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Planning for Efficient Drilling Operations (A Case Study of Drilling well PW 03B)

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ABSTRACT

Deep geothermal drilling is a capital-intensive undertaking that entails a sequence of carefully coordinated interdependent activities with a goal to drill to the target depth within the scheduled time, cost and design. The various activities need to be coordinated in a flawless manner to minimize any disruptions to the drilling activities. This calls for proper overall planning before commencement of drilling and during the drilling operations. Poor planning leads to inefficient drilling due to waiting on materials, consumables, equipment and human resource which translates into non-productive time (NPT) and consequently escalated costs. Drilling in the Paka geothermal prospect commenced in the year 2018, and as of May 2025, nineteen wells had been drilled. Among them is Paka Well 03B (PW 03B) drilled between September and December, 2022 using one of the Geothermal Development Company (GDC)-owned rigs to a depth of 2,791m in 78 days against a set target of 3,000m and 80 days. A savings of 38% of the budget set aside for this well was also recorded. Timely provision of materials and consumables, use of the correct equipment and teamwork were some of the reasons contributing to successful completion ahead of the scheduled time, and with minimal non-productive time. This paper analyses the planning methodologies and tools that were employed while planning and drilling this well. Moreover, recommendations are given for better approaches in planning to achieve better drilling results in future.

1 INTRODUCTION

The word “planning” can be defined as the systematic way of organising and availing resources towards a set goal. Drilling on the other hand is defined as the art of making a hole with a target to reach a resource mostly water, geothermal fluids or other minerals. Its rewards and successes are gauged on the capability of drilling a useable hole at the lowest dollar per foot ($/ft) in vertical drilling, or at the highest equivalent barrel of oil per foot (bbl/ft) in horizontal or multilateral well drilling (Azar, 2007). Drilling is a vital activity in geothermal resource development, being the final stage of exploration where the resource is proven and involves planning and designing the well before drilling commences. It represents one of the most capital and time intensive stages of the project development, representing almost a fourth of the total field expenditure making efficiency very critical in determining the viability of a project. A successful drilling operation must integrate contributions from the geological sciences, logistics, engineering and human resource if the end result is timely project completion, safety, cost and overall project sustainability. In the drilling context, “planning” means listing, defining, scheduling, and budgeting for all the activities required in the drilling activity (Ngosi and Omwenga, 2015). Effective planning is, therefore, confirmation that all adequate resources are allocated and availed as needed, there are competent personnel to carry out the task, all equipment are ready and sound, and all risk management plans are in place. According to Devereux (1998), the success or failure of a well is heavily dependent on the quality of well planning prior to the spud in date.

In Kenya, the planning aspects include review of existing information on a field, detailed surface exploration, exploration drilling and well testing, appraisal drilling and well testing, feasibility studies, production drilling, powerplant design, environmental and social impact assessments, reservoir evaluation, power station construction and commissioning, reservoir management, and shutdown and abandonment (Mwangi, 2007). It is common practice to assume that problems may be encountered during the drilling of a well, and wells differ from one another even in the same region (Azar, 2007), but with proper planning, this can be minimized or eliminated. Poor planning result in Non-Productive Time (NPT) which consequently results in extended drilling

time and hence, cost overruns. While it is not possible to completely eliminate NPT, effort should be put to minimize it and lessen its impacts on the drilling time. Process improvement and adoption of new drilling practices are fundamental in taking care of the inefficiencies during the drilling operations (Okwiri, 2013).

Geothermal Development Company (GDC), a special purpose vehicle in Kenya mandated to avail 5000MW of electricity from geothermal resources in Kenya by 2030 has been in the drilling industry since 2009; the first stride towards real drilling made in 2011, in the Menengai geothermal prospect where it has drilled more than fifty (50) deep geothermal wells, then in the Baringo-Silali geothermal prospect where drilling is on-going. Advanced planning has also been made in readiness to drill in other geothermal prospects; for instance, in Suswa where geological studies have proven existence of a resource, drilling sites pegged and infrastructural works at an advanced stage prior to mobilization of the drilling rigs. As a result, it has accomplished and experienced personnel to map and carry out the drilling operations and boasts of its seven-owned deep drilling rigs and two coiled tubing units. Since the drilling of the first well, many lessons have been learnt resulting in improved drilling skills and spent resources.

During drilling, different challenges are encountered, some as a result of the geological formation, drilling technicalities, availability and application of drilling materials and skill and experience of the drilling crew. A review done by Shell Columbia indicated that the biggest cause of all drilling related issues and cost are directly related to the well instability which is caused sometimes by controllable and other times uncontrollable reasons (Bashir, etal., 2021). Direct indicators of challenges during the drilling operation are among others under gauge holes, increase in the cement required for casing operations or plugging and excess cuttings, while indirect ones are stuck pipe, drilling string failure and excessive doglegs. Characterization and optimization of the drilling fluid are identified as key to preventing or mitigating most of the drilling challenges. Proper planning for the drilling, therefore, comes in handy to improve the efficiency in drilling.

