Performance Evaluation of Polycrystalline Diamond Cutter (PDC) Bits Used in the Production Interval of Well AW-01 in the Akiira Ranch Field, East African Rift Valley, Central Kenya

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ABSTRACT

Inherent to geothermal drilling are many challenges, which might be distinct from traditional oil and gas drilling. These include harder rock formations, total losses, high temperature, and, typically, a limited budget. These downhole conditions and monetary differences have led to drilling geothermal wells with 'fit for purpose' equipment and technology chosen to perform best under these conditions and constraints. One of the most important pieces of drilling equipment is the drill bit: up until recently the tricone bit (also called roller cone) had been the only choice in bits, for the vast majority of geothermal wells. However, as evidenced by the results of the first Akiira Geothermal LLC ("AGL" or "Akiira") exploration well, PDC bits have some advantages over the tricone bits in specific applications, and this widely available technology is worth consideration in geothermal environments.

The aim of this paper is to compare the performance of both PDC and tri-cone bits used while drilling the production interval of vertical exploration well AW-01, in the Akiira Ranch Field, East African Rift Valley, Central Kenya. Also, and as part of the technical analysis carried out, this paper highlights specific drilling parameters and values related to each bit used, such as footage drilled, drilling time and the average rate of penetration (ROP).

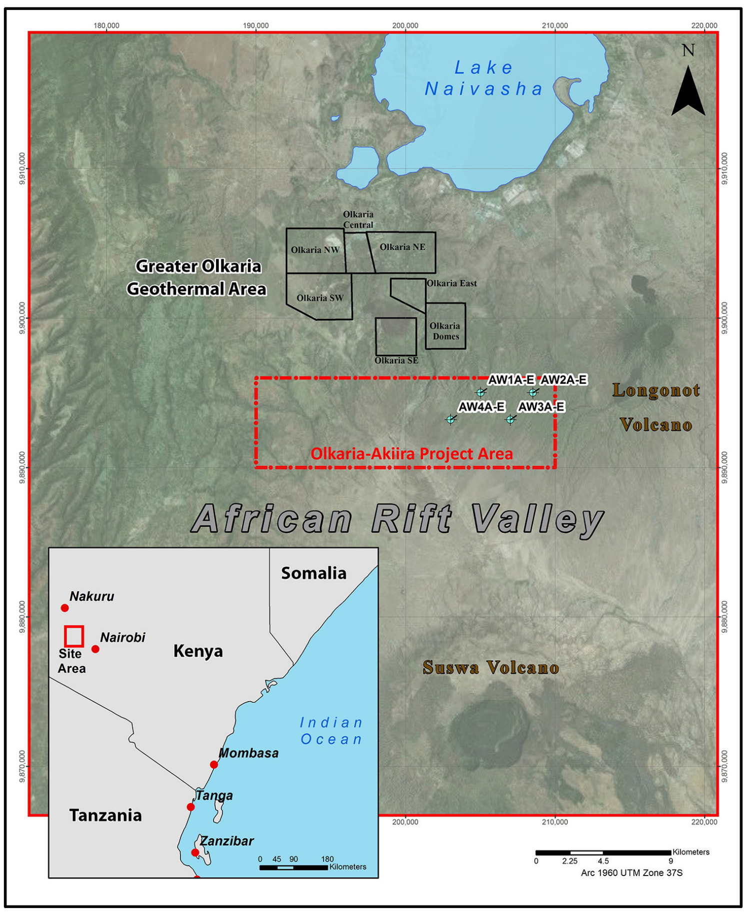

Figure 1. Site Map.

Background

Worldwide, the drilling of geothermal wells is on the rise, and bit selection is an important aspect of the well design which will save drilling time and money if the most appropriate bit for a particular geological formation is selected. For geothermal projects, historically, drilling has been done almost exclusively with tricone bits, using both milled tooth (steel tooth), and tungsten carbide insert (TCI) bits; one of the reasons for this 'status quo' is the purchase price of a PDC bit generally several times more expensive than an equivalent rock bit. Also, PDC bits may sustain catastrophic failures when drilling abrasive formations. PDC bits have been around since the 1970s, and are designed to shear the rock, rather than crush it, which is how the tricone bit functions.

