Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Evaluation of Potential Recompletions of Asal Offset Wells: Techniques and Challenges Assets Evaluations

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Keywords: Drilling, Recompletion, Sidetracking, Perforation, Seal off.

ABSTRACT

Djibouti have decided to move ahead into the development program of geothermal energy. Several projects are progressing in different geothermal field, such as Fiale deep drilling project, Galla La Koma shallow drilling project, Hanle exploration wells, as well as Pk20-Ambado exploration wells. Besides these, a particular project concerning the re-entry of Asal offset wells is settled to evaluate whether these wells can produce, or re use for sidetrack, or as a injection wells. In this regard, asset project evaluation & completion engineering studies has been conducted to define conditions and techniques of re-opening these 40 years wells. Asal offset Wells were drilled between 1972 to 1988 during the first geothermal exploration project. Some of these wells were tested but didn't produce due to sever scaling deposition on the wellbore.

Various recompletion methods were researched, examined and analyzed for potential use at the Asal field. To recomplete these wells, they required to review all available options used in the oil, gas and geothermal industry today as well as experimental methods. While casing designs were analyzed to determine the potential options and costs for recompletion methods. Risks associated with each recompletion method were weighed heavily against costs and the availability of equipment. These options were viewed in light of the rig that ODDEG has and plans to utilize in this operation. This rig has a drilling limit of 800 meters, this limit is for drilling to that depth, when recompleting the wells drilling may not have to occur in the operation therefore this limit should not be problem, however if the operation called for running in and set packer, bridge plugs or cement plugs we believe that the rig should be able to run to a depth of 1000 meters.

Based on the list of recompletion methods, a recompletion program was developed for each method that had higher probabilities of success. We applied each of these methods to the ASAL wells. The programs that are included in this report are all written for the Asal 1 well. Each of these procedures can then be applied to each of the ASAL wells as the existing completion programs is very similar, only minor changes in depths and sizes would need to be incorporated to make each method case or well specific. These programs represent a step by step procedure to recomplete each well at a zone of interest. The procedures would need to be better defined once the exact recompletion method is chosen and operations are to proceed ahead. These plans contained procedures for abandoning the bottom hole and then a procedure to recomplete the well in a new zone. After each of these procedures were developed, a relative cost estimate was prepared for each of the options. These costs were estimated using U.S. rig and equipment pricing as international reference. We feel that the U.S. price could then be factored up a certain percentage (20% to 30%) to insure that the figures will be useful for Djibouti.

Finally, all potential risks and issues that may arise during recompletion were analyzed. The major risks involved in each recompletion method are mentioned in the recompletion programs as well as in the "Potential Risks and Issues" section of this report. The conclusion is the final section of this report. These represent the opinions of our personnel based on experience, document review and research performed.

1. INTRODUCTION

During the drilling of the GLC-1 well, it was decided to evaluate the potential recompletions on the wells previously drilled in the Asal field, Djibouti. It was presented with all pertinent data from the six (6) geothermal exploration/production wells, ASAL 1, ASAL 2, ASAL 3, ASAL 4, ASAL 5 and ASAL 6. The data provided related to the drilling and testing information that was collected in 1975, when these wells were originally drilled. The request was to access the risk and options available to recomplete these well at a shallower, possibly, more productive zones. Each of the wells were drilled to depths greater than 1100 meters and they all encountered zones containing high commercial temperatures. The wells that could flow were tested and evaluated. The final field study report conducted and written by Aquator which contained detail information on each well including fluid temperatures and reservoir pressures as well as fluid chemistry and production test results was provided for review. All the wells demonstrated limited capacity for long term production. Accumulative total mass flow from the wells declined sharply after several months of production testing. The fluids produced from the wells had a tendency to deposit a great deal of scale (Chloride) in the test runs. The roughness of the scale produced excessive friction, reducing the wellhead pressures during flowing conditions. Therefore, these wells were not prime candidates for the construction of a production facility. It was tasked with reviewing the well data, analyze if possible shallower zones were present in the wells and can the wells be recompleted in these new zones.

We proceeded to review numerous documents pertaining to the drilling, completion and testing of the Asal wells. The drilling records, particularly those that pertain to lost circulation or formation fluid flows and lithologies were examined to determine the optimal zones of recompletion for each well as it relates to potential production. All lithology and lithologic changes in the wellbore were noted and marked as potential recompletion zones. No daily drilling data was available so penetration rates and changes to these zones could not be correlated, therefore lost circulation was the prime indicator as well as data from the temperature logs run throughout the project drilling and testing. Based on this information a determination as to which zones would be considered for recompletion was made.