2 DRILLING WELL PW 03B

2.1 Layout plan

Table 1 shows the planned design laid before drilling the well commenced based on the drilling programme (GDC Internal Communication):

Table 1: Plan for the well prior to commencement of drilling

Layout plan	Target
Total measured depth after drilling	3,000m
Drilling days	80
Target:	Directional (J-type)
Azimuth:	N270E
Kick of point	350-450 m
Materials and consumables availability	All materials will be delivered prior to the beginning of each section

Other requirements for the well included sufficient potable drinking water, health amenities, a medic and an ambulance, personal protective clothing for the staff, an operations vehicle, a standby vehicle, permits to work and gas detectors. For the drilling crew to be able to deliver on the task, tools and equipment are required including a resident crane and forklift.

2.2 Design of the well

This well is located in Baringo County, Kenya in the Paka geothermal field 186351E, 101995.5N with an elevation of 1555.19 meters above sea level. The well is a J-type directional well which was aimed to have an Azimuth of N270E. Well PW 03B was an appraisal well which was supposed to appraise and provide more data and information on the extent of the geothermal resource in the western side of the Paka Caldera, subsurface geology, hydrothermal alteration mineralogy and the chemical characteristics of the reservoir, while the steam produced by the well would then form part of the steam resource for power plants to be developed in the geothermal field. This was the third well on the well pad where there are two other wells:

Table 2: Wells on the Paka well pad 03 (PS 03)

Well name	Purpose	Type
PW 03	Exploratory	Vertical
PW 03A	Appraisal	Directional

Figure 1 is a map of the location of the well (GDC Internal Communication):

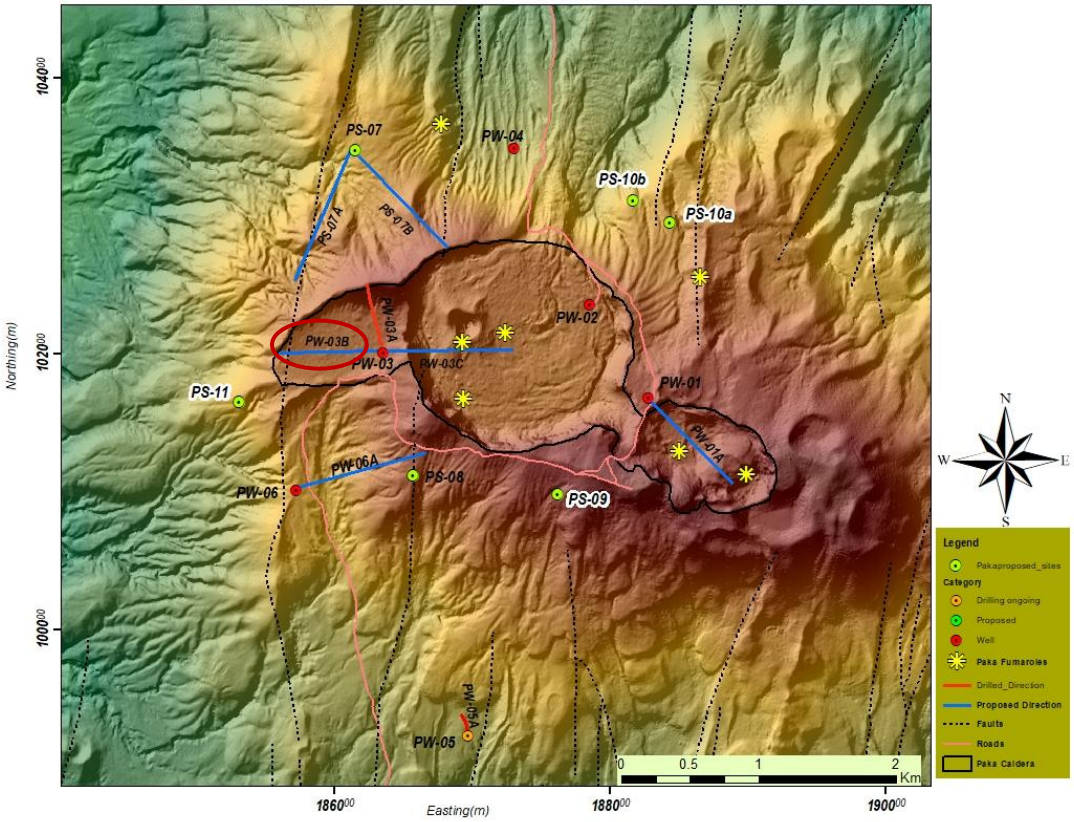


Figure 1: Location of well PW 03B (GDC Internal communication)

Successful drilling and discharge of the two wells informed further drilling of another well (PW 03B) on the well pad.

