A practical approach used to plan and execute, quantify and qualify an effective well clean-up strategy

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SUMMARY

Bringing a new well on-line is an expensive proposition and the need to ensure optimal performance is critical. Saturation and contamination of the drilling fluid with fines and subsequent invasion of the formation has historically resulted in hundreds of hours per well of invisible lost time during the clean-up phase of the well. New technologies, workflows and methods that can reduce costs/turnaround on projects were conducted on a large multi-well project in Perth, Western Australia, to maximise well efficiencies.

Data from multiple sources were used to optimise and validate well clean-up operations with the aim to maximising production. This case study uses integration of well testing transient pressure data, Borehole Magnetic Resonance (BMR) derived transmissivity and flow logging to quantify success of clean-up/development of water wells, to reduce cost and optimise productivity.

This case study demonstrates the successful implementation of an integrated approach to well clean-up using several scales of permeability data from core to wireline BMR to well test. This case study demonstrates that, in this particular setting, the use of the presented methodology was cost effective, yielded positive confirmation of asset delivery, and has led to a 90% reduction in clean-up associated time.

Key words: BMR, hydrogeology, invisible lost time, drilling fluid, breaker, clean-up, development

INTRODUCTION

Groundwater is a major water source for Perth, Western Australia. With an increasing population and drying climate, additional pressure is being placed on Perth's groundwater sources. A solution to augment Perth's public supply involves injecting highly treated recycled water into confined aquifers to replenish the groundwater (Water Corporation, 2019).

After successful commissioning of the Stage 2 Groundwater Replenishment (GWR) Scheme, Water Corporation will effectively double the size of the Scheme to have a recharge capability of ~28 GL/yr through eight large diameter wells, each designed to have a maximum yield of 15ML/d. The recycled water that is injected to the aquifers is sourced from treated wastewater which undergoes advanced water treatment: ultrafiltration, reverse osmosis and ultraviolet disinfection, to produce water that meets Australian standards for drinking water.

The drilling program for the large diameter injection and production wells is the largest and deepest undertaken by the Water Corporation, requiring a radical shift from the traditional water well delivery model, leveraging of oil and gas, and mining expertise, methodologies and innovative technologies to plan, drill and complete the wells. Extensive analysis has occurred at the injection sites including; geochemical characterisation, core plug analysis, clogging studies, surface and downhole geophysics and high rate aquifer pumping tests.

Context

The wells are classified by the water industry standards to be deep water large diameter wells. They are designed to access target zones at 1.4 km depth and to be wide enough to accommodate a large high rate submersible pump. The basic well construction consisted of:

- 14” DN350 Intermediate GRE (Glass Resin Epoxy) casing installed to 1000m inside a 20” (500 mm) hole
- 6” (DN155) Stainless Steel (SS316) production screens which are installed in a 12.25” (311 mm) hole and gravel packed with synthetic highly spherical proppant.

The completed wells are some of the highest yielding bores in the world, designed to produce/inject up to 15 ML/d or 95,000 bbl/d. across a gross interval of between 100 m to 400 m. This can be achieved due to the splendid nature of the aquifers which often exhibits multi-Darcy permeabilities.

Understanding and protecting the permeability of this fluvial facies is critical to the success of the project. Minimising damage to the formation is paramount to meeting the required injection/production rates. Clogging of pore throats caused by poorly designed drilling fluid systems and damage during clean-up can have an impact on the subsequent energy use such large recharge rates require. For the injection wells, an increase in friction caused by a localised bridge-off (clogging events) can be irreversible and costly.

The Water Corporation has historically spent several hundreds of hours per well, performing well development operations to remove invaded filtrate and optimise productivity (Water Corporation, 2017). Much of this time has traditionally been perceived to be a necessary part of the asset acquisition process. “It will take as long as it takes” is a typical mantra used during this stage of delivery.

Prior to detailed design, post-mortem analysis of previous standalone wells identified improvement opportunities for the design team to focus on (Water Corporation, 2017). One of these opportunities was the drilling fluids design and well clean up compatibility/optimisation. In one instance, a well 700m deep took three months to clean-up (several hundred hours of combined pumping time). This was not a standalone anomaly, durations of several hundred hours for clean-up has been the norm. It became evident that much of the time taken to clean the wells the was due to one or more production impairment mechanisms.