Regarding the project, Akiira Geothermal, LLC (AGL) proposed four deep, standard-diameter well locations in the northeaster portion of the Olkaria-Akiira prospect. These locations are shown on the site map in Figure 1, and were based primarily on the interpretation of shallow resistivity data and regional geology. The wells targeted the zone beneath a shallow low-resistivity anomaly that is interpreted to represent a zone of high temperature hydrothermal alteration. Location AW1A-E (henceforth AW-01) was the first well drilled and was planned to be drilled vertically to a depth of 9,842 ft (3,000 m) but was slightly shortened to a depth of 9,440 ft (2,877 m). The well was spudded on August 3rd, 2015 at 19:00 hours, utilizing the services of KenGen Rig #1, and the rig was released at 20:00 hours, September 24, 2015.

Drilling Operations at AW-01

The Akiira drilling operations on well AW-01 took 47 days in total. In terms of time, this was the shortest geothermal well drilled in Kenya, a fact which can partially be attributed to the use of PDC bits.

During the drilling of the reservoir section of well AW-01, the use of PDC and TCI bits were alternated, due to delays in the delivery of PDC bits to the rig site. This resulted in the opportunity to observe the effects of lithology and other drilling parameters on bit performance. Figure 2 shows the visual differences between PDC, TCI, and milled tooth bits (left to right), in surface and profile views.

The 20" conductor pipe was set at 181 ft (60 m), the 13 3/8" surface pipe was set at 979 ft (298 m) and the 9 5/8" production casing was set at 3,924 ft (1,196 m) and cemented to surface. The well was drilled to a total depth of 9,440 ft (2,877 m) with a 7" slotted liner set at 9,430 ft (2,874 m) as shown in Figure 3.

Figure 2. Rotary Bit Styles.