2.3 Planning for PW 03B

Requirements (planning) for drilling begin right from the time of citing the well. This encompasses well design, resource allocation, safety, logistics, and management of risks. Effective planning therefore involves thorough geological reviews, comprehensive equipment selection to fit the envisaged formation, timely provision of materials and consumables, experienced drilling crew or training, and provision of specialized services like measurement while drilling (MWD), fishing and directional drilling. Planning to drill well PW 03B was no exception.

Prior to commencement of drilling, consideration was made on accessibility of the site in terms of infrastructure (access roads, the well pad and water for drilling). Since this was the third well on the well pad, the existing roads originally cut when drilling the previous two wells were graded, and the leakages of the water line fixed prior to mobilizing the rig back to the well pad.

Analysis on planning and drilling this well was done using information from the following tools:

- The Daily Drilling Reports
- Daily geological reports
- NPT analysis reports
- Material requisition and supply records
- Cost and budget reports
- Well completion reports
- Interviews with drilling crew

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2.3.1 Pre-drilling Planning

Before drilling, a conceptual model originally prepared using information obtained from the geo-scientific studies was used to prepare the well prognosis which also contained information of the geological formations and the proposed casing designs. The drilling engineers then prepared the drilling program which provided details on all activities during drilling, cementing and the casing programmes. Total drilling time was set at 80 days against an estimated budget of Kshs. 835,011,455.44.

Well PW 03B was designed as per Table 3 and Figure 1 below:

Table 3: Design parameters for well PW 03

Hole section	Casing size	Depth of casing
Top hole (26" diameter)	20" diameter	100m
Intermediate hole (17½" diameter)	13-3/8" diameter	300-400m
Production hole (12½" diameter)	9-5/8" diameter	1000-1200m
Main hole (8½" diameter)	7" diameter slotted liners	
Displacement		
Horizontal displacement at production casing depth	250-300m	
Horizontal displacement at production total measured depth	Over 800m	

