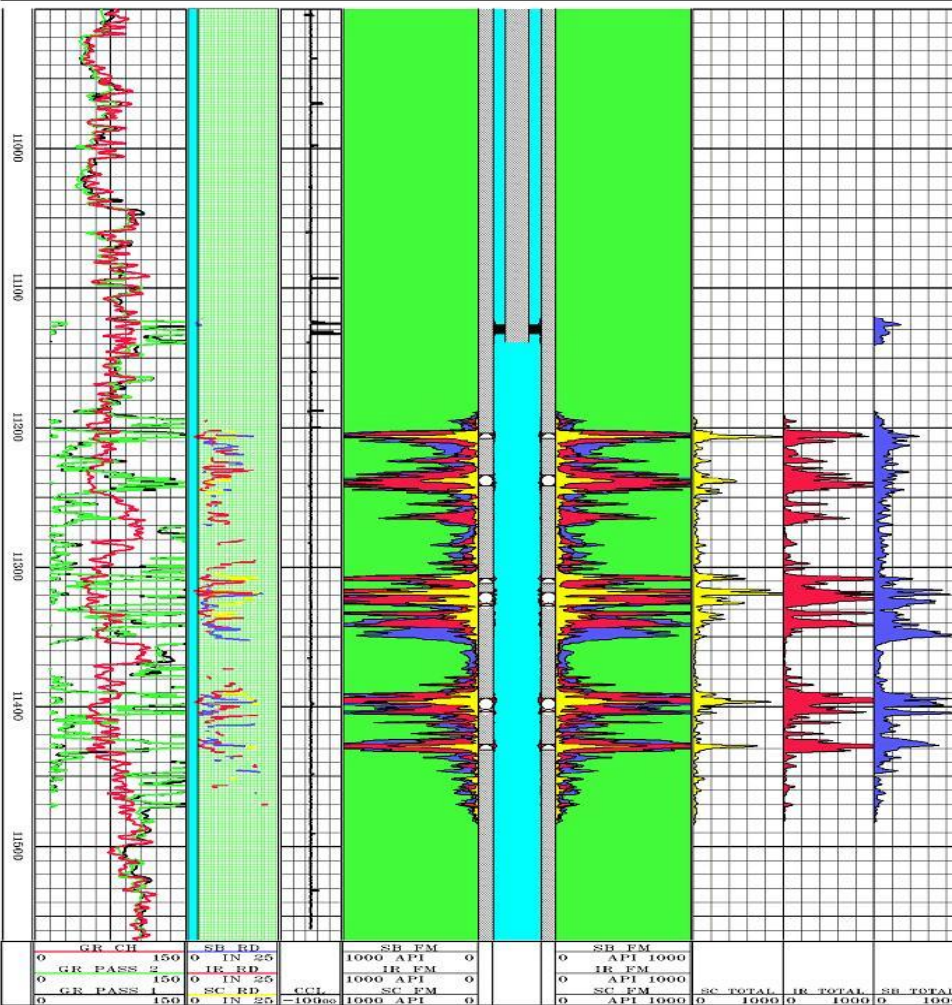
50,000 # of 20/40 sand traced with 21 mCi of Sc-46 ZW (2.5 ppq)