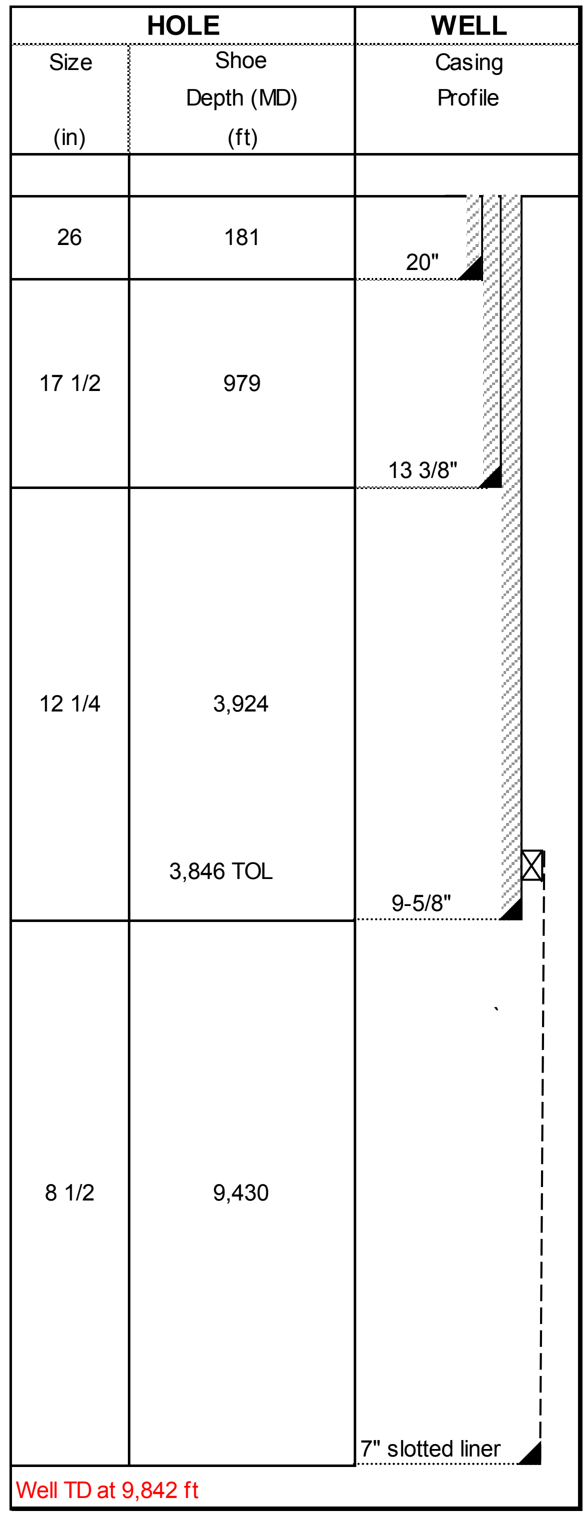

Figure 3. Well Schematic.

Bit Performance

The ROP log from the 8 ½" production interval is shown in Figure 4 with each bit interval identified showing a different color footage. This is presented together with the general downhole lithology encountered, and a partial caliper log, to illustrate the occurrence of junctures in critical features.

The first bit used to drill the production interval (after drilling out the shoe track) was the fifth bit for the well. Figure 5a shows the PDC bit (King Dream, Chinese made, model GW506O-1) provided by the drilling contractor, with an aggressive 6-blade design which drilled for 36 hours, and made an impressive 2,567 feet of new hole in just one run. This PDC showed a high ROP of 115.3 ft/h, which dropped subsequently to 88.4 ft/h and then to 70.3 ft/hr for an average overall ROP of 71.3 ft/hr. Figure 4 shows a spike in ROP at 4,700 ft MD, which coincides with a fractured basalt layer, and lower ROP was recorded at both 5,100 and 5,700 ft MD where two thin rhyolite beds were logged (10 – 30 ft thickness). Prior to pulling out the bit, the well transitioned to a new lithology, shifting from a massive trachyte unit to interbedded rhyolite with welded ash tuff, which corresponds with the ROP dropping to 4 ft/hr. This sudden drop was a good indication that the bit may have been at the end of its life and in fact it came out severely worn out (8–5-BT-N) as shown in Figure 5b.