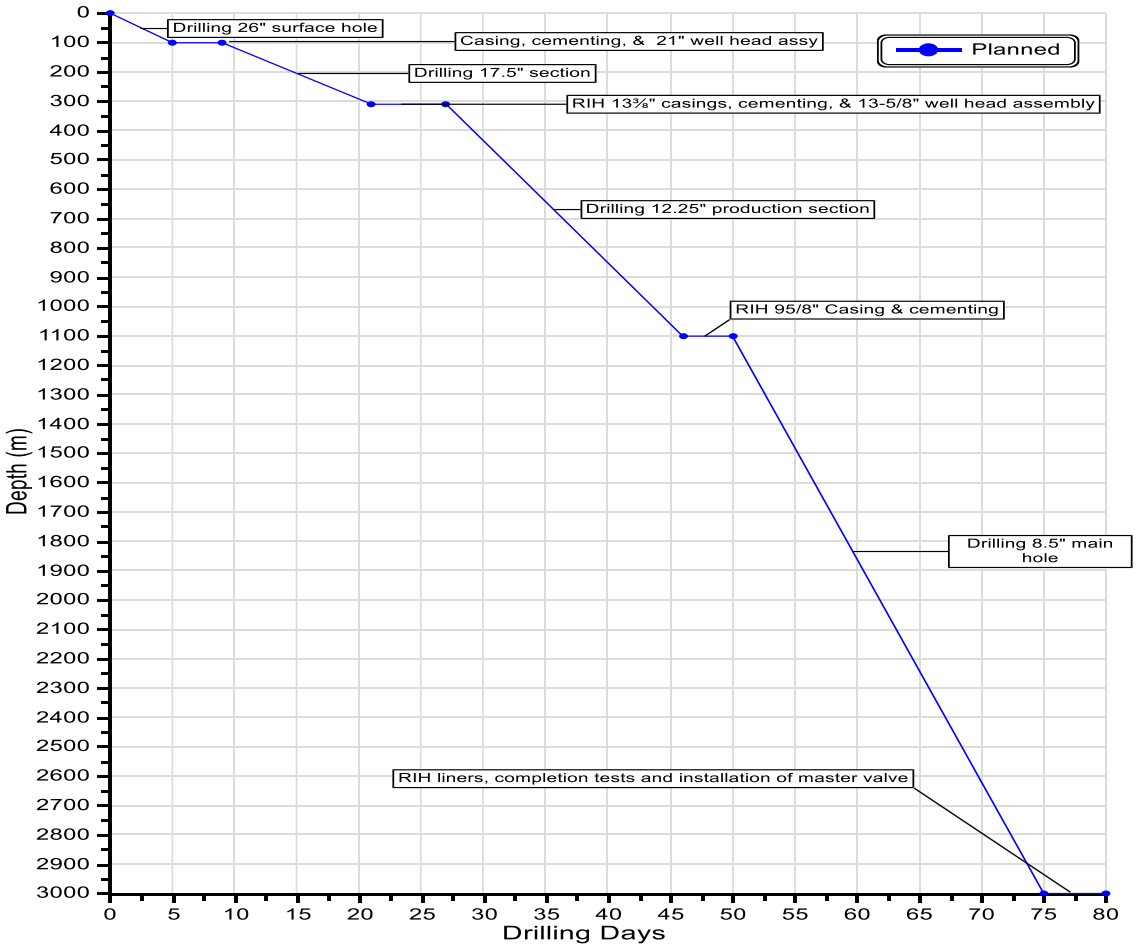


Figure 2: Well PW 03B Design (GDC Internal Communication)

Risks anticipated during the drilling operation were mapped to identify potential lost circulation zones. Anticipated problems while drilling are indicated in Table 4 below:

Table 4: Anticipated problems and mitigation measures during drilling by hole section

Hole	Anticipated problems	Planned mitigation measures
Surface (0-100m)	• Severe losses • Sloughing formation • Hard formation • Unconsolidated formation • Washouts	• Use of bentonite mud of 1.1 Specific Gravity (S.G.), caustic soda, Calcium hydroxide and Lost Circulation Materials (LCM) like walnut and mica flakes • Plugging after 10m of drilling without returns
Intermediate hole (100-311m)	• Severe losses • Sloughing formation • Hard formation • Unconsolidated formation	• Use of bentonite mud of 1.1 S.G, caustic soda, Calcium hydroxide and Lost Circulation Materials (LCM) • Introduction of compressed air as a drilling fluid • Plugging in case of sloughing formation
Production hole (311-1100m)	• Severe losses • Unconsolidated formation • Hard formation • High temperatures • Stuck pipe • Well kicks • Hydrogen Sulfide exposure • Directional control	• Use of water and mud sweeps, caustic soda, Calcium hydroxide and Lost Circulation Materials (LCM) • Introduction of compressed air as a drilling fluid • Plugging in case of sloughing formation
Open hole (1100-3000m)	• Hard and fractured formation • High temperatures • Kicks and blow outs • Well kicks • Hydrogen Sulfide exposure • Directional control	• Use of aerated drilling fluid • Expedient hole cleaning • Continuous monitoring of the directional orientation

2.3.2 Resource allocation

A Rig move plan was developed and all equipment scheduled marked for this exercise. Necessary servicing of the drilling rig components was done prior to mobilization to ensure minimal NPT due to maintenance. The blow out preventers (BoP)s were also tested and confirmed okay. Other resources required were allocated and availed; bit selection (Roller Cone and Polycrystalline Diamond Compact (PDC) bits) done for the deep hole as per advice from the geologists on the formation and drilling consumables. Due to long lead times for drilling consumables, procurement is done at least six (6) months before a drilling operation commences, which was done for well PW 03B. These consumables were put in a nearby GDC-owned lay-down area awaiting transportation by trailers specifically allocated to each well as per need. To ensure a smooth and continuous 24-hour operation, a drilling Shift Rota was prepared, and necessary approvals were provided. A maintenance crew also on a 24-hour Shift Rota prepared and followed a preventive maintenance schedule and were on stand-by during the operation in case of emergencies or breakdowns. Since the operations are tracked continuously, real-time monitoring tools were availed, majorly the RIMBase software installed in the drilling engineer's computer, and the Systems, Applications and Products in Data Processing (SAP) normally maintained by staff within the Supply Chain stores, Finance and Planning office. This ensured that drilling parameters are monitored continuously, and anomalies detected and addressed as they occur. A safety check and drills were performed before spud-in to ensure the crew were safety aware during the operation.

2.4 The drilling operation

Execution of drilling well PW 03B was made possible due to pre-drilling planning. The well was spud in on 16th September 2022, and completed on 2nd December 2022 at a depth of 2,792m and Azimuth 260.53° lasting 78 days. The well was drilled at a cost of Kshs. 518,688,709.63 against a budget of Kshs. 835,011,455.44. Extreme operation limits and difficult formation contributed to termination of the well 209m before the planned drilling depth. Total non-productive time of fifteen (15) days was recorded, attributed to grievances from the local communities, downhole challenges, delay in material delivery and wait on repairs.