Drilling fluids practices within the water well industry have historically been focussed on the short-term objectives of wellbore stability with little regard to production impairment. This practice is driven by commercial sensitivities; contractors have little incentive to decrease damage from drilling, furthermore, this behaviour is reinforced by a reduction of time spent on well clean-up operations incurring additional profit loss at the back end of delivery. Driven by commercial sensitivities, this behaviour can cause a restriction of information and has often resulted in a divergence between objectives of the operator and objectives for the drilling fluid company / drilling company.

Responsibility lies with both parties in recognising that in addition to achieving operational success, the need to protect the reservoir from permanent impairment is paramount. Major attention in the detailed design phase was spent collaboratively ensuing that any production impairment effects were reversible.

Key to the life of the well is the clean-up phase post-completion. A well with minimal skin damage would reduce the assets operational costs by optimising productivity (reducing friction) at the sand face.

METHOD

Production Impairment / Formation Damage and Recovery

Aquifer formation damage is caused by one or more of the following production impairment mechanisms occurring:

1. Invasion of the aquifer by fines-laden drilling fluid during the drilling process. The introduction of fines is unavoidable;
2. Residual filter cake (mud cake) often left on the borehole wall

Well development is the process in which the near-bore of the well is cleaned up. This process is intended to remove the impairment from the drilling process (points 1 and 2 above). However, acceptance criteria for clean-up / development have traditionally not been defined, instead determined by the behaviour of the well as it is pumped. Historically development stops when fines have been eliminated from the produced water and pressure response of the well has stabilised. This sometimes-over-zealous approach delivers a well that can have skin damage as the fines are dragged through the rock, stopping when bridge-off of the pore-throats has occurred.

3. Over pumping the well enough to generate substantial fluid drag forces, mobilising large fines that are likely to reduce permeability near the wellbore (Geilikman et al., 2005)

Aquifer Drilling Fluid Design

The drilling fluid should not have an impact on the aquifer’s production / injection potential. A separate aquifer specific drilling fluid was utilised to reduce any contamination from the previous drilled section. To facilitate the clean-up operation the design team focussed on designing a bridging and breaker drilling fluid package, with the intent to not only protect the aquifer, but to also facilitate a smooth clean up with less reliance on high lift off pressures to remove the filter cake.

Oil-field ‘drill-in’ methodologies use a drilling fluid design that allows a specific damage mechanism via a reversible process, to initially protect the aquifer then allow for maximum allowable permeability regain. That is, the wells are deliberately ‘damaged’ with materials which can be removable.

The aquifer drilling fluid system was designed to meet three objectives:
1. A bridging package would minimise formation damage thereby maximising well productivity;
2. Optimising hole stability to ensure fully gravel packed wells; and,
3. Designed to be broken down; required to be acid soluble

The final drilling fluids package selection was backed up by laboratory tests. Core was used to help characterise the aquifer’s mineralogy and placed in specially designed test rigs during dynamic flow loop tests, to verify drilling fluid/breaker suitability and compatibility with the aquifers and completion materials. One key aspect was the design and optimisation of an integrated breaker required to dissolve the sized calcium carbonate, starches and polymers whilst remaining compatible with stainless steel screens.

Clean-Up Philosophy

Step rate bean-up produces large transient gradient of pressure increases that can generate substantial fluid drag forces, mobilising large fines that are likely to reduce permeability near the wellbore. Geilikman et al. (2005) using laboratory flow tests, quantified additional formation damage or skin induced by flow velocity to conclude bean-up skin is more sensitive to a higher drawdown than a shorter total bean-up time. Hence, continuous bean-up is less adverse to bean-up inflicted skin compared to step-wise bean-up.

Development Acceptance Criteria

The quantification of permeability from the BMR log formed the basis of the clean-up strategy in the wells, determining the optimal completion required to achieve the critical interstitial velocity and minimum allowable sand face drawdown. Historically porosity and permeability in the oil and gas industry was obtained from the interpretation of wireline logs, where formation assumptions were often required to be made. Wireline logging measurements range from the very basic to advanced techniques. Both Gamma ray and resistivity have been the mainstay of hydrogeology logging, with density often not used due to concern of loss of tool downhole. For a better understanding of the hydraulic properties, a nuclear magnetic resonance log can be used to quantify a porosity and permeability profile.