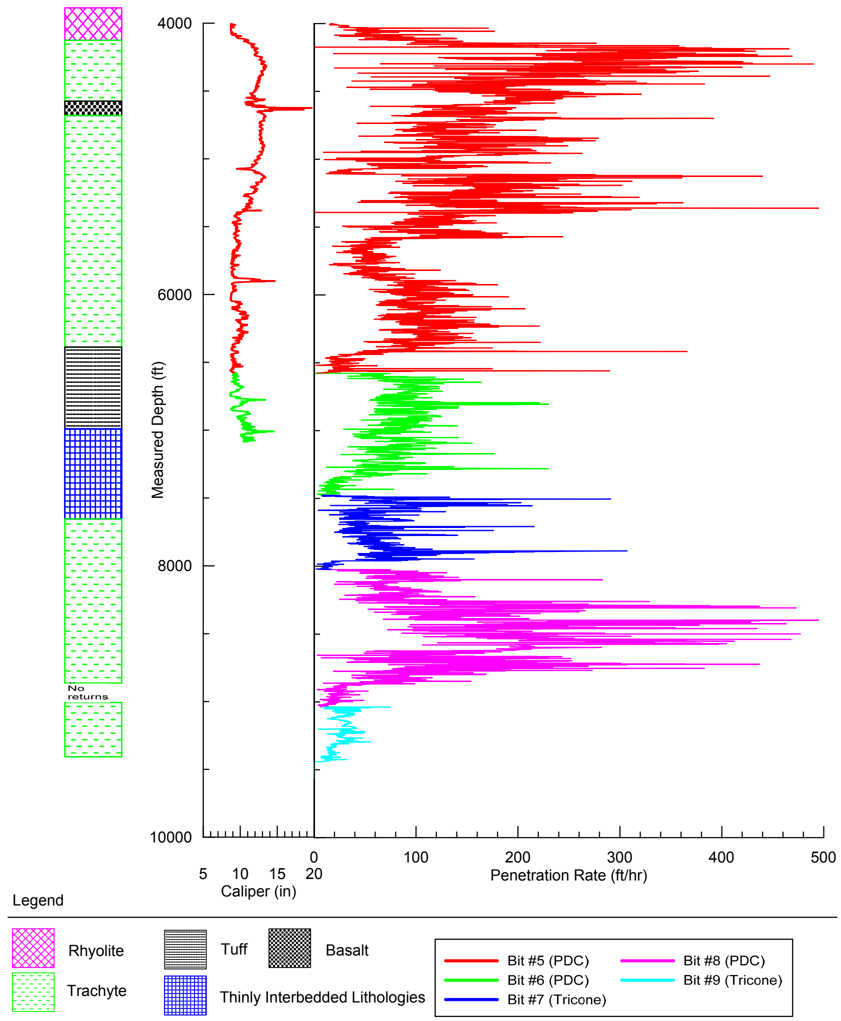

Figure 4. ROP and GEO.

Bit #6, again a PDC (from National Oil Varco, or "NOV", model SKH813M – shown in Figure 5c) continued to drill through a hard welded tuff unit, layered with some rhyolite, and few basalt flow deposits. This was an 8-bladed bit, and due to the noted changes in lithology, and the fact that the well is the first exploration well in the field, a slower ROP was recommended to better identify subsurface hydrothermal alteration. The bit started out with an average ROP of 61.8 ft/hr, slowly decreasing to 50.4 and 44.2 ft/hr, concluding just before being pulled out of hole at 5.2 ft/hr for an overall average ROP of 25.3 ft/hr. Bit #6 completed 899 feet of new hole in two runs for a total of 35.5 drilling hours and a bit

Figure 5a. Bit #5 Unused.

Figure 5b. Bit #5 Used.

Figure 5c. Bit #6 Unused.

Figure 5d. Bit #7 Used.

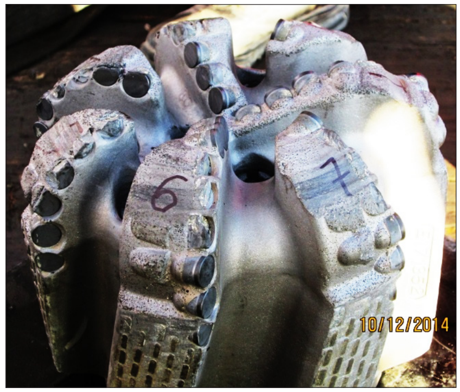

Figure 5e. Bit #8 Used.

Figure 5f. Bit #9 Used.

dull grading of 3-4-CT-S. It can be said that the differences in performances observed between bits #5 and #6 can very likely be attributed to the changes in lithology, as well as to the make and manufacturer of the PDC bits.

Bit #7 was a TCI tricone bit (REED, model TD61AKPR) that drilled 548 feet in 15.5 hours with an overall average ROP of 35.4 ft/hr. The lithology in the interval drilled, is composed of several thinly interbedded volcanic deposits, and an inferred felsic intrusive body. The major rock type is trachyte, with significant presence of volcaniclastics deposits, crystal ash tuff, rhyolite flows, felsic intrusions, and massive welded tuff. This alternating sequence completely wore down the bit, which had become locked, as evident by uneven wear shown in Figure 5d. The performance of this bit, is attributed to the hard lithology and secondary mineral alteration observed in tuff deposits and in relation to the intrusive felsic bodies.

Bit #8 was another PDC from NOV (the 7-bladed Hycalog, model FT713) which drilled 1,012 feet of new hole in 20.4 hr, starting with a high initial ROP of 110.3 ft/hr, which quickly decreased, for an overall average ROP for the section of 49.6 ft/hr. Figure 5e shows wear on this PDC bit which resulted in missing cutters on most of the blades.

Bit #9 was a TCI tricone bit (Baker, model VM-30DVHX) which drilled 405 ft in 20.5 hours with an average ROP of 19.8 ft/hr. During this bit run there was significant time spent reaming the hole, and when the bit came out of the well, the back row of tungsten carbide insert buttons had been broken off (bit dull grading 3-8-CT-G), as can be seen in Figure 5f.