Geothermal drilling is a bottom-up process with location of the production zone and the necessary flow to extract energy determining the overall well geometry (Vormall, etal., 2013). The wells are drilled in four sections; the top hole, the intermediate hole, the production hole and the main hole, all sections with a specified size and

length of casing as per the well design. In reference to the well design, Table 5 shows the actual output after drilling based on the on-site judgement made in collaboration between the drilling engineer and the on-site geologist as per the real-time parameters and the formation.

Table 5: Actual well design outputs

Hole section	Hole depth	Casing size	Length of casing
Top hole (26" diameter)	102m	20" diameter	102m
Intermediate hole (17½" diameter)	308m	13-3/8" diameter	308m
Production hole (12½" diameter)	1091m	9-5/8" diameter	1091m
Main hole (8 ½" diameter)	2743	7" Diameter slotted liners	1719m

2.4.1 Planned versus Actual drilling parameters

A comparison of planned drilling parameters against parameters achieved after drilling are shown in Table 6:

Table 6: Planned versus Actual drilling parameters

Parameter	Planned target	Actual achievement	Deviation	Remarks
Drilled depth	3000	2791	209	Terminated earlier than the target due to extreme operation limits (high torques and pick up weight) and difficult formation
Drilling days	80	78	-2	Terminated earlier attributed to better planning and improved drilling capabilities
Azimuth	N270E	N260.53E	-9.47	Within the allowable limits of +-10
Kick-off point	250-300m	355m	55m	Determined by onsite parameters and the formation
Horizontal displacement	>800m	934m	>800m (134m)	The target was achieved. A bigger separation distance ensures no collision during drilling and prevents interference in sharing the resource
Budget / Cost (Kshs.)	835,011,455.44	518,688,709.63	-316,322,745.81	A saving was recorded, a good indicator of efficiency
NPT	0 days	15 days	15 days	Lost time was recorded mainly due to interference by the local communities, taking 58% of the total NPT

Non-productive time (NPT)

Non-productive time (NPT) is defined differently by different authors. It is the time when drilling is not advancing as planned. Rabia (2001) defines NPT as the time taken for an abnormal operation due to failure of the equipment or otherwise, leading to stoppage or slow operations. In Table 7, the NPT distribution indicates that Local Community interference contributed the largest share (58%), while there was minimal contribution by wait on water, and logistics and maintenance issues due to effective planning. Future drilling operations will envisage eliminating or further reducing the causes of NPT, by evaluating the causes of grievances in the region and addressing them through planning. Identifying the reasons for the NPT (root cause analysis) is the starting point to reducing drilling time and saving money (Emhanna, 2018). Analysis of NPT has been ongoing in GDC in order to identify the root causes and manage them, which has attributed to drilling efficiency evidenced in this well.

Table 7: NPT tabular distribution (GDC Internal Communication)

NPT Description	Time (hours)	Time (days)
Local community interference	218	9.08
Wait on fuel	39.5	1.65
Wait on repairs	35	1.46
Wait on transport and logistics	32.5	1.35
Stuck pipe / Fishing	24	1.00
Wait on directional drilling team	13	0.54
Others	12	0.5
Circulating and reaming troublesome zones	5	0.21
Wait on water	0.00	0.00
Total NPT	**379.00**	**15.79**

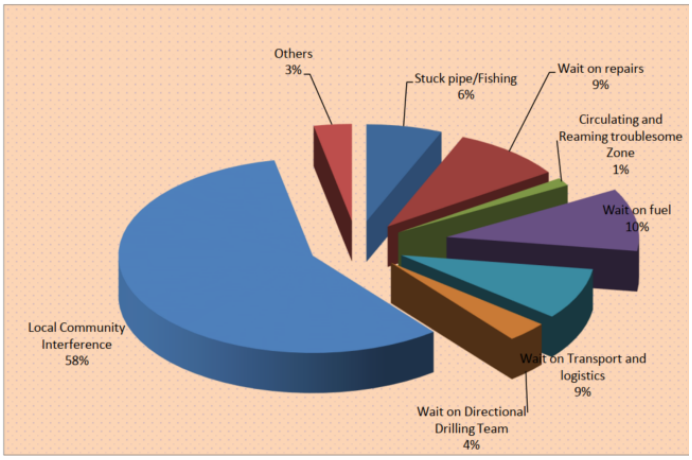


Figure 3: NPT pie-chart distribution (GDC Internal Communication)

The major challenges faced during the operations included:

- Interruptions from the local community
- Stuck pipe experiences
- Delayed delivery of materials and consumables, and
- Extreme drilling operations limits

2.4.2 Time versus depth

Figure 3 below is a graphical indication of how time progressed with depth.