Fraced: 11/05/02

Logged: 12/12/02

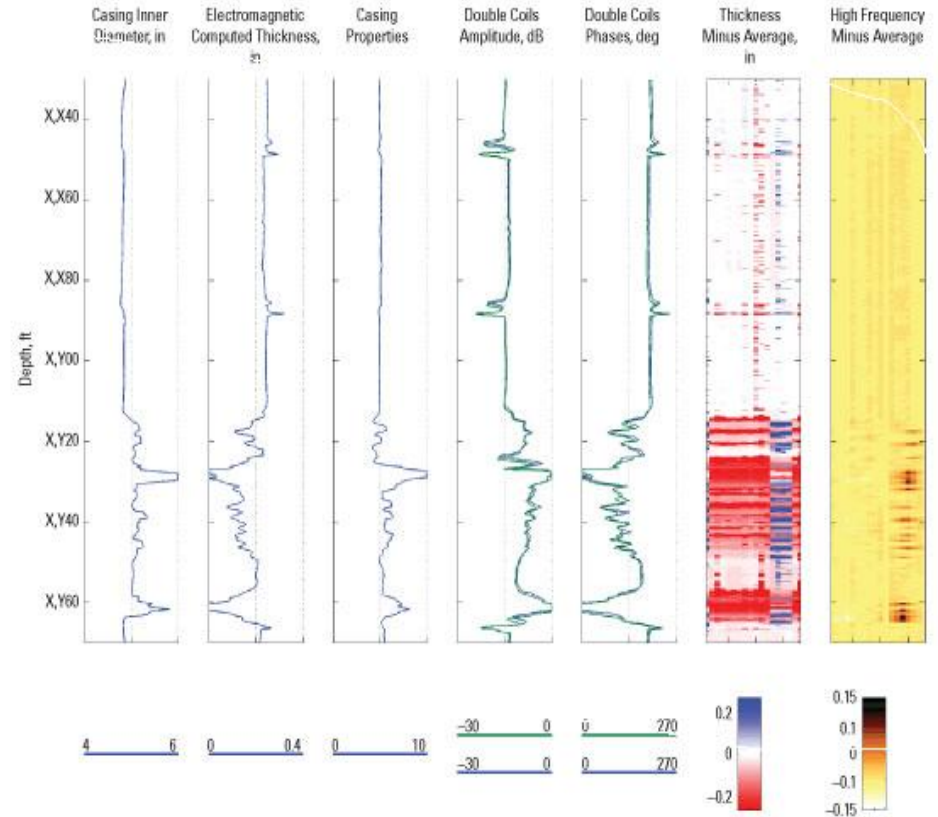
Formation: Cotton Valley (Taylor)

