# Case Studies of An Effective Methodology to Collect Formation Water to Meet Regulatory Requirements for Formation Water Sampling*

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Search and Discovery Article #42231 (2018)**
Posted June 18, 2018

*Adapted from oral presentation given at 2018 Pacific Section AAPG Convention, Bakersfield, California, April 22-25, 2018


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## Abstract

New underground injection control (UIC) regulatory activity come with challenges. California regulatory agencies have enhanced scrutiny on underground injection projects. One of the requirements under the California UIC regulations is to collect formation water samples and submit water analysis results together with the application package to confirm whether the Total Dissolved Solids (TDS) of a formation or aquifer is greater than 10,000 ppm, which is non-underground source of drinking water (non-USDW) under the federal Safe Drinking Water Act (SDWA).

Various methodologies for collecting water samples were evaluated before selecting wireline tools, to collect water samples. The water samples were collected open-hole using downhole special wireline equipment with high technologies to analyze/detect not only fluid types being pumped through the tool's flowline but also the contamination levels (due to mud filtrate invasion), to prove the representative formation fluid quality of the collected samples.

This article summarizes water sampling methods using two different types of wirelines sampling tools from two different leading wireline contractors. Depending on the key sensors each tool has, strategies to detect contamination levels were studied and developed. The following executions and on-the-fly decision making have proved this sampling method is the most suitable and cost-effective for the specific regulatory required sampling.

Formation water samples were successfully collected with monitored contamination levels to prove the accuracy of the formation TDS of this sampling method compared to the log-derived TDS. This crucial data helps demonstrate the TDS and water quality in order to comply with California UIC requirements. This is a new sampling method that had never been used in the San Joaquin Valley region for formation water sampling. Despite initial concerns from regulatory agencies about the accuracy of this method, the regulators have not only accepted this formation water sampling technology, but now advocate for its use by other operators.

Pacific Section AAPG Convention
April 22 – 25, 2018
Bakersfield, California

# Case Studies of An Effective Methodology to Collect Formation Water to Meet Regulatory Requirements for Formation Water Sampling

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# INTRODUCTION

## 1.1 Project and Regulations

- California regulatory agencies have enhanced scrutiny of underground injection control (UIC) projects.
- UIC regulations require collection of actual formation water samples and submittal of chemical analysis as part of an application package to confirm whether the formation's or aquifer's Total Dissolved Solids (TDS) is greater than 10,000 mg/l, which is non-underground source of drinking water (non-USDW) under the federal Safe Drinking Water Act (SDWA).
- Two case studies for wireline formation water sampling: the deep Spellacy formation and the shallow Tulare formation, respectively in the San Joaquin Valley, California

# INTRODUCTION

## 1.2 Limitation of Recommended Sampling Methods

- Ground Water Sampling Guidelines:
  - Diffusion of oxygen at the air interface stimulates biodegradation due to groundwater sitting stagnant in monitoring wells
  - Volatilization at the air-water interface
  - Mixing different sources via adventive flow within water column; changes in fluid levels, temperature, pressure, etc.
- Sampling groundwater monitoring wells present a given set of conditions, slightly different than the cases studied, new well conditions.

# INTRODUCTION

## 1.2 Limitation of Recommended Sampling Methods (cont.)

- The wireline formation tester method offers a closed sampling system not affected by any of the conditions that purging is used to mitigate.
  - The concentration of Na and Cl ions dissolved in water (saltwater) should not differ greatly depending on the groundwater sampling methodology; unlike other constituents (metals, hydrocarbons, solvents).
  - The top depth of a case studied formation is more than 4,000 feet below ground surface → infeasible to use the purging methods recommended in the Water Sampling Protocol.

# INTRODUCTION

## 1.3 Cost of Sampling

- Looking for the most cost-effective initiatives and technologies to maintain environmentally safe production operations.
- The sampling cost is in addition to cost of drilling a new well, which generally includes logging, petrophysical analysis, and reservoir characterization.
- Guarantee the collection of enough volume of cleaner, purer samples in a much less time, low to non-filtrate contamination.

Incremental cost for formation water sampling

| Method of sampling | **Incremental to drilling Costs ($)** |
|---|---|
| Wireline Formation Tester | 80,000 -150,000 (estimation) |
| Artificial Lift (ESP, Rod pump etc.) sampling | 360,000 – 420,000 (estimation) |

# COMPARISON OF SELECTED WIRELINE SAMPLING METHODS

Three (03) main parameters were used to assess three (03) wireline sampling methods:

- Lowest level of contamination
- Pumping volume capacity
- Efficiency versus Cost

Selected Wireline Sampling Method Comparison

| Method | Fluid Contamination Monitoring | Flow area ($in^2$) | Efficiency/Cost | | |
|---|---|---|---|---|---|
| | | | Ease for drilling operations | Suitability for mix of consolidated/ unconsolidated formations | Additional Information |
| Wireline Sampling Tool with larger radial probe with inflatable elements | Sample contamination monitoring | 79.44 | -Retractable mechanism to ensure reliable extraction at stations.<br>-Seals in almost every borehole condition | Great for:<br>Unconsolidated formations<br>Low permeability zones | Formation Pressure<br>Drawdown<br>Mobility ratio |
| Extra Large Diameter (LD Probe) | Sample contamination monitoring | 2.01 | Constraint caused for the fluid dead volume at the inflation time | Trade-off between large area and complex deploy vs. smaller area and simple deploy | |
| E-Probe | Sample contamination monitoring | 6.03 | Higher intake velocity but small area | Better for consolidated formations | Formation Pressure<br>Drawdown<br>Mobility ratio |