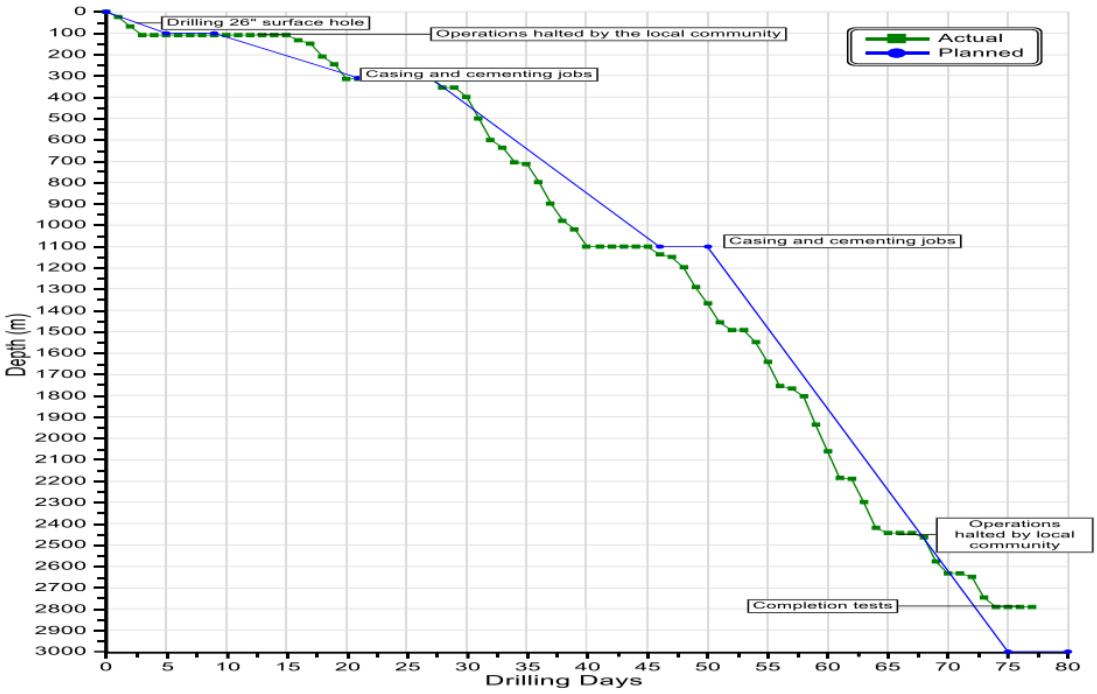


Figure 4: Time versus depth during drilling of well PW 03B (GDC Internal Communication)

A comparison of drilling depth with time for wells around well PW 03B is presented in Figure 4 indicating continuous improvement due to better planning before and during commencement of the drilling operations.

