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Learnings from High Rate Water Injection in Deep-Water Slope Channel Complex and Frontal Splay Turbidite Reservoirs, Offshore Ghana*

Sekhar Sathyamoorthy[1], Bryan T. Cronin[1], and Elizabeth M. Loudon[1]

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[1]Tullow Ghana Limited, Accra, Ghana (sekhar.sathyamoorthy@tullowoil.com)

Abstract

Fractured injection is important to ensure high rates are delivered to sustain prolific oil producer wells in deep-water fields. Geology plays an important role in how these water injector wells perform and behave. Different injection strategies and well designs are required to sustain field performance, depending on the depositional setting and reservoir body geometry and fabric.

Learnings from Ghana show that injectivity decline may not always be caused by impairment but rather should be expected when injecting at high rates into a ‘narrow’ slope channel complex reservoir, with multiple reservoir body elements, laterally bounding intra-shale intervals, and a thick, but internally rheologically variable cap rock.

This paper adds to the limited information currently available in public domain literature regarding water injection performance and behavior under fractured conditions in different consolidated deep-water turbidite reservoirs.

Development Overview

First oil production from deep-water turbidite reservoirs offshore Ghana commenced in 2010 with Jubilee, followed by TEN in 2016. These fields are located in West Cape Three Point and Deepwater Tano licenses, some 130 km southwest of the port city of Takoradi, Ghana – Figure 1.

Total instantaneous oil production to date is ca. 170,000 stb/d from two turret moored FPSOs. Infill drilling commenced in February 2018 after a ca. 2-year halt on drilling activity. Significant reserves remain in TEN and Jubilee. Water injection performance is key in maintaining reservoir pressure and providing efficient sweep of oil towards producers. Thereby, maximizing oil recovery in the fields.

Turbidite Reservoirs Offshore Ghana

Jubilee accumulations comprises a complex system of Upper Cretaceous to Lower Campanian marine slope turbidites. The reservoirs are a 'flared' turbidite system comprises erosionally-confined channel systems in the proximal part, which broaden out down-slope into less confined, splay-dominated deposits containing the majority of the thicker, well connected and high-quality reservoir sands.

TEN accumulations comprise a complex system of Upper Cretaceous continental slope stacked turbidites. The main reservoir to the west has a long and narrow sinuous character associated with turbidite channels. Stratigraphically younger second reservoir lies to the east of the main reservoir with broad, splaying, down-dip geometries. The conceptual geology model representing TEN reservoirs are illustrated in Figure 2.

Oil production and water injection in both fields are primarily from sand facies associated with Clustered Frontal Splays and Confined Channel Complex.

Water Injector Performance

Typical water injection performance in splay dominated geology – Figure 3:
- High rates exceeding 20,000 b/d
- Sustained injectivity at fairly stable injection pressure
- Injection maintained below shale fracture limit (to avoid breach of shale cap or reservoir management issues)

Typical water injection performance in channel complex geology – Figure 4:
- Rapid increase in injection pressure, reaching shale fracture limit
- Reduced water injection rates over time when operating at shale fracture limit
- Rates increase after a period of shut-in, then decline again to a low rate
- Indication of high-pressure build-up around the well from shut-in data, despite high depletion at producer well

Reduced injection rates are often associated with skin or impairment in the well. Improving injectivity requires some form of stimulation or fracturing of the formation. However, experiences in Ghana have shown that geology plays a very important role in injector performance. Injectivity declines can occur despite fracturing of formation rock and stimulation will have no impact on its performance.

Key Learnings

Tackling water injection challenges in Ghana required a multi-discipline effort. Both internal and external experts on various subject matter contributed to the improved understanding and improvement plans.

Several key learnings to date from the Ghana experience are outlined below:
- Expect lower sustained well rates in multi-stacked channel complex geology
- IBHP trend is heavily influenced by reservoir geometry and heterogeneity

- Fractures could be present despite reducing injectivity
- Skin was found to be not a good indicator of well performance especially when injection is under fracturing conditions
- Injector under-performance not remediated by back-flushes
- Risks of exceeding IBHP Limit:
    - Loss of zonal isolation over time
    - Increased pressures in sand stringers between reservoir and cap rock with impact on future drilling and well designs

Key recommendations proposed by the integrated study team:

- Revise well designs to target multiple sand lobes and increase net sand penetrated
- Test impact of injection at high pressure via field trials before full field implementation
- Start early on improving geo-mechanical understanding for new projects

Conclusions

1. High rate fractured injection required to sustain prolific oil producer wells in deep-water turbidites reservoirs.

2. Geology plays an important role in how the water injector well performs:
    - It is more challenging to inject in multi-stacked channel complex geology, especially when channels are narrow with multiple sand packages
    - Lower injection rates do not mean impairment!