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# COMPARISON OF SELECTED WIRELINE SAMPLING METHODS

Simulation was run using:

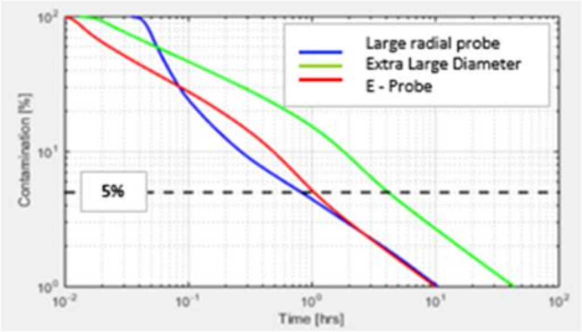
- a fixed flow area value
- at three different pressure drawdowns (500 psi, 1000 psi and 1500 psi)
- to achieve a specific fluid contamination target of 5%

Simulation Results for the Three Selected Sampling Methods

## 500 psi drawdown

| Tool | Target contam | Rate [cc/s] | Δ p [psi] | V2S [L] | TST [hrs] | Sample contam. |
|---|---|---|---|---|---|---|
| Saturn 7in | 5.0 | 27.00 | 114.7 | 79.8 | 0.82 | 5.00 |
| LD probe | 5.0 | 6.78 | 500.0 | 100.9 | 4.16 | 5.00 |
| E-probe | 5.0 | 27.00 | 448.4 | 101.0 | 1.04 | 5.00 |

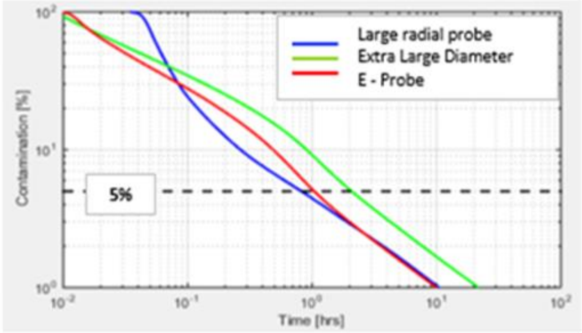
Contamination Target




## 1000 psi drawdown

| Tool | Target contam | Rate [cc/s] | Δ p [psi] | V2S [L] | TST [hrs] | Sample contam. |
|---|---|---|---|---|---|---|
| Saturn 7in | 5.0 | 27.00 | 114.7 | 79.8 | 0.82 | 5.00 |
| LD probe | 5.0 | 13.57 | 1000.0 | 100.9 | 2.08 | 5.00 |
| E-probe | 5.0 | 27.00 | 448.4 | 101.0 | 1.04 | 5.00 |

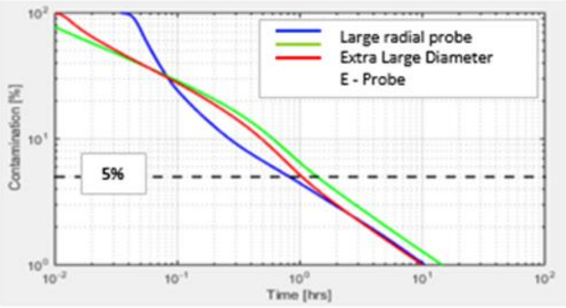
Contamination Target




## 1500 psi drawdown

| Tool | Target contam | Rate [cc/s] | Δ p [psi] | V2S [L] | TST [hrs] | Sample contam. |
|---|---|---|---|---|---|---|
| Saturn 7in | 5.0 | 27.00 | 114.7 | 79.8 | 0.82 | 5.00 |
| LD probe | 5.0 | 20.35 | 1500.0 | 100.9 | 1.39 | 5.00 |
| E-probe | 5.0 | 27.00 | 448.4 | 101.0 | 1.04 | 5.00 |