Various recompletion methods were researched, examined and analyzed for potential use at the Asal field. To recomplete these wells, we reviewed all available options used in the oil, gas and geothermal industry today as well as experimental methods. While casing designs were analyzed to determine the potential options and costs for recompletion methods. Risks associated with each recompletion method were weighed heavily against costs and the availability of equipment. These options were viewed in light of the rig that ODDEG has and plans to utilize in this operation. This rig has a drilling limit of 800 meters, this limit is for drilling to that depth, when recompleting the wells drilling may not have to occur in the operation therefore this limit should not be problem, however if the operation called for running in and set packer, bridge plugs or cement plugs we believe that the rig should be able to run to a depth of 1000 meters.

To recomplete the wells and to make potential zones accessible for the production of a resource, the casing and cement across these zones must be removed from the wells or perforated to allow communication with the formations. This direct line of communication between the formation and the wellbore is essential. We also analyzed the option of sidetracking the well out of a window in the existing wellbore to a different hole location in the zones of interest.

Based on the list of recompletion methods, a recompletion program was developed for each method that had higher probabilities of success. We applied each of these methods to the ASAL wells. The programs that are included in this report are all written for the Asal 1 well. Each of these procedures can then be applied to each of the ASAL wells as the existing completion programs is very similar, only minor changes in depths and sizes would need to be incorporated to make each method case or well specific. These programs represent a step by step procedure to recomplete each well at a zone of interest. The procedures would need to be better defined once the exact recompletion method is chosen and operations are to proceed ahead. These plans contained procedures for abandoning the bottom hole and then a procedure to recomplete the well in a new zone. After each of these procedures were developed, a relative cost estimate was prepared for each of the options. These costs were estimated using U.S. rig and equipment pricing as we have no knowledge of how to price it in Djibouti. We feel that the U.S. price could then be factored up a certain percentage (20% to 30%) to insure that the figures will be useful for Djibouti.

Finally, all potential risks and issues that may arise during recompletion were analyzed. The major risks involved in each recompletion method are mentioned in the recompletion programs as well as in the "Potential Risks and Issues" section of this report. The conclusions are the final section of this report. These represent the opinions of our personnel based on experience, document review and research performed.

2. ASSETS EVALUATION: PRELIMINARY REVIEW

2.1 Document Review

We received various documents pertaining to the drilling, completion and testing of the geothermal production wells in the Asal field in Djibouti. The distribution of information was not equal among all of the wells. Some wells had more construction information where others had more testing information. Table 1 below identifies the documents that were provided and reviewed.

Table 1 – List of Documents Provided

Well	Documents Provided
ASAL 1	Fiche-Log_Asal1.pdf
	Wellbore Schematic Asal1.jpg
	Draft Final Report.pdf
ASAL 2	Fiche-Log_Asal2.pdf
	Wellbore Schematic Asal2.jpg
	Draft Final Report.pdf
ASAL 3	Completion Data Well Asal 3.pdf
	Master Logs of Asal 3 Well.jpg
	Draft Final Report.pdf
ASAL 4	Completion Data Well Asal 4.pdf
	Draft Final Report.pdf
ASAL 5	Fiche-Log_Asal5.pdf
	Wellbore Schematic Asal5.jpg
	Draft Final Report.pdf
ASAL 6	Completion Data Well Asal 6.pdf
	Draft Final Report.pdf

Like all document review processes, some materials provided better insight than others, but all were examined for pertinent data relating to each well. The "Draft Final Report.pdf" document was a very length in-depth look at the entire field. This document was thoroughly reviewed and formation information was pulled out to help complete this recompletion analysis. The document review resulted in a clear picture of the completion status of each well including casing profiles and lost circulation zones.

Through an effective document review, each well was defined by the pertinent data available. Appendix #1 – Pertinent Data per Well at the end of this document lists all pertinent data, along will wellbore schematics, for each well. From this list of pertinent data, we was able to determine potential recompletion zones, recompletion methods and relative costs per recompletion method. Assumptions were made about each wellbore environment. All assumptions will be discussed in depth in a different section of this report.