3. Multi-discipline effort required to tackle water injection challenges:
    - Early information of geo-mechanics and fracture propagation helps with selecting optimum injector well design and injection philosophy
    - Implement high injection pressure in stages, starting with field trials
    - Highly deviated well design expected to significantly improve injectivity
    - Use of smart completions proven extremely useful

4. Experiences offshore Ghana provides an analogue for water injection in multi-stacked channel complex geology

Figure 1. Tullow Ghana operations and location of Jubilee and TEN fields.

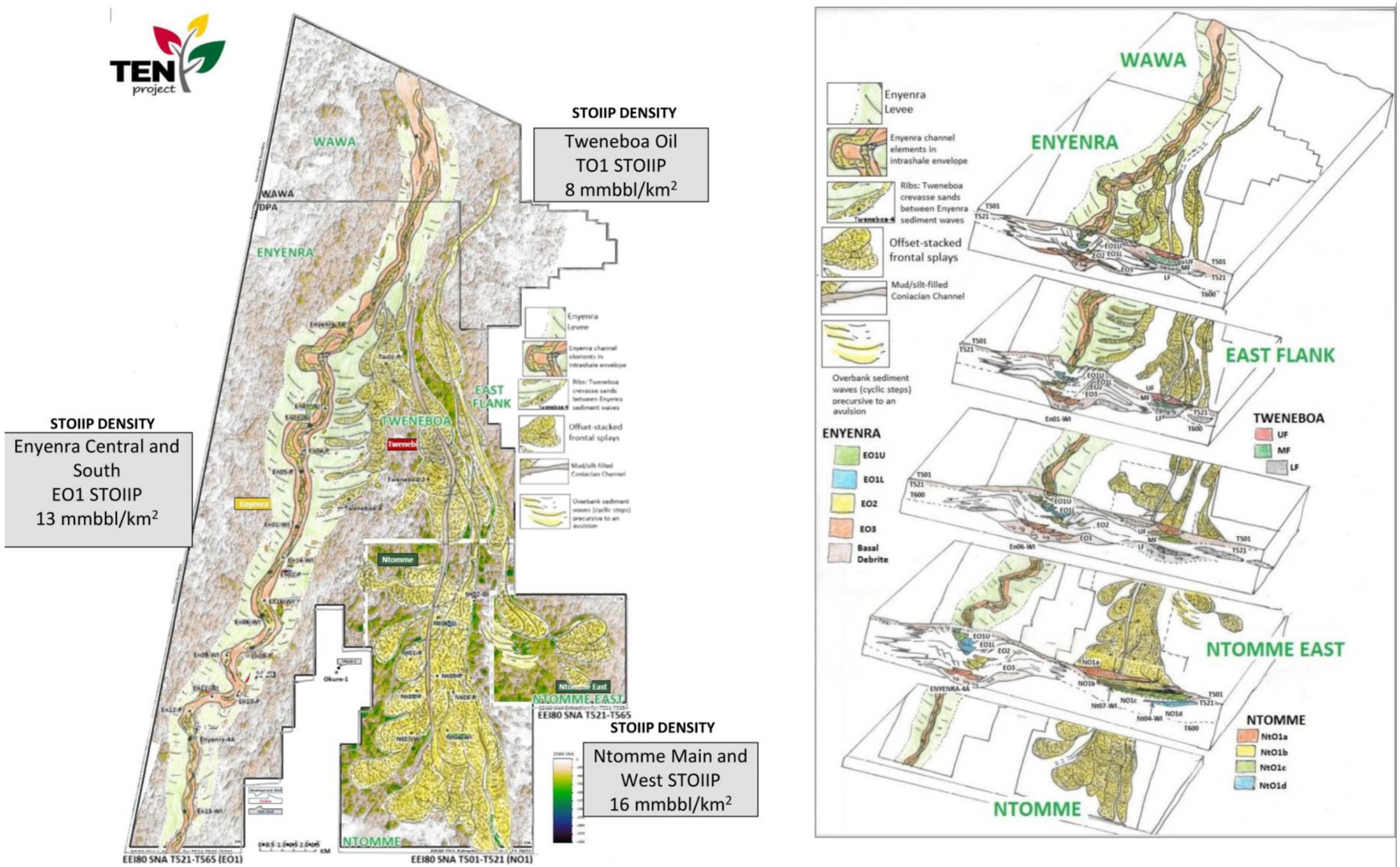

Figure 2. Conceptual geology model for TEN fields.