Contamination Target

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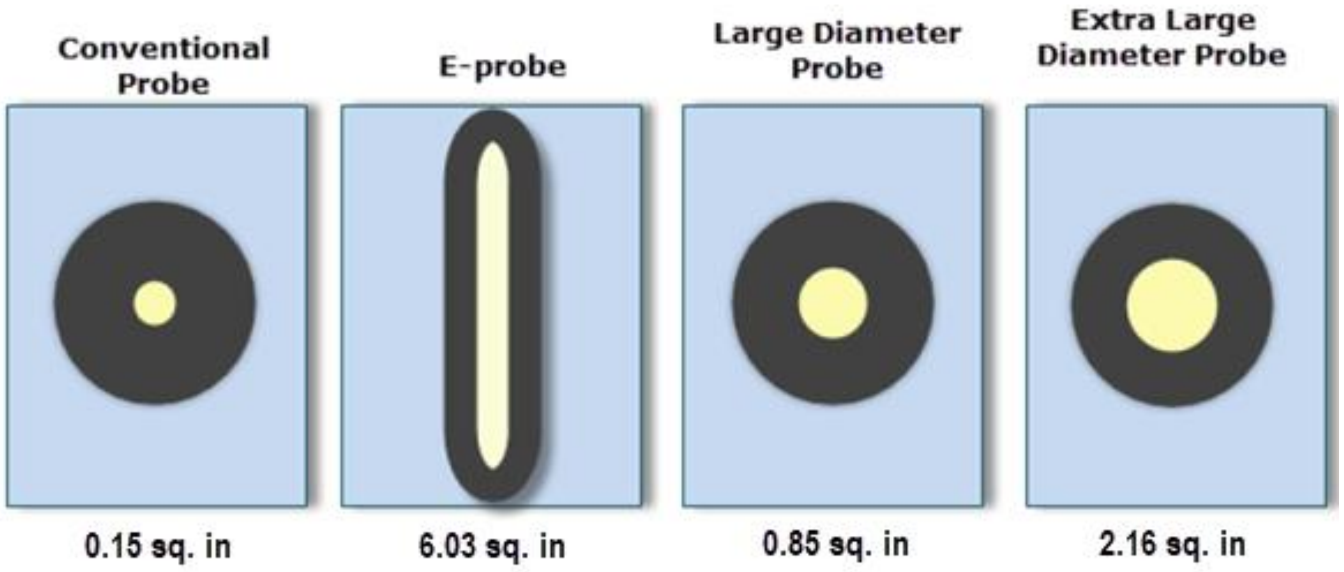
# METHODOLOGY OF WATER SAMPLING USING WIRELINE

1. Tool Configuration Selection

2. Probe Module

- defines maximum inflow volume of formation fluid into tool for a period of time by having a finite flow area
- Formation permeability is critical for probe module selection

Probes Shapes/Sizes vs. Flow Areas

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# METHODOLOGY OF WATER SAMPLING USING WIRELINE (cont.)