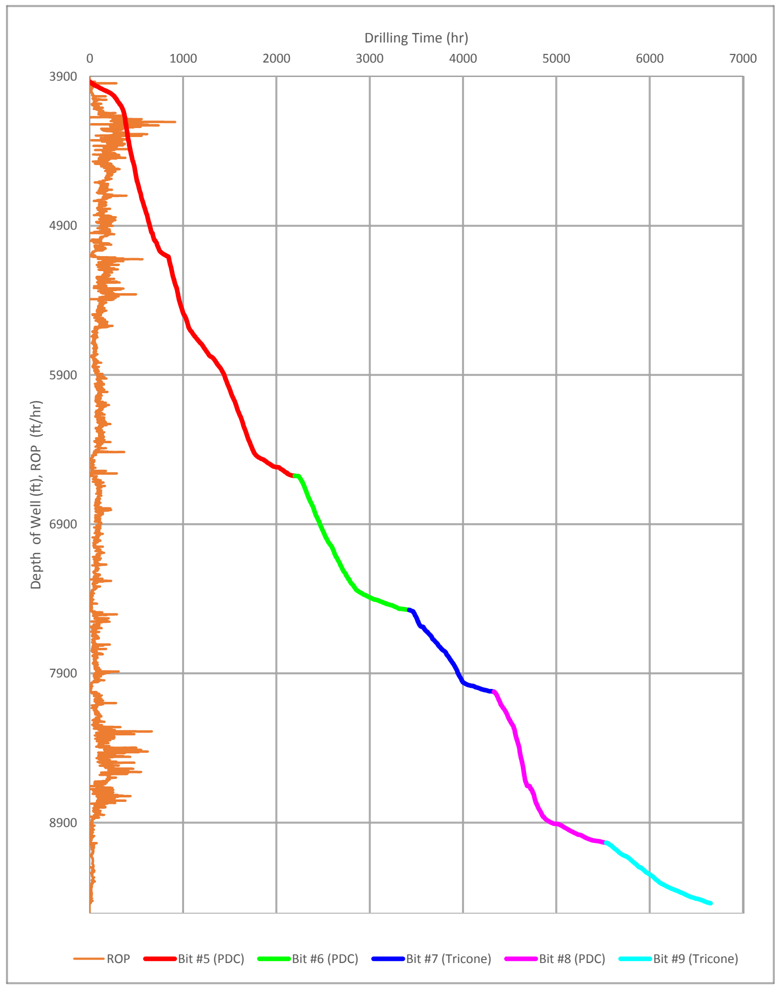

Figure 6. Drilling Time and ROP.

Bit Performance Analysis

The length of time spent drilling by each bit is shown in Figure 6: a steeper angle indicates higher ROP, and gentler slope shows a lower ROP: the ROP recorded for each bit is shown in orange along the left side of the figure. As also illustrated in Table 1 the PDC bits generally outclassed tricone bits in terms of footage drilled and ROP achieved. Additionally, in terms of bit dull grading, PDC bits out-performed and outlasted the tricone bits used to drill the production interval in well AW-01.

Table 1. PDC and tricone bits runs summary.

Bit No.	Size (inch)	Bit Type	Drilling Time (hours)	MD in (ft)	MD Out (ft)	Footage	Average ROP	WOB (Klbs)	RPM	BHA
5	8.5	PDC	36	4,009	6,576	2,567	71.3	20	50	Motor
6 [1]	8.5	PDC	35.5	6,576	7,475	899	25.3	20 - 25	210	Motor
7	8.5	Tricone	15.5	7,475	8,023	548	35.4	22	45	Motor
8	8.5	PDC	20.4	8,023	9,035	1,012	49.6	25	50	Motor
9	8.5	Tricone	20.5	9,035	9,440	405	19.8	25	40	Motor

[1] Bit number 6 completed two runs and these numbers are calculated from the sum of both runs

Table 2. PDC and tricone bits runs – Footage and drilling time.

Bit No.	Bit Type	Footage (ft)	Drill-ing Time (hours)
5	PDC	2,567	36
8	PDC	1,012	20.4
6	PDC	899	35.5
7	Tricone	548	15.5
9	Tricone	405	20.5

Another approach to measure bit performance is to compare the amount of new hole drilled by each bit. Table 2 presents the bits in descending order of footage drilled, and shows that the three PDC bits drilled significantly more footage per bit compared to the tricone bits. This is also evident in Figure 7 which shows a comparison of the bit performance in terms of ROP and drilling time.