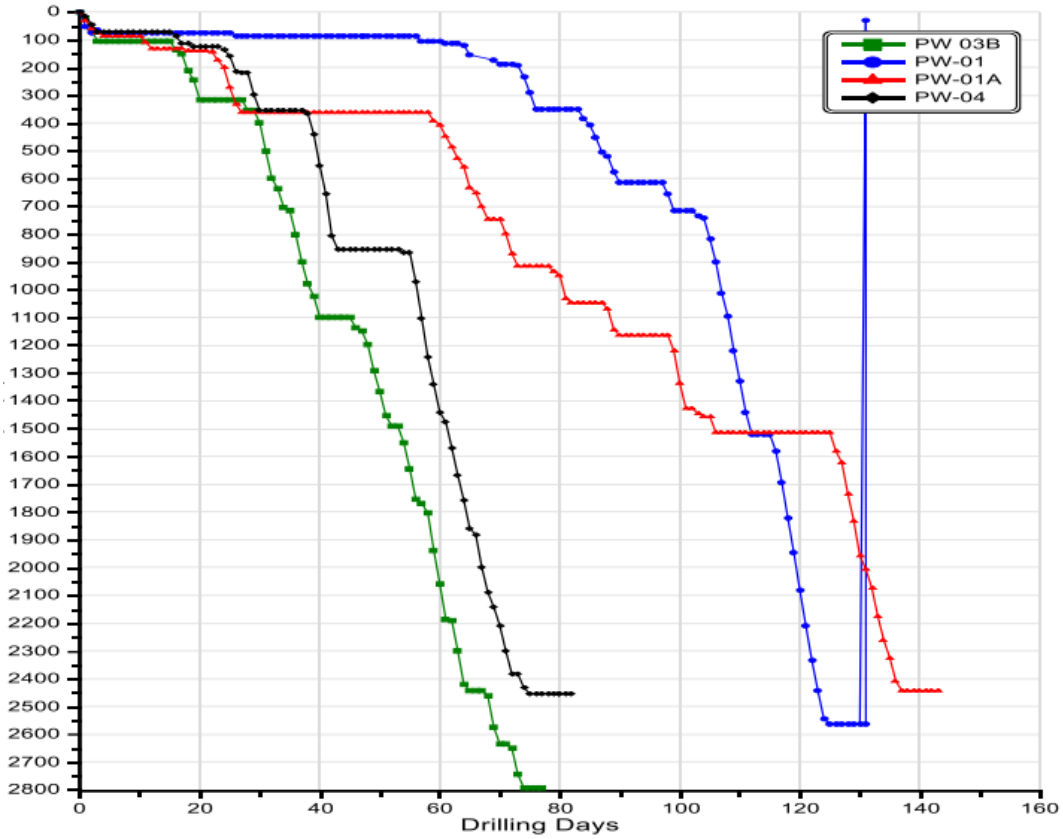


Figure 5: Comparison of drilling depth and time for wells neighbouring well PW 03B (GDC Internal Communication)

Planned versus allocated budget

A breakdown on budget consumption and allocation is shown in Table 8 below:

Table 8: Estimated budget for drilling well PW 03B (GDC Internal Communication)

Activity	Description	Budget (USD)	Actual Consumption (USD)	Variance (USD)
Site Preparation	Well pad preparation	464,673.08	12,137.35	452,535.73
	Access Road Preparation	69,046.15	14,769.23	54,276.92
	Laying of Water line	779,227.09	20,363.96	758,863.13
Rig Mobilization	Rig down, Rig Move & Rig up	65,336.80	28,955.43	36,381.37
	Staff cost	203,039.07	309,392.87	-106,353.80
	Equipment Depreciation	146,949.95	117,113.11	29,836.84
Waterline Maintenance	Waterline & pump station maintenance	65,740.43	12,521.35	53,219.08
Drilling Consumables	Drilling Detergent	47,140.84	38,199.66	8,941.18
	Diesel	487,384.62	590,678.40	-103,293.78
	Cement & cement additives	150,826.11	56,225.66	94,600.44
	Mud & Additives	66,685.06	12,329.20	54,355.86
	Water (Diesel for Pump station & Warma)	949,070.77	139,060.58	810,010.19
Maintenance	Lubricants	152,820.27	30,944.66	121,875.61
	Thread Compounds	4,139.30	580.76	3,558.54
	Rig Spares	107,899.95	20,622.22	87,277.73
	Service Parts	562,734.82	555,613.36	7,121.46
Drilling Hardware	Casings consumables and accessories	264,083.53	226,643.18	37,440.35
	Well head equipment	90,985.78	130,621.15	-39,635.37
	Rock Bits	87,101.75	84,874.26	2,227.48
Other Expenses	Drilling shift staff	893,041.81	832,488.67	60,553.14
	Depreciation of Rig & Equipment	558,490.11	544,527.85	13,962.25
	Camp cost- Well drilling	36,875.19	17,107.20	19,767.99
	Camp cost - Rig move	9,218.80	7,018.34	2,200.46
	Catering cost	147,692.31	159,998.03	-12,305.72
	Transport (staff & material mobilization)	12,961.48	27,126.65	-14,165.17
Total		**6,423,165.04**	**3,989,913.15**	**2,433,251.89**

Due to better planning interventions, the well consumed Kshs. 518,688,709.63, (USD 3,989,913.151), 38% lower than the estimated amount of Kshs. 835.011,455.44 (USD 6,423,165.042).

2.4.3 Planning interventions during drilling well PW 03B

Measures, actions, and strategies can be employed in future projects to improve efficiency by referencing and analyzing the previous planning methodologies and their implementations. During drilling of well PW 03B interventions made are listed in Table 9:

Table 9: Major Planning interventions during drilling of well PW 03B

Planning intervention	Impact in improved drilling performance
Adequate and timely provision of drilling water	Avoided NPT related to unavailability of water
Early procurement of materials and consumables	NPT was not recorded for waiting on materials except for diesel
Scheduling maintenance activities	Ensured availability of the rig and its components minimizing lost time on repairs
Scheduled logistical support	Ensured availability of lifting and moving equipment lowered the lost time
Daily operations and safety meetings	Avoided communication-related NPT since staff were notified on all aspects of the operations and any emerging issues. Risks expected were also discussed and mitigation measures put in place
Appropriate bit and drilling fluid selection	Improved on the speed of drilling and lessened the possibilities of unstable conditions, washouts and stuck pipe