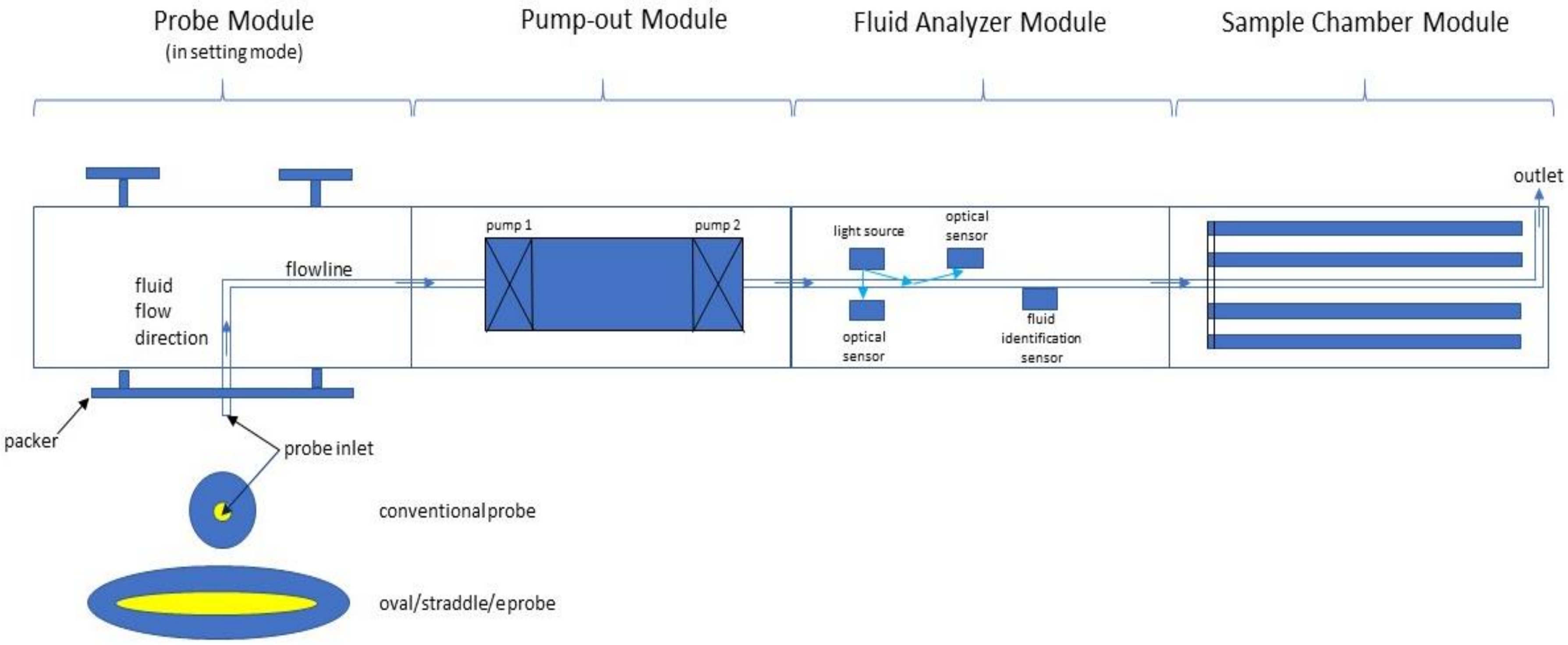
## 3. Pump-out Module

- Defines how fast fluid can be transferred through the tool

## 4. Sampling Chamber

- Collects samples for laboratory analysis to confirm the composition

Sampling Tool Configuration

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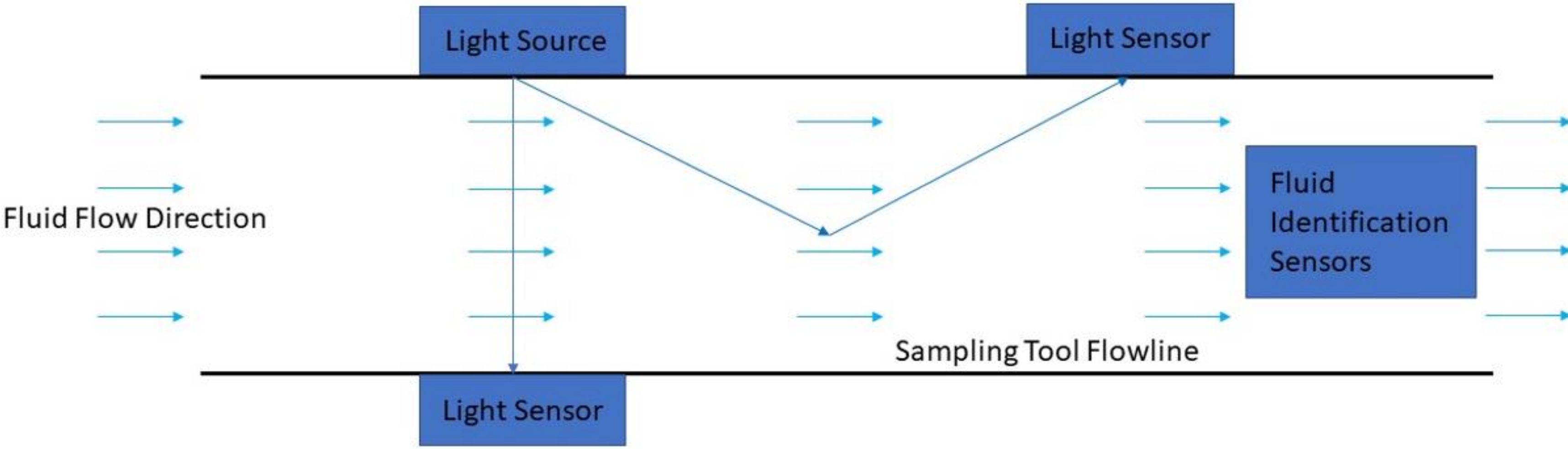
# METHODOLOGY OF WATER SAMPLING USING WIRELINE (Cont.)

## 5. Downhole Fluid Sensor

- Uses different physical methodologies:
  - ➢ resistivity,
  - ➢ optical density, compositional analysis,
  - ➢ magnetic resonance, etc.
- Allows monitoring of the contamination level.

Schematic of Fluid Sensor with Sensors in Flowline



# METHODOLOGY OF WATER SAMPLING USING WIRELINE (cont.)

## 6. Sampling Point Selection

- Basic formation properties (porosity and permeability) are important for job planning
- Acquired from previous wells or in a previous logging acquisition runs

## 7. Log-Derived Salinity

- Connate water contains sodium chloride which contributed to salinity concentration of fluid
- Resistivity of the solution at a certain temperature can be estimated if know the equivalent sodium chloride concentration
- In reverse, the salinity of a fluid can be calculated if resistivity and temperature are known