2.2 Review of Recompletion Methods

Various methods of recompletion exist throughout the oil, gas and geothermal industries. However, since the task was to recomplete these wells in zones that exist behind cemented casing, some recompletion methods were instantly eliminated because they are not relative to this type of operation. Instead, we focused on 3 major types of recompletion: Perforation of Casing, Sidetracking out of Casing, and Cutting/Removal of Casing. Out of these three major types, we was able to determine four possible recompletion techniques. Two of the techniques are different methods for the cutting and removal of casing.

The perforation of casing is, somewhat, clearly defined by the name. This method involves the shooting of holes through the steel casing and into the formation. These holes or perforations can extend several feet into the formation allowing fluid to flow into the wellbore and to the surface. Cemented casing strings can be perforated using an explosive gun that is either run on wireline or tubing. Once the explosive gun is lowered to the desired depth, the charges are initiated and the shaped charges create holes in the casing. This is a common completion method for oil and gas wells, but is not used very much in geothermal wells due to the need of higher flow rates. Geothermal wells require a greater flow area to produce the quantities needed for power generation. However, by increasing the shot size and shot frequency, it is possible to obtain a large enough flow path to support geothermal production. This is not used as a primary method in geothermal because it requires a casing string to be cement across a production interval which is not done in geothermal because the cement could plug off the fractured reservoir formations. Since the wells in question already have the casing installed, this is a viable recompletion method. The basic order of operations for such a recompletion is as follows:

1. Seal off lower zones in wellbore.
    a. Temporarily or permanently abandon lower portion of well.
2. Perforate casing.
3. Clean out debris from wellbore.
4. Removal of temporary abandonment (if required).
5. Testing of recompleted zones.

A step by step procedure has been developed to perforate the casing in Asal 1 as an example. This procedure is included in this report as Appendix #2 – Perforating Program, of which the next section will describe in depth.

Sidetracking or dual leg completion is a common practice in the oil, gas and geothermal industries. It consists of drilling an original wellbore to the reservoir that is to be exploited. A second leg of the well is then drilled out starting shallower in the well. This second leg (sidetrack) can begin inside of casing or in the open hole section. Since the task is to recomplete these wells in zones behind cemented casing, the sidetracks will be designed to begin inside of the cemented casing strings. Wells can be sidetracked by cutting a window into the steel casing by using a mill and whipstock. The whipstocks are basic ramps that are set in a well allowing the mill to act directly on the steel casing to create a window. Once the window is cut into the casing, a directional assembly is utilized to steer the bit away from the original wellbore and towards a specific target. Once the sidetrack is completed, the whipstock can be removed allowing the well to produce from both developed legs. Whipstocks can remain in the well if the first (original) leg is deemed as a minor producer. If the second leg produces at a significant rate, then the first leg may not be re-opened. The reason for this is, once the whipstock is removed it will be very difficult to re-enter the sidetrack for work-over or logging operation. This is because the bit or tools will want to follow the least path of resistance which is usually in the vertical direction into the original leg of the well. If the whipstock is to be left in place, then a slotted liner can be run into the sidetrack to help support the formation. Once the slotted liner is run or the whipstock is left in place, the bottom of the well is effectively sealed off from future production. The basic order of operations for such a recompletion is as follows:

1. Permanently or temporarily abandon lower portion of original hole.
2. Install whipstock.
3. Cut window into casing.
4. Drill sidetrack leg.
5. Run slotted liner – optional.
6. Test sidetrack leg.
7. Remove whipstock and open lower portion of well – optional.
    a. Only possible if whipstock is removable and slotted liner has not been run.

A step by step procedure has been developed to sidetrack out of the casing in Asal 1 as an example. This procedure is included in this report as Appendix #3 – Sidetracking Program, of which the next section will describe in depth.

The cutting and removal of cemented casing has been a common practice to abandon oil or gas wells with casing cemented to surface. By removal of casing the well is able to be sealed with cement plugs that create a cement to formation bond that effectively seals off formations. This sealing will not allow fluid migration to occur between two different formations. However, in the case of the Asal wells, a portion of the casing is to be removed from the wellbore without removing all of the casing string to surface. This can be quite difficult because the casing will be the same size as the casing you will be pulling it through. This requires the casing to be ground up or cut into vertical strips that can be removed through similar casing. For instance a 7” casing will not pass through another 7” casing, but if the casing is cut into vertical strips, those strips can be removed through the 7” casing above it. This method is very difficult to perform and is not guaranteed to be successful. It is similar to performing open heart surgery from a mile away while being blind folded. Many methods for cutting casing exist throughout the industry. These methods are described in Table 2 – Methods of Cutting Casing below.