2.5 Discussion

The case study on structured planning for well PW 03B has demonstrated that planning plays a major role in enhancing efficiency during drilling. A comparison on set targets for this well and the drilling outputs between this well and the wells in the neighbourhood confirm that progressive improvements made in planning had a significant effect on drilling this well. PW 03B was drilled in lesser time and a lower cost since most of the logistical delays and scheduled maintenance of the equipment were minimized alongside adoption of better communication methods which improved collaboration across different stakeholders in the drilling operations. These findings align with global observations that emphasize the role of planning in reducing NPT and optimizing performance in drilling operations. Challenges observed in incapability to drill to the target depth and suspension of drilling activities by the local community need to be picked and addressed for future operations. Recommendations are made on a more vibrant Corporate Social Responsibility (CSR) and more collaborative grievance settling modalities to avert the community interference and project road closures. Establishment of a drilling fluid section for the Drilling department will be a great stride towards bettering the quality of drilling fluids used for drilling, while the directional drilling team should be enhanced to combat the NPT related to delay in their availability for the operations. The drilling team should be continuously trained and sensitized on current trends to enhance skills and further improve efficiency. Constant communication and review meetings should also be reinforced, where progress and improvements are discussed for implementation in other forthcoming operations.

Collection of data during planning and execution of the plans was undertaken using the Systems, Applications and Products in Data Processing (SAP) system for reservations and the RIMBase software for records and progress monitoring. Integration of these tools enhanced data accuracy, traceability, and ease of data management, though not without shortcomings. In the recent past, additional licences for the software have been procured to expand user access and responsiveness to the information, hence improvement in the speed and efficiency of the operations, mostly reducing the cost of wait on materials, and information on further timely procurements in case of low re-order levels. The Material Movement Module has also been fronted, to further streamline the processes of reservations and issuance of drilling hardware and consumables, which will contribute to overall operational efficiency.

2.6 Conclusion

Systematic planning technologies have a definite impact on efficient drilling operations, a game changer in providing a solution to the need for energy and in geothermal, for climate change adaptation and mitigation since it is a clean and renewable source. Integration of knowledge in geological studies, engineering logistics, technology and human resource provision and training all come in handy towards a successful operation. Integration of digital tools such as SAP and RIMBase software and the NPT analysis with the existing plans demonstrate the importance of data-dependent decision-making in achieving drilling efficiency. Technical expertise, proper planning and accurate data collection played a key role in enhancing operational performance and achievement of the overall drilling efficiency. Comparison of the set targets for drilling of well PW 03B and the experience in drilling the neighbouring wells is a testimony that good planning reduces NPT and improves drilling efficiency.

REFERENCES

Azar J.J. and Samuel G.R.: Drilling Engineering, PennWell Corporation, pp 14 (2007).

Bashir, M. N., Naseer M.N., Quazi M.M, Wakeel M.S., Ali I, Soudagar M.E.M. AND Bhatti J.: Systematic Review of Drilling problems and their Solutions in Petroleum Engineering, *Journal of ICT, Design, Engineering and Technological Science (JITDETS)*, Vol. 5, No. 2, (2021), pp 1-16.

Devereux, S.: Practical well planning and drilling manual, PennWell Publishing Company, pp 4 (1998).

Emhanna, S.A.: Analysis of Non-Productive Time in Drilling Operations – A case study of the Ghadames Basin: Second Scientific Conference of Oil and Gas (2018).

GDC Internal Drilling Reports – Drilling Programme, Well Completion report (2022).

Mwangi, M.: Planning of geothermal Projects: A Case study on Kenya, *Presented at Short Course II on Surface Exploration for Geothermal Resources organized by the UNU-GTP, GDC and KenGen at Lake Naivasha, Kenya,* 12 pp. (2007).

Ngosi and Omwenga: *American Scientific Research Journal for Engineering, Technology and Sciences (ASRJETS)*, ISSN (Print) 2313-4410, ISSN (Online) 2313-4402, Volume 14, No. 3. (2015) pp16-26.

Okwiri, L.: Geothermal Drilling Time analysis: A case Study of Menengai and Henghill. Report 25 in: *Geothermal training in Iceland 2013*. UNU-GTP, Iceland, 577-598 (2014)

Rabia, H.: *Well Engineering and Construction*, Entac Consulting (2001).

Short Course: Rules and regulations for drilling and completing geothermal wells, *organized by the African Union Commission (AUC) and the German Federal Institute for Sciences and Natural Resources (BGR)UNU-GTP, GDC and KenGen at Lake Naivasha, Kenya,* 12 pp. (2014).

Vollmar D., Wittig, V. & Bracke, R.: Geothermal Drilling Best Practices: The Geothermal translation of conventional drilling recommendations – main potential challenges, *IGA Academy Report 0104-2013,* pp 1-12.