## 8. Strategies Developed Based on Key Functions of Fluid Sensors

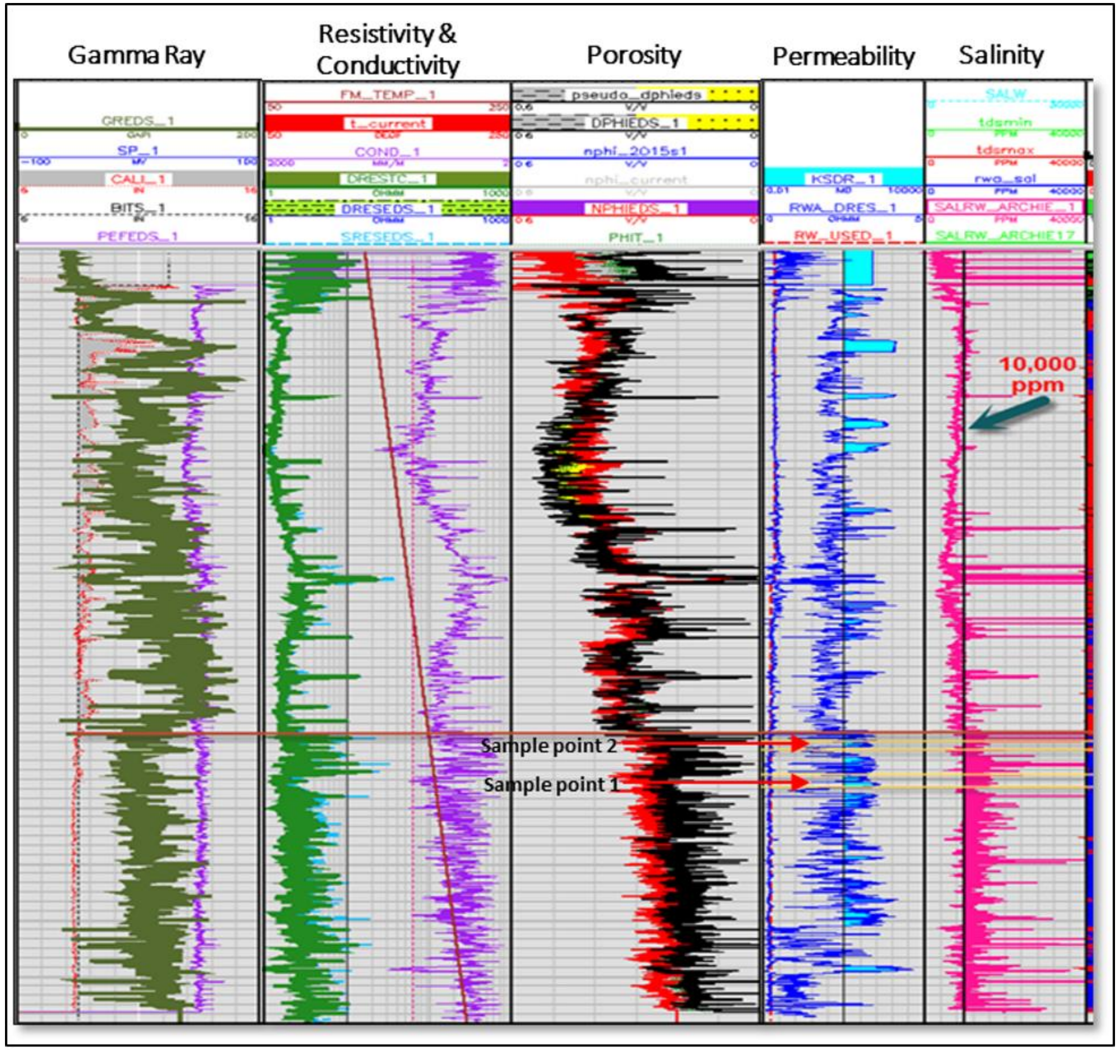
- Different wireline operators have different fluid sensors developed based on physical theories
- These sensors, with certain range of resolution and accuracy that fit the need of identification of fluid type in the flowline, can measure the physical properties of the formation fluid directly

# CASE STUDY 1: SPELLACY WATER SAMPLING

## 1. Sampling Depth Selection

- Based on the log results, rock and fluid properties, such as permeability, porosity, and estimated TDS were analyzed
- Two good quality sand intervals, one being the primary option and the other as back up, with high permeability and porosity were selected

Sampling interval selection using open logs

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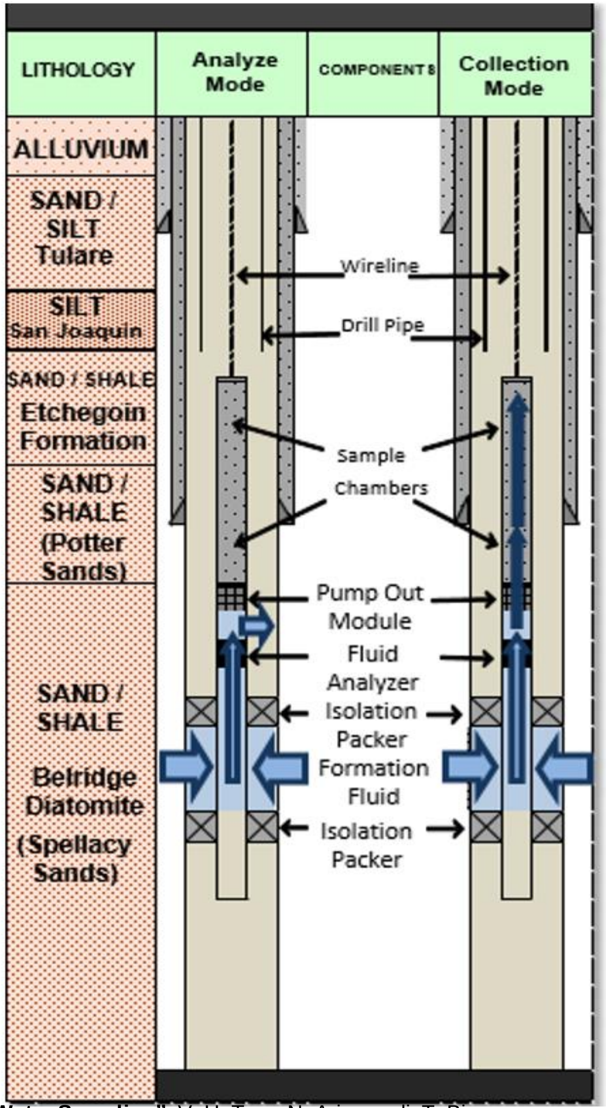
# CASE STUDY 1: SPELLACY WATER SAMPLING (cont.)