**Confirms All Zones Effectively Stimulated Near Wellbore**

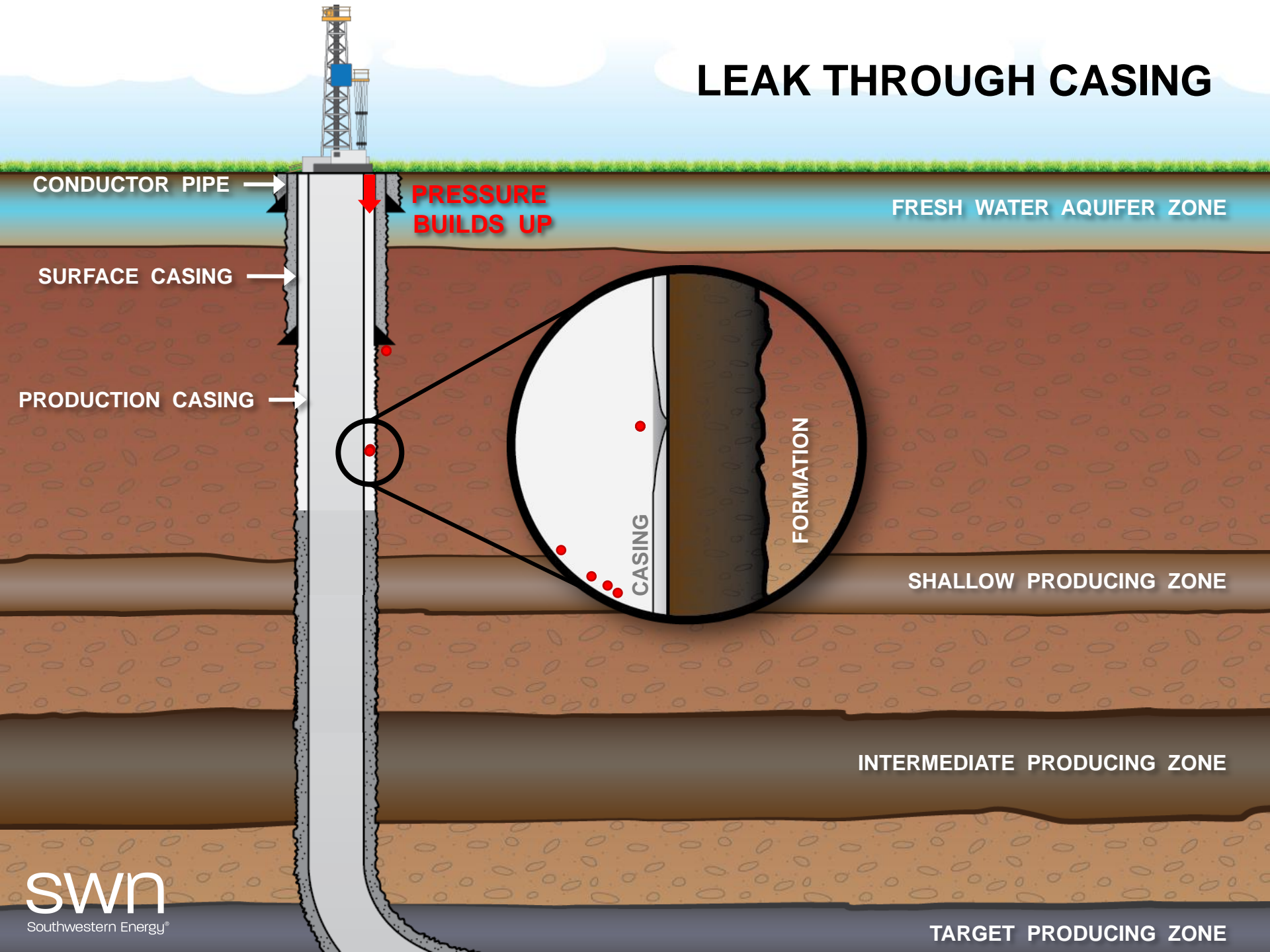


*Handwritten signature: A → V+*

- During the life cycle of the well, regular maintenance may be required.
  - Confirmation of casing integrity by running Casing Inspection Log to determine current condition



# LEAK THROUGH CASING





## Drinking Water From Household Wells



Cover photo courtesy of Charlene E. Shaw, U.S. Environmental Protection Agency

# Well Integrity Is the Key!

**Proper Planning,  
Documentation and  
Assessment are important  
keys to maintaining well  
integrity and  
environmental protection**



# **Assessment Methods for Well Integrity during the Hydraulic Fracturing Cycle**

James Bolander  
Southwestern Energy

*The statements made during the workshop do not represent the views or opinions of EPA. The claims made by participants have not been verified or endorsed by EPA.*

## **Introduction**

The objective will be to evaluate well integrity of casing and cement during the drilling and completion phases surrounding hydraulic fracturing. Critical processes will be evaluated using passive monitoring techniques (pressure and volume measurements) and direct mechanical techniques to determine effectiveness of casing and cement to protect drinking water resources.

As defined by the EPA Draft Study Plan, drinking water resources will include “any body of water, ground or surface, that could currently, or in the future, produce an appropriate quantity and flow rate of water to serve as a source of drinking water for public or private water supplies.”

The primary focus of this assessment will be to concentrate on well integrity during drilling and completion activities associated with running and cementing of production casing operations, completion activities including the hydraulic fracturing process and post-frac activities. Many of the solutions discussed are based on a conventional cased and cemented completion; however, most of the methods discussed will be applied over any type of well configuration.

The purpose of this paper will be to discuss assessment methods and will not expand into remedial solutions to meet hydraulic fracturing or producing well criteria.

## **Pre-frac Evaluation**

The first step to evaluating well integrity of the production string will be to monitor and interpret the pressures and volumes associated with the primary cement job. Key issues to review include test results of the field blend samples (if applicable), actual cement slurry density, cement slurry volumes, pump pressure, fluid return volumes, displacement volumes and lift pressure. Based on the well design, the amount and type of cement will be determined to achieve zonal isolation and sufficient coverage for isolation above the zone(s) to be completed. Knowing the design parameters (estimated TOC, hydrostatic pressure and displacement volumes) are key in the on-site monitoring of the treatment. Ensuring that the cement blend is correct and that the correct dry cement / mix water ratio is followed is a critical factor to ensuring the proper quality of cement. Monitoring return volumes and lift pressure will be the first indication of adequate coverage of the productive horizon, any hydrocarbon strata or any strata containing protected water. Monitoring the displacement volume will allow

the estimation of the cement quality at the casing shoe. Monitoring and evaluating these key components of the cement job will assist in planning of the initial steps of a well's completion.

After the production casing has been set and cemented a priority needs to be confirmation of the wellbore integrity prior to moving forward with perforating and the hydraulic fracture processes.