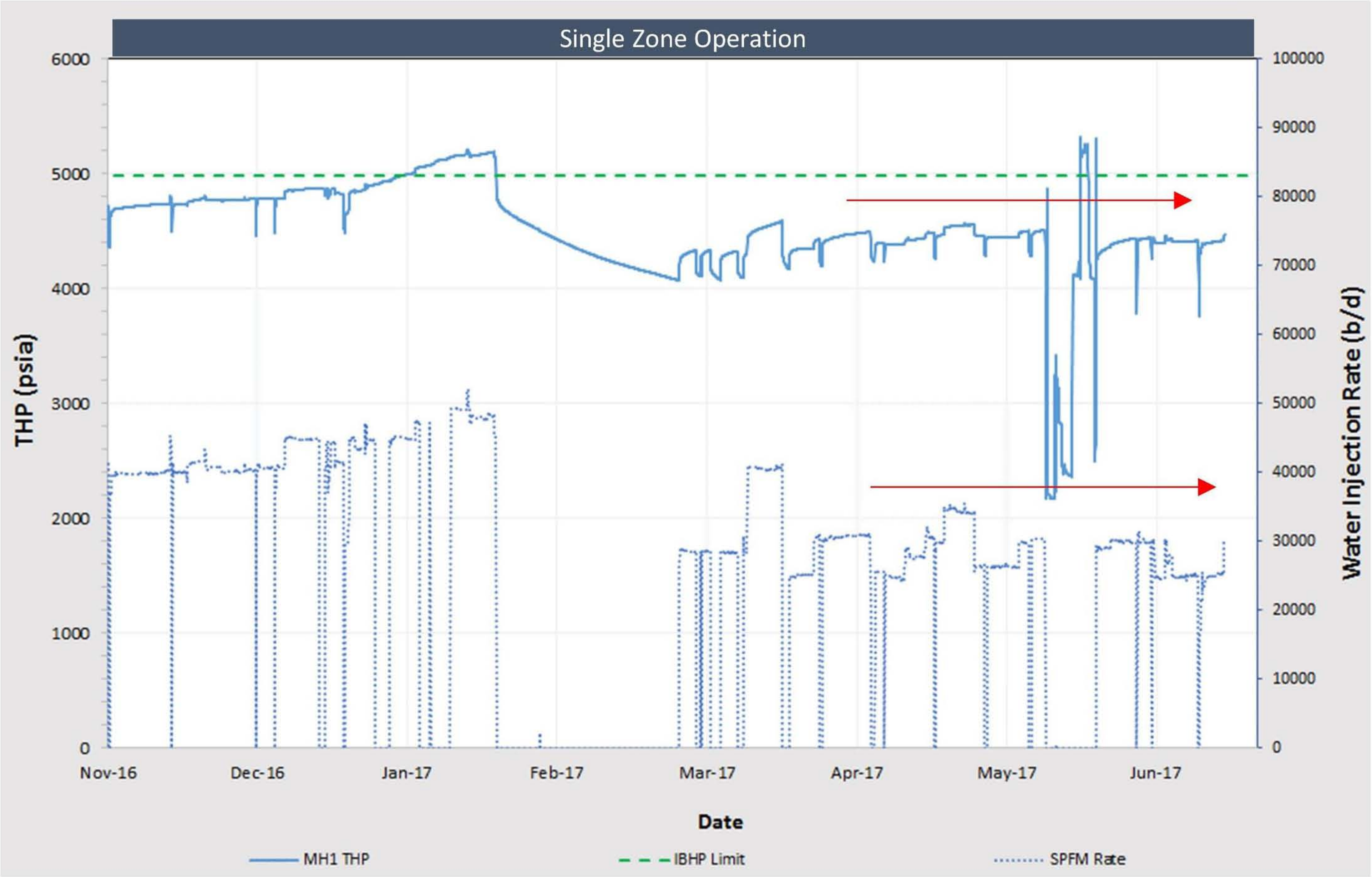

Figure 3. Typical water injector performance in splay dominated geology.