Wireline Sampling Tool Configuration




## 2. Selected Water Sampling Method

- Drill pipe conveyed wireline sampling tool with large radial probe was selected
- The tool is comprised of multiple components:
    - pretest pressure and mobility measurements
    - real-time downhole live fluid sensor for fluid contamination measurement and fluid identification
    - large radial probe and packer module for zonal isolation
    - internal pumping unit to pump fluid
    - samples chambers for fluid retrieval
- Large radial probe was used due to the following reasons:
    - fluid sampling in unconsolidated formation
    - presents extremely low operational risk
    - seals in almost any borehole condition
    - capable of work in low permeability fluid sampling cases
    - larger contact area with formation
    - less sampling time

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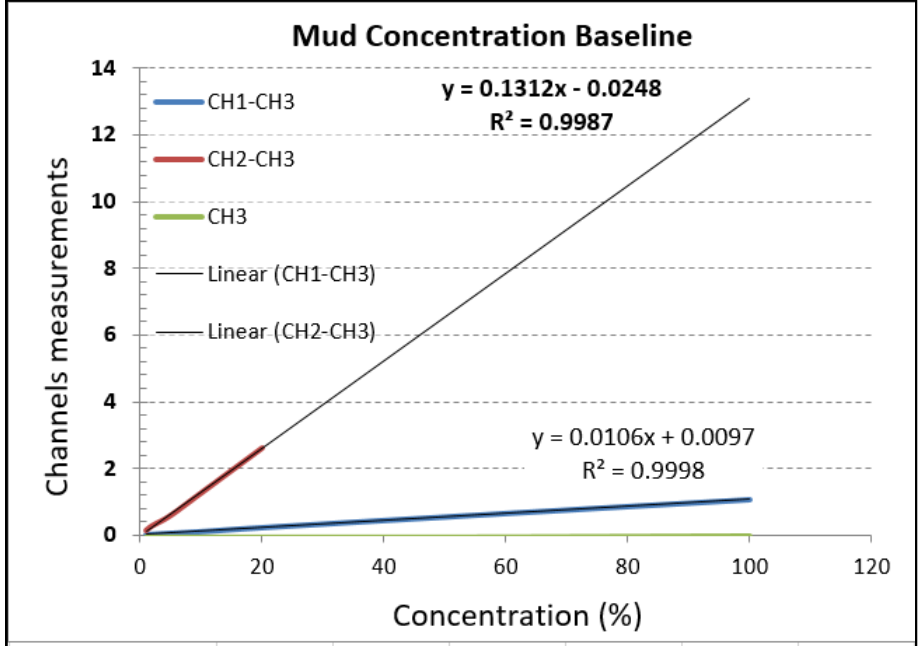
# CASE STUDY 1: SPELLACY WATER SAMPLING (cont.)

## 3. Fluid Contamination Measurement

- To monitor the contamination level in water samples, real time downhole live fluid sensor was used.
- The live fluid sensor was calibrated in the lab in advance using mud filtrate with various percentages of blue dye concentration and clear water.
- The real-time data from live fluid sensor and the calibration results were used to determine the contamination level in the fluid samples.

Live Fluid Sensor Calibration Results




| Shop Calibration | | | | | | |
|---|---|---|---|---|---|---|
| Contamination % | Time | CH1 | CH2 | CH3 | CH1-CH3 | CH2-CH3 |
| 100 | 1:30:00 | 1.03 | 5.00 | -0.04 | 1.07 | 5.04 |
| 50 | 0:05:30 | 0.5 | 5.00 | -0.05 | 0.55 | 5.05 |
| 20 | 0:08:30 | 0.18 | 2.57 | -0.05 | 0.23 | 2.62 |
| 10 | 0:12:30 | 0.06 | 1.21 | -0.05 | 0.11 | 1.26 |
| 5 | 0:16:00 | 0.01 | 0.53 | -0.05 | 0.06 | 0.58 |
| 2 | 0:19:30 | -0.02 | 0.22 | -0.05 | 0.03 | 0.27 |
| 1 | 0:22:30 | -0.03 | 0.08 | -0.05 | 0.02 | 0.13 |
| 0 | 0:25:30 | -0.04 | -0.04 | -0.05 | 0.01 | 0.01 |

# CASE STUDY 1: SPELLACY WATER SAMPLING (cont.)

## 4. Wireline Sampling Tool Run and Sample collection

- The formation water sample was collected in three chambers (two 1-gallon chambers and one 2 ½ gallon chamber) by redirecting the fluid into the sample chambers once the dye concentration had reached the pre-specified level.
- Reservoir pressure data was collected at two different depths which indicated that reservoir is sub-normally pressured.

## 5. Sample Custody Transfer, Analysis, and Results

- Water was decanted into new and clean containers supplied by laboratory and labeled with sample ID
- The water samples were analyzed in the laboratory using DOGGR & EPA approved methods
- TDS was 26,000 ppm, which demonstrates that the formation water is not an underground source of drinking water (non-USDW)

# CASE STUDY 2: TULARE WATER SAMPLING

## 1. Downhole Fluid Sensor Selection

- Fluid ID module selected to perform the downhole analysis
- Using fluid density sensor → accuracy as low as 0.01 g/cc with the resolution of 0.0001 g/cc
- Using resistivity sensor → resolution as low as 0.02 ohm-m
- Flowline temperature sensor → resolution of 0.01$^{o}$F → correct apparent resistivity value to the surface temperature resistivity due to high temperature from steam-flood injection activities nearby

## 2. Sampling Strategy

- Mud salinity was selected and control at maximum of 500 mg/L, to create the contrast with formation water to be expected greater than 9,000 mg/L.
- Initially, the flowline will be expected to see high resistivity due to the filtrate (low salinity) invaded to formation.
- After a pumping out time, the flowline will be cleaned and have formation representative fluid with lower resistivity (due to high salinity). With a certain permeability, the expected time for clean out pumping can be simulated for job planning.