Nuclear magnetic resonance is a well-known measurement procedure and used in medical, chemical, and oil and gas industries and has been described elsewhere (Kleinberg, 2001; Neville and Hopper, 2017). The measurement is only sensitive to hydrogen in fluid form and as such makes a valuable technique to measure fluids contained in pore spaces. As such the oil and gas industry has been using it since the 1970's to aid the resource estimation. The use of BMR in hydrogeological characterisation is increasing, as recently the tool size (length and diameter) has been significantly reduced in order to be run in water bores (Hopper et al., 2017). BMR provides continuous measurements of hydrogeological properties at a scale intermediate between core and well test data, providing a convenient framework for integration of all data. It also allows for the zoning of logs to get a more accurate value across the aquifer. Results of the BMR log are total porosity (lithology independent), specific yield, specific retention and permeability / hydraulic conductivities.

The main output of the BMR log is a T2 distribution that can be used as a pore size distribution. This T2 distribution can then be used to determine a permeability log either using global averages or localised calibrated values. Using the permeability log, further analysis can be undertaken to calculate a hydraulic conductivity assuming a fluid density and viscosity. While this gives valuable information on the hydraulic conductivity at each depth, an integrated transmissivity curve over the depth of the log was also calculated. Its use allowed the user to subtract a bottom and top integrated transmissivity to give a direct measure of transmissivity for the zone of interest. Thus, allowing for the determination of the expected performance of the well post completion. See Figure 1 for an example log from one of the bores. Track 2 shows the natural Gamma log, track 3 shows the T2 Distribution which gives a pore size distribution. This is used to perform a textural analysis (track 4). The T2 distribution can also be used to determine specific retention (track 5) and specific yield (track 6). The hydraulic conductivity (track 7) is determined and an integrated Transmissivity for the logged section (track 8).

Furthermore, the initial evaluation of aquifer productivity with BMR derived transmissivities provides accurate baseline for well productivity, allowing quantification of success of the completion by comparing flow logging and well testing analysis with the initial BMR aquifer evaluation.

BMR yields a unique definition of aquifer characterisation used to refine non-unique solutions generated during well testing. This method provides a simpler solution than probabilistic modelling might.

Whilst well testing is still required for long term production evaluation for identifying any boundary conditions, the use of pressure transient data during clean-up provides further tools to define potential production zone impairment by providing estimates of skin as well as near-wellbore transmissivity against BMR transmissivity estimates.

CONCLUSIONS

The Water Corporation has historically spent several hundreds of hours per well, performing clean-up operations. Based on the work presented in this paper, much of this time has been identified and classified as Invisible lost time.

This Case Study demonstrates that using integrated technologies and innovations, interdisciplinary workflows and methods within this paper can;

1. Reduce costs/turnaround on projects (in this case >90% reduction in clean-up time); and
2. Identify and increase potential productivity of aquifer.

The practical approach used:

- A novel Drilling fluid designed to protect near-well bore and stress-cage of the well during the drilling process;
- Design of an acid soluble drilling fluid system which could be broken down and pumped out during well development; and
- Development of acceptance criteria to verify a clean well. The comparison of flow logging and cumulative BMR derived transmissivity allowed;
    1. Verification of synthetic against actual, therefore quantifying clean up performance; and,
    2. Identification of impaired production zones for further targeted clean–up where deviation of two sets of the data occurs.

This approach can be scaled as necessary.

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REFERENCES

Hopper T.A.J, Trofimczrk K. K., Birt B.J., 2017, Development of a Slimhoe Downhole Nuclear Magnetic Resonance Tool for Iron Ore – Some Applications and Limitations, Iron Ore 2017 Conference, Paper 059.

Kleinberg R.L., 2001, NMR Well Logging at Schlumberger. Concepts in Magnetic Resonance, Vol 13(b), 396-403

Water Corporation, 2019, Groundwater Replenishment, Brochure. (https://www.watercorporation.com.au/-/media/files/residential/water-supply/gwrt/gwr%20brochure_february%202019.pdf)

Water Corporation, 2017, GWR Concept Design File Note – Drilling Fluid and Development

Geilikman et al., 2005, Bean-up Guidelines for Sand Control Completions M. B. Geilikman, SPE, D. E. Dria, SPE, D. R.

Stewart, Shell International EandP, Inc., and G. K. Wong, SPE, Shell EandP Company.