Table 2 – Methods of Cutting Casing

Method	Description
Explosive Cutting	• Performed by a variation of a linear shaped charge. • Effective at cutting pipe along a horizontal axis. • May leave a flared end piece due to explosive charge. • Not to be mistaken for but similar to a split shot or coupling charge (DCST).
Chemical Cutting	• Requires a focused spray of corrosive chemicals to effectively corrode pipe at the point of spray. • May be difficult if scale is present. • Difficult to perform on a vertical axis due to chemical movement once sprayed. • Requires a high level of expertise and experience to accomplish. • Requires rig over-pull to pull casing apart.
Radial Torch Cutting	• Thermite Plasma is used for its extremely high temperatures ± 5000°F • Cut is performed using a nozzle similar to jet cutting. • Good at cutting along horizontal axis. • More research is needed to determine effectiveness on a vertical axis.
Abrasive Cutting	• Similar to Radial Torch Cutting, but instead of Thermite Plasma a mixture of sand or carbonate pellets are carried at high velocity with water. • Nozzle is placed close to casing ID. • Good at cutting multiple strings of casing. • Possible to cut in vertical axis, but may be very difficult to control cutting apparatus.
Mechanical Cutting	• Through the use of rotation at surface or through the use of a mud motor, casing is cut using a cutting tool with arms that extend to the casing ID. • Cutters are placed on the arms and cuts are made as the tool is rotated. • As it is rotated, the arms continually push outwards toward the casing which allows for deeper cuts to be made. • Horizontal cutting is not applicable for a standard mechanical cutter. • A casing section mill is a mechanical cutter with vertical mill cutters below the horizontal casing cutters
Spiral Cutting	• Currently still in the experimental phase. • Consists of cutting the casing using a vertical skate cutter. • Cutter will create a spiral cut throughout the casing section that is scheduled to be removed. • After each cut the casing is pulled on to release it from the cement bond. • Once the section is spiral cut, the rig will pull hard on the up part of that section, freeing the casing from the cement bond. • As the casing is pulled and elongated, the OD will be reduced allowing it to fit inside of the uncut casing above. The casing can then be removed from the well.

For the purpose of recompletion of the Asal wells, only a Casing Section Mill and possibly the Spiral Cutting Approach may be useful to cut and remove casing. A step by step procedure has been developed to cut and remove casing with utilizing those two cutting techniques. The procedures are included in this report as Appendix #4 – Casing Section Milling Program and Appendix #5 – Spiral Cutting Program, of which the next section will describe both in detail.

As described above there are several different recompletion methods for recompleting behind cemented casing. For the purpose of this study, we focused on 4 methods of recompletion: Perforation of Casing, Sidetracking out of Casing, Casing Section Milling and the Spiral Cutting Approach.

3. APPLICATION OF RECOMPLETION METHODS

In the previous section several recompletion methods were examined and analyzed. These methods are Perforating Casing, Sidetracking out of Casing, and the Cutting/Removal of Casing. Some techniques were eliminated from consideration due to applicable design limitations. The eliminated techniques are all from the Cutting/Removal of Casing method and consist of: Explosive Cutting, Chemical Cutting, and Radial Torch Cutting. Each of the remaining methods were examined and applied to each of the Asal wells to determine the best-case application and costs associated with each technique.

In order to complete the tasks, some information was not available in the documents provided; some assumptions about the wells were needed. The assumptions that were used to create the individual procedures and costs are listed in Table 3 – Well Assumptions.