# CASE STUDY 2: TULARE WATER SAMPLING (cont.)

## 3. Pre-Job Sensor Simulation

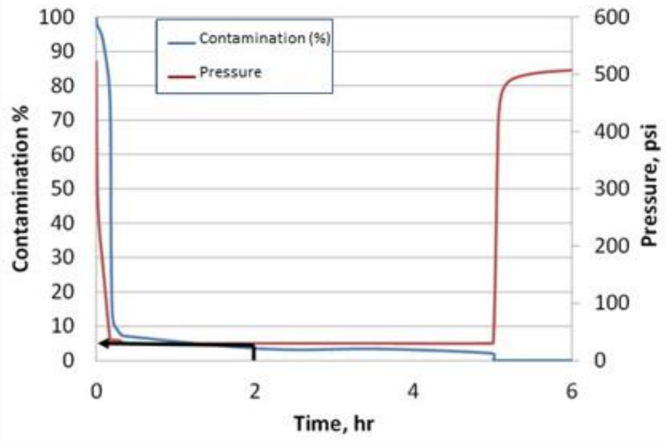
- A simulation was performed to predict the clean-up time and sensors' responses through time
- Two scenarios with different permeability values for a given set of reservoir properties and fluid characteristics

Reservoir Properties and Fluid Characteristics Input for Pre-job Stimulation to estimate Clean-Up Time

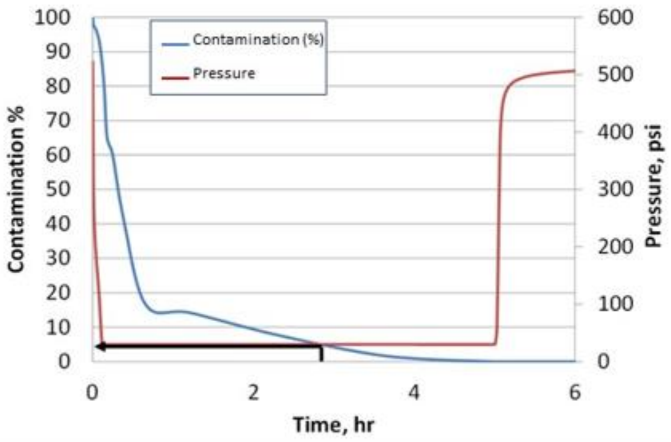
- Rmf water-based mud @ 500 ppm chloride
- Rw range of 4000 pm to 10000 ppm
- Oval Pad
- 8 ¾" Hole to 1000' TD
- 8.9 - 9.2 ppg water-based mud

- Average sand thickness: 30ft
- Average porosity: 0.35
- Average permeability: 3500 md
- oil viscosity 4000cp at reservoir temperature (~90 deg. F)
- Formation pressure: 510 psi (the simulation was unstable for pressure below this value)

K = 3500 md: To reach 5% contamination, it is required to pump for about 2 hours with 10 cc/sec




K = 3000 md: To reach 5% contamination, it is required to pump for about 2.8 hours with 10 cc/sec

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# CASE STUDY 2: TULARE WATER SAMPLING (cont.)