This confirmation process involves measuring the presence and quality of the cement bond or seal between the casing and the formation and confirmation of the mechanical / pressure integrity of the casing or tubing.

Confirmation of cement presence and quality can be obtained using various wireline tools which can confirm the presence, height, bond and overall quality of the cement. Based on the results of the pressure and volume monitoring of the cement job, different steps may be chosen to confirm that an adequate seal is present.

**Case #1** – Proper density, proper returns, lift pressure and displacement observed during primary cementing. If design was sufficient for isolation and field conditions are known, a temperature log may be run which can determine and confirm the top of cement (TOC) measuring the heat change of cement during the setting phase. Based on average curing time, this log should be run within the first 8 – 24 hours of pumping. Another wireline log option would be a conventional cement bond log (CBL). The CBL operates on an acoustic principle: it transmits a signal and measures the time travel from a set distance from transmitter to receiver. Understanding the travel time of free pipe and empirical standards based on pipe size and cement type are key in understanding the quality of cement bond and isolation that is present, as well as the TOC. It is recommended to allow the cement to set a minimum of 48 hours prior to running the CBL. If necessary, pressure can be applied to the casing during the CBL procedure if a micro-annulus is observed between the casing and cement sheath.

**Case #2** – Returns, lift pressure or displacement does not correlate with design criteria. Risk is insufficient coverage or channeling which could jeopardize proper isolation of protected water. If there are no shallow horizons which require coverage and sufficient cement height was designed, a conventional CBL may be sufficient to determine if adequate bonding above your zone of interest is present to maintain pressure control for hydraulic fracturing. If there are concerns about top of cement and quality, a radial ultrasonic tool (CET, USIT, CAST-V) log may be run. The radial ultrasonic tool uses a high-frequency sonic pulse which will give a full 360° interpretation of cement quality. In addition, the ultrasonic tool also measures casing parameters such as diameter and thickness to confirm casing design specifications.

Once top of cement (TOC) and quality have been verified, and are considered adequate for zonal isolation and hydraulic fracturing activities, casing integrity will be addressed. Several studies have indicated that a minimum of 10 feet of zonal isolation is required dependent upon hole and casing size

Casing integrity will be confirmed with a surface-applied pressure test. Based on design criteria (Casing parameter – burst and maximum anticipated treating pressure) the casing and tree will be tested to a pressure greater than the maximum anticipated treating pressure (MATP) with an appropriate safety factor (Burst Safety Factor  $\sim 1.3$  and/or not less than 500 psi greater than MATP). The pressure test is conducted using a high pressure pump truck and water. With the frac tree valve closed, the tree and casing are tested for an average test time of 30 minutes. The pressure will be monitored and if a pressure drop is observed (10% range), the casing will be removed from service until such time the casing demonstrates full pressure integrity.

If during the pre-frac assessment process, casing and cement integrity are deemed to be insufficient, the well should be removed from service until remedial operations have been completed to restore integrity. Once remedial operations have been completed, repeat the well integrity assessment to determine casing and cement integrity to confirm adequate pressure and zonal integrity will be achieved to perform hydraulic fracture operations and well production operations.

### **During Hydraulic Fracturing Treatment**

Continuous monitoring of key parameters during the frac treatment (surface injection rate and pressure and annuli pressures) is important in the continued monitoring of well integrity. These key frac parameters are important in the evaluation of the post frac analysis (height, length and conductivity) they are also important in the monitoring of well integrity.

Surface injection pressure is a component in the calculation of net pressure ( $BHTP - P_c$ ), which is an important monitoring tool to determine if there is a loss of well integrity during the frac treatment. A negative slope of the net pressure plot is indicative of excessive frac height growth. This could be attributed to break out of zone and/or confining layer (discussed in previous Workshop Theme) or loss of cement integrity during pumping. If there is a loss in cement integrity, a corresponding spike in annular pressure may be observed.

In addition, monitoring of annular pressures may also indicate a breach in the casing which could result in potential exposure of protected water.

If during a hydraulic fracturing treatment, there is reason to suspect any potential breach in the production casing, production casing cement or isolation of any sources of protected water, cease pumping and perform diagnostic testing on the well as is necessary to determine if breach actually occurred and if remedial operations are required to restore well integrity.