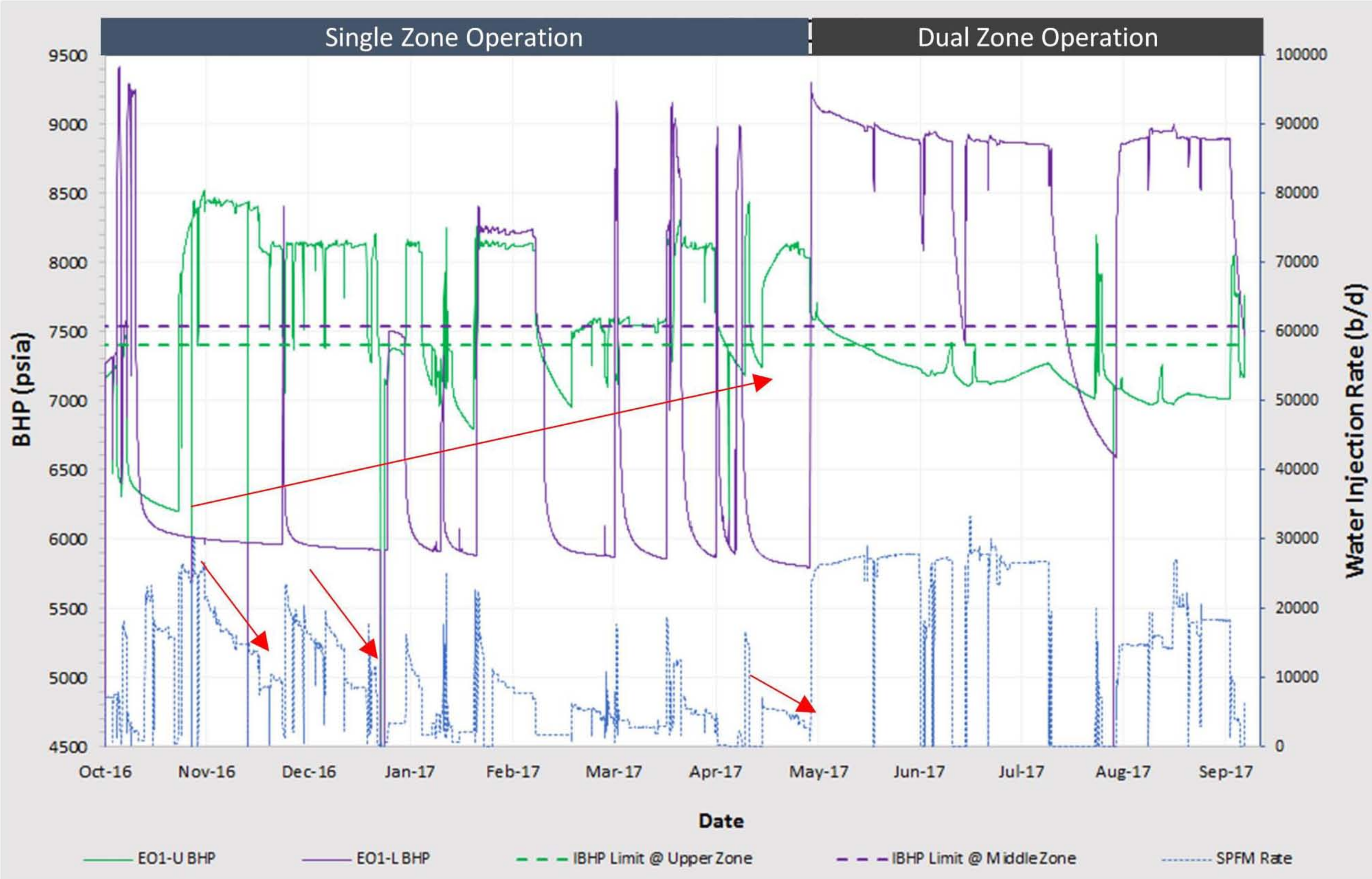

Figure 4. Typical water injector performance in channel complex geology.