New PDC Bit Technologies

Innovations in PDC design and technology have led to great advances in bit efficiency and greater longevity which is helping to economically expand the application of PDC bits to include geothermal wells. Conventional PDC cutters are flat on the surface and have a shearing effect on the rock. Advances in PDC cutters have swapped out the flat top and replaced it with conical points that increase the focus put on a rock's stress field, resulting in increased footage and ROP. Emphasis has also been put by the new generation of PDC bits on bit durability (i.e. resistance to abrasive formations), steerability (i.e. in directional wells applications) and to reduce vibrations and stick-slip while drilling. Additionally, rock heterogeneity (i.e. intercalation of hard and soft formations) can be drilled much more effectively by modern PDC bits compared to the first generation of PDC bits used in the drilling industry.

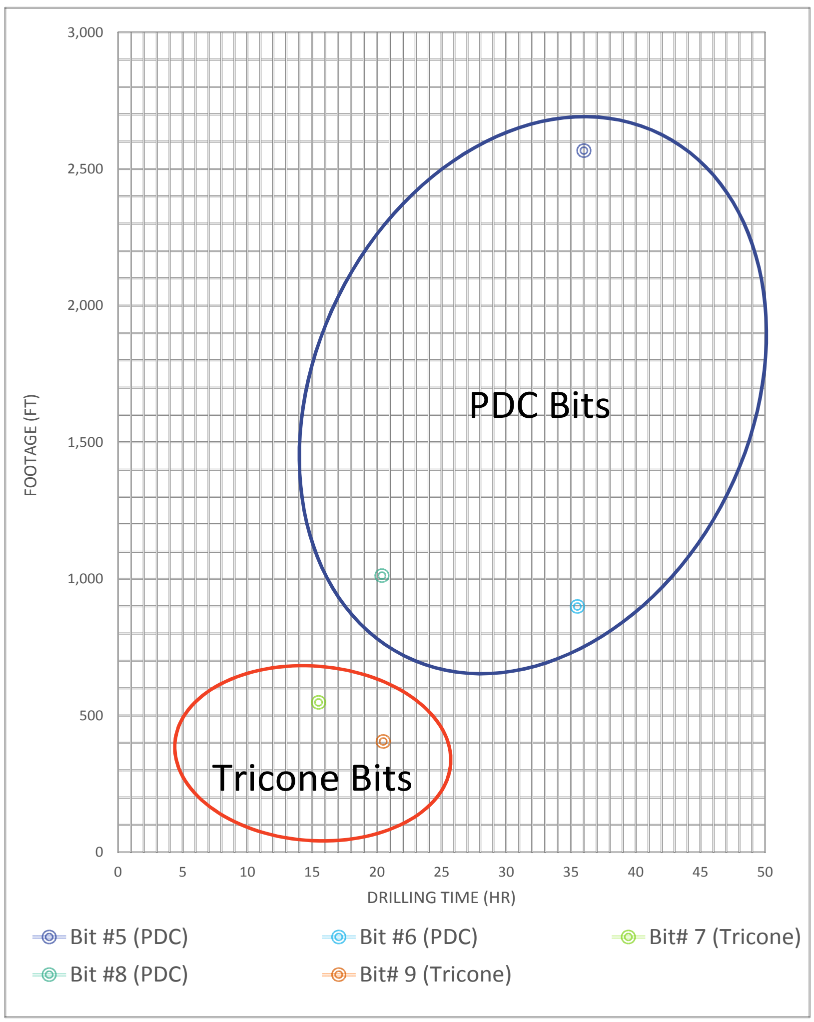

Figure 7. Bit Performance.

Drill Bit Economics

The upfront cost of PDC bits is more compared to TCI bits, which are more expensive than milled tooth bits. However, the value of each bit should be based on the bits' performance, and money saving abilities in the long run. To calculate the true cost of a drill bit, additional consideration must be given to the cost of an individual trip in and out of the well for a bit change, and the total footage of new hole made per bit together with spread-rate (or rig operating cost) of the drilling rig in use. Performance is measured in cost per foot, and a bit with high ROP, which drills more footage, can lower the daily expense of rig time by shortening the duration of drilling operations.