During the frac job process, additional assessment methods may include evaluation of microseismic events near the wellbore which may indicate a loss of cement integrity.

Other evaluation techniques such as use of tracers (chemical and radioactive) are important in the planning and execution of the hydraulic frac treatment but will be discussed in the next section.

## Post –frac Evaluation

Similar to pre-frac assessment, post-frac evaluation involves both passive monitoring techniques and direct measurements.

Passive monitoring during the post-frac period includes continuous monitoring of well production rate and pressure data, and fluid and gas compositional data in the flowback and production stages.

- Monitoring of rate and pressure data:
  - Monitor flow rate changes that are anomalous to the wells typical behavior which may include the following: change in gas/liquid rate which could indicate an influx from an external source due to a breach in the casing or tubing.
  - Flowing pressure changes can also be affected due to influx from an external source and should be consistent with rate changes.
  - Monitoring of annular pressures is important throughout the life of the well from initial flowback until abandonment. Changes should be noted and corrective actions taken, if necessary. As stated in API Guidance document HF1, “maximum and minimum allowable annular pressures should be assigned to all annuli and these should consider the gradient of the fluid in each. These limits establish the safe working range of pressures for normal operation in the well’s current service and should be considered “do not exceed” limits.”
- Fluid and gas compositional analysis may also be utilized to monitor for changes in characteristics. An example would be influx of fluids from an external source which could change the flowback/produced fluids base characteristics such as total dissolved solids (TDS). In addition, regular fluid compositional analysis recorded on a well can aid in the determination of scaling and corrosion tendencies.

Continuous monitoring of pressure, flow and gas/liquid is an important tool in the maintenance of a well. In addition to monitoring the above parameters, regular inspection of the wellhead assembly and equipment removed from a well during a workover operation to inspect for leaks and/or corrosion/erosion damage.

Mechanical methods of evaluating well integrity may involve the running of tracer logs after the hydraulic fracture treatment or the running of mechanical and/or electromagnetic inspection tools to evaluate the condition of the tubing and casing in the well. Additional logs may be run which can detect flow behind pipe or a production log which confirms flow pattern within wellbore.

To aid in the post frac analysis of the effectiveness of a well’s hydraulic fracture treatment, the job may be traced using radioactive tracers throughout the treatment to confirm the placement of the fluids and proppant during the job. A multiple isotope gamma-ray (GR) tool is run in the well after the treatment to measure the location of the isotopes to confirm placement within the perforated interval. The tool is limited to measurements near the wellbore (<2’) which can also be used to determine any channeling behind the casing during the fracture treatment which could compromise well integrity.

Another tracer method is the use of chemical tracers in the hydraulic fracturing fluids. Specific chemical tracers can be placed in the frac fluid at different stages to confirm flowback of fluids from different stages. This confirmation can be used to determine if all frac stages are contributing and can also be used to fingerprint flowback fluids, if necessary.

During the life cycle of the well, regular maintenance may be required which includes workover operations in which tubing and packer installed in the well will be pulled out. Visual inspection of the equipment is important as mentioned above to document the condition of the equipment. In addition, mechanical inspection logs may be run to verify the condition of the casing. A mechanical multi-finger caliper log can be run which physically measures the internal diameter of the casing and its condition. Depending upon casing ID, the caliper tool may record as many as (64) measurements of the internal diameter measuring changes in ID which would detect corrosion pitting and possible holes or splits in the pipe. Electromagnetic flux and ultrasonic tools can be run which will measure the changes in internal diameter as well as casing thickness.

These inspection tools can be run throughout the life of the well to document changes of the casing's condition over time. Understanding the condition of the casing over time is important in the planning of future operations such as refracturing and/or recompletions in the well to maintain well integrity over the well's life cycle.

## **Conclusion**

There are many techniques available from passive monitoring to use of mechanical tools to monitor the integrity of the well throughout the well's life cycle. Proper planning and documentation is important to maintain well integrity and ultimately protection of the environment.

## **References**

- American Petroleum Institute, API Guidance Document HF1, "Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines", October 2009
- U.S. Environmental Protection Agency, "Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources", February 2011
- Various Vendor Technical Brochures and Technical Specification Sheets on various wireline tools (Schlumberger, Baker Hughes (Atlas) and Protechnics)