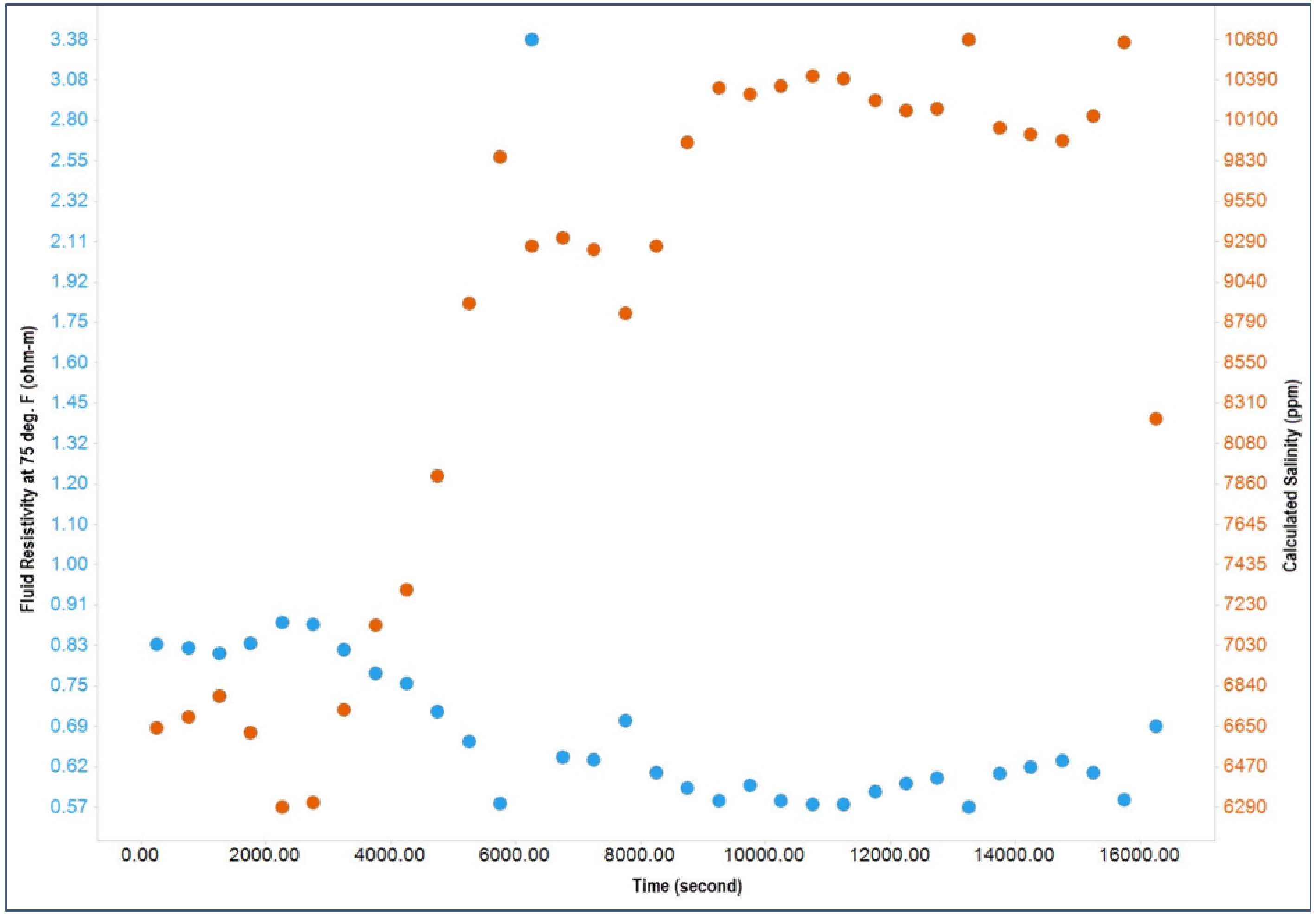
## 4. Results

- Salinity started from 6,000 ppm range and increased to 10,000 ppm range at the end of the pump out time
- The consistent values → fluid travelling inside the flowline reached the low contamination level of 5% which was simulated after 3 hours.

## 5. Lab Analysis versus Realtime Data

- Three samples of 1,000 cubic centimeters were collected
- Lab analysis shows salinity values range from 9,000 ppm to 9,500 ppm

Realtime Fluid Resistivity and Calculated Salinity Chart

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# SAMPLING PROTOCOL SATISFACTION

- The first time ever to apply this technique to get an actual and accurate reservoir fluid sample for regulatory and compliance purposes in San Joaquin Valley, California.
- Working proactively in managing regulatory requirements, with early engagement with the regulatory agencies to discuss the various fluid sampling techniques, as well as a well-defined and implemented strategy led to a successful acceptance of this methodology by the regulatory agencies.
- Wireline sampling method is demonstrated as a closed sampling system, in contrast to sampling monitoring wells, which are open to atmospheric/mixing influences, and therefore it is not effected by any of the conditions that purging is used to mitigate.
- Furthermore, TDS concentration do not change with additional purging.
- Regulatory agencies' approval of this technique led to their advocacy for its use in new wellbores that allow operators to characterize the reservoir for compliance.

# LESSONS LEARNED AND CONCLUSIONS

- Case Study 1
  - The operational risk for the tool getting stuck → run the tool on drill pipe
  - The lost circulation material (LCM) plugging the flowline caused high differential pressure and additional rig time → have a backup equalizing system.
  - Pre-job calibration for TDS concentration allowed the effective quantification of the contamination level.

- Case Study 2
  - Knowing the direct measurement characteristic of the analyzer → create a monitoring plan with mud salinity design.
  - Pre-job simulation: 2.8 hours needed for cleanup down to 5% contamination in two cases.
  - In real operation, the pump malfunctioned (due to the loose sand clogging the probe) →add 0.5 hour to fix the pump → pump returned to normal and back to the trend after 2.8 hours.
  - Unlike case study 1, risk of getting the tool stuck in hole is high.
  - Regulatory agencies' initial responses were not to accept wireline sampling as a valid sampling technique since it was an unconventional method.
  - Regulatory agencies have now not only accepted this formation water sampling technology, but also advocate for its use by other operators.

# CONCLUSIONS

- This paper highlights the applications of wireline sampling method as a reliable and cost-effective solution for a quantitative contamination level water sampling in a specific condition, slightly different where the groundwater sampling for monitoring wells guidelines are not applicable (deep and exploration wells).

- Through the key technologies used in sensors of wireline sampling tools, strategies can be developed to monitor contamination levels to achieve the representative formation water sample that satisfies the requirements of regulatory agencies allowing operators to have an alternative to comply to requirements at a low cost.