As shown in Figure 8, the 8 ½" section was started 10 days behind the planned 'time versus depth' curve and as a result of the excellent performance from the PDC bits used, the well reached TD two days ahead of the plan.

Conclusions

One of the main considerations for cost reduction while drilling, is to reduce the number of operating days. This can be attained keeping the bit on bottom drilling by using a bit which lasts for more footage, and has a high ROP. PDC bits have proven they are a viable means of accomplishing this goal, and in well AW-01 their use was a lead reason for the well having been completed on time and within the expected cost.

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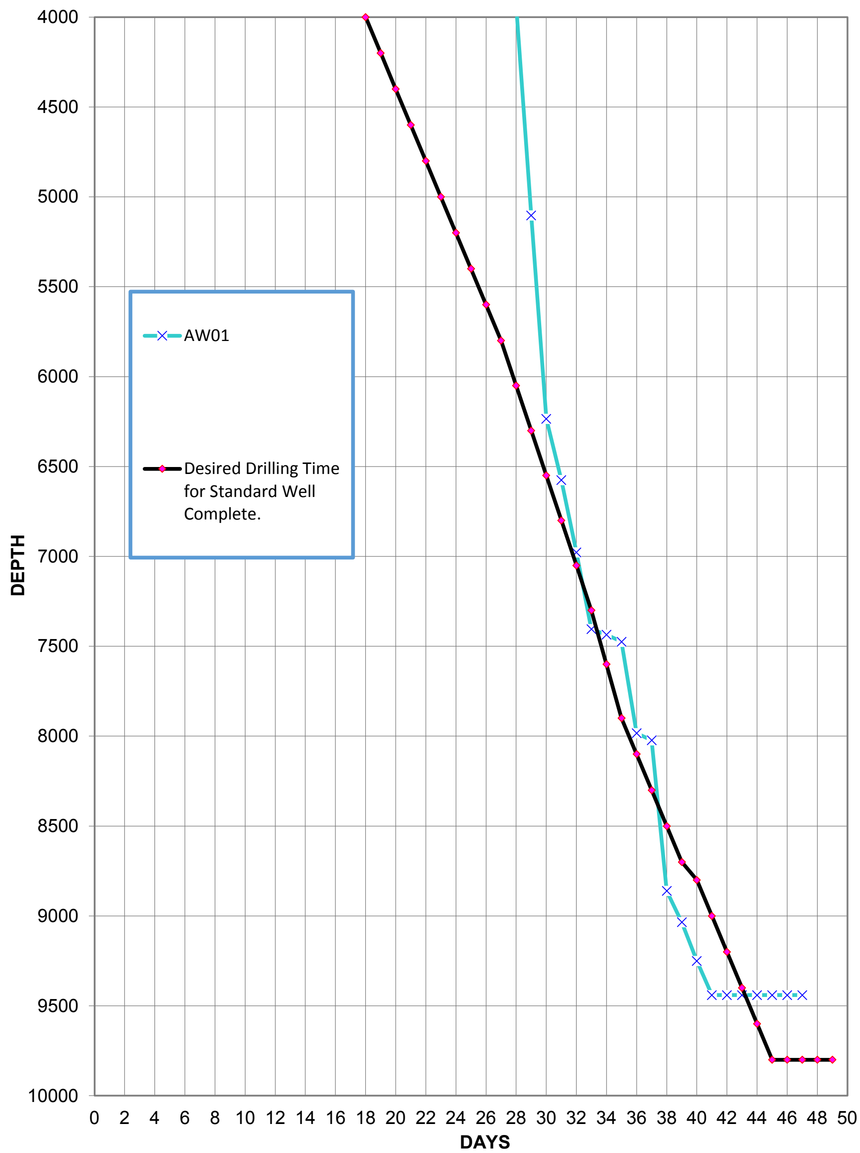

Figure 8. Planned vs Actual Drilling Time.