Table 3 – Well Assumptions

Well	Assumptions
All Wells	Wellbore has not been abandoned and is open to bottom. ~~Wellbore is free of scale or any build up on the sidewall of the casings~~
ASAL 1	Recompletion to take place between 396m (bottom of 9-5/8” casing) and 651m (bottom of 7” casing). o To recomplete the well shallower than 396m means that perforations will need to be shot through two cemented casing strings. [redacted]s were experienced in the Rhyolitic formation between 404m and 527m. [redacted]Losses were as great as 20 [redacted]bls/hr or 88 gpm) at 455m. [redacted]terpretation of the “Fi[redacted]al1.pdf” document shows a [redacted]ater Inflows” (translation) column that identifies losses (or gains) [redacted]t 408m, 416m and 455m.
ASAL 2 [redacted]	[redacted]Recompletion to take place between 464m (bottom of 9-5/8” casing) and 984.6m (bottom of 7” casing). o Location of recompletion chosen strictly on casing design and ease of recompletion. To recomplete the well shallower than 464m means that perforations will need to be shot through two cemented casing strings. Losses were not recorded on this well. No losses were experienced on this well per information provided. o Rhyolitic formations exist from 560m to 642m. This should be the main focus of recompletion due to the hot aquifer that was stated to exist in this interval.
ASAL 3	Recompletion to take place between 397m (bottom of 13-3/8” casing) and 1016m (bottom of 9-5/8” casing). o Location of recompletion chosen strictly on casing design and ease of recompletion. To recomplete the well shallower than 397m means that perforations will need to be shot through two cemented casing strings. Losses or inflows were not recorded on this well. o Rhyolitic formations exist from 409m to 515m. This should be the main focus of recompletion due to the hot aquifer that was stated to exist in this interval.
ASAL 4	Two possible recompletion zones. o Recomplete from 425m to 550m. This zone was shown to have a hot aquifer in the contact between hyaloclastite and basalt formations. This zone did cause some issues during drilling. o Recomplete from 900m to 1100m. This zone had lost circulation in the trachytes and porphyritic basalts from 950m to 1075m.

	- This zone is very close to the 9-5/8” casing shoe, but would be easier to complete than the aforementioned shallower zone.
ASAL 5	- Water flow zone at 220m is considered a cold flow and recompletion should not be performed at this depth. - Two possible recompletion zones. o Recomplete from 300m to 570m. - This zone was shown to have higher temperatures, particularly the fluid flow zone at 550m. - Most promising zone of recompletion. o Recomplete from 1050m to 1200m. - This interval showed one formation of altered tuff that could be altered rhyolite. - Temperatures from 572m (13-3/8” casing shoe) to 900m are in decline and no water intrusions or lost circulation was noted in the data provided. - Temperatures begin to increase at 1000m and continue to increase to well TD.
ASAL 6	- Water flow zone at 265m is considered a cold flow and recompletion should not be performed at this depth. - Recomplete from 300m to 500m. o This zone was shown to have lost circulation during drilling o 7” Casing was cemented in place. o Most promising zone of recompletion.

One item that was mentioned in several reviewed documents was the apparent presence of scale in the wellbore. The carbonate scale was deposited on the casing during the initial testing phase. This scale would need to be removed and the casing cleaned in order to proceed with any recompletion. The abandonment of the bottom hole and setting of plugs requires that the casing be clean and clear of debris in order for a proper seal to set up. If scale is present then a pressure/fluid seal cannot be accomplished. In addition one or more of the wells may already be abandoned. These wells would need to be re-opened and cleaned before recompletion operations can begin. So it may assist in the decision making process to know which wells have been abandoned and which wells have significant scale build up before proceeding with recompletion planning.

At this point in the process, all well documents have been reviewed, pertinent well data has been compiled, recompletion methods have been analyzed and assumptions have been made for each well. The next step is to define which recompletion options are applicable to the Asal wells. The truly applicable techniques are Perforating Casing, Sidetracking Wellbore, Casing Section Milling and the Spiral Cutting Approach. Table 4 – Wells per Applicable Technique below displays which wells can be recompleted by each technique.

Table 4 – Wells per Applicable Technique

Technique Name	Applicable Wells
Perforation of Casing	- ASAL 1 - ASAL 2 - ASAL 3 - ASAL 4 - ASAL 5 - ASAL 6
Sidetracking Wellbore	- ASAL 1 - ASAL 2 - ASAL 3 - ASAL 4 - ASAL 5 - ASAL 6
Casing Section Mill	- ASAL 1 - ASAL 2 - ASAL 3 - ASAL 4 – Bottom Zone Only - ASAL 5 – Bottom Zone Only - ASAL 6 – Below 388m Only
Spiral Cutting Approach	- ASAL 1

- ASAL 2
- ASAL 3
- ASAL 4 – Bottom Zone Only
- ASAL 5 – Bottom Zone Only
- ASAL 6 – Below 388m Only

The perforation of casing is a common practice in all drilling industries. The tools are regularly available it and it does not require a large rig to complete. In some instances a wireline truck is all that is required to perform the work. In order to successfully recomplete the well with perforations, there are certain steps that need to be taken. The bottom portion of the well will need to be temporarily or permanently abandoned using cement and a mechanical bridge plug. This