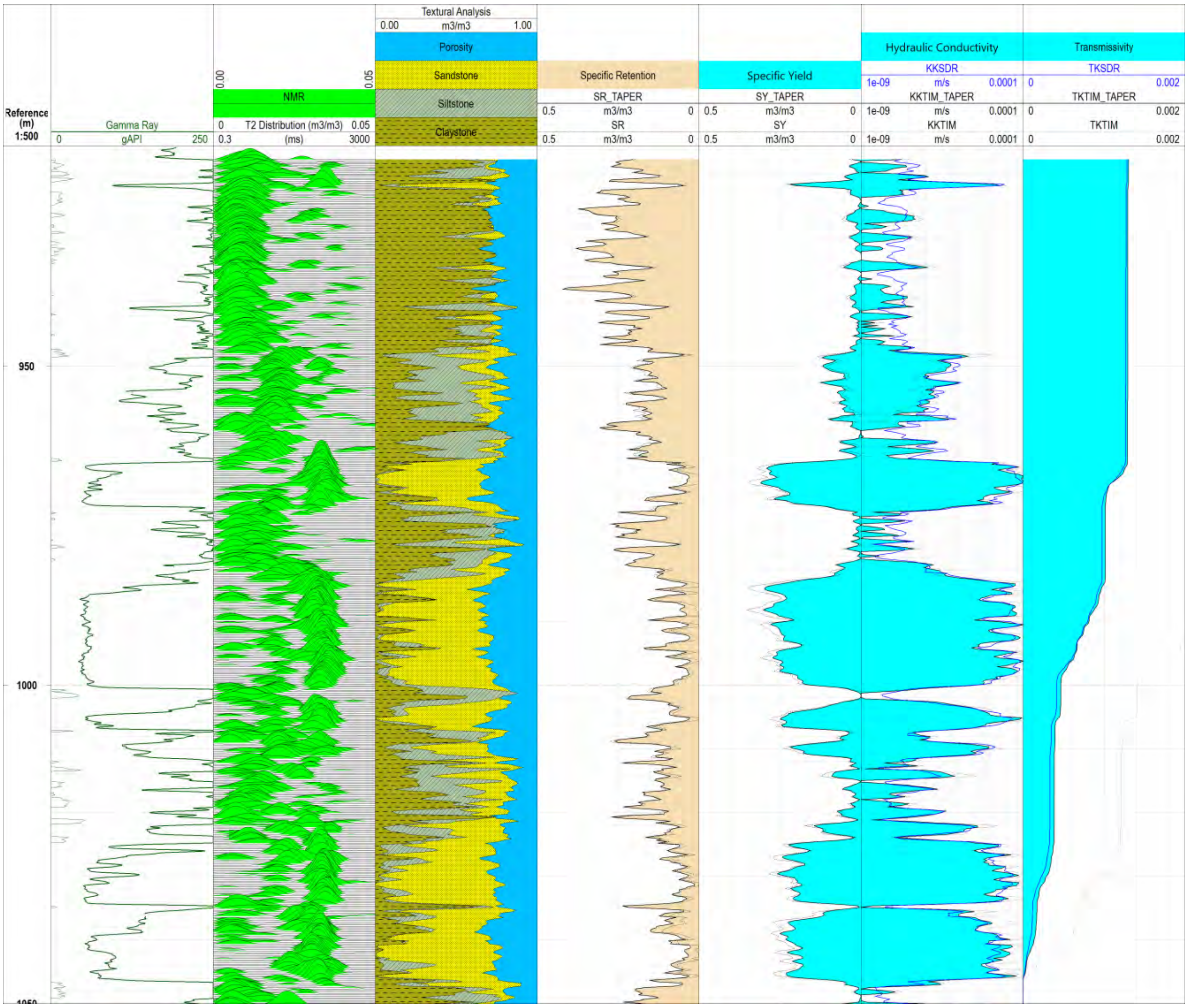

Figure 1: Example BMR wireline log from one of the wells. Track 2 shows the natural Gamma log, track 3 shows the T2 Distribution which gives a pore size distribution. This is used to perform a textural analysis (track 4). The T2 distribution can also be used to determine specific retention (track 5) and specific yield (track 6). The hydraulic conductivity (track 7) is determined and an integrated Transmissivity for the logged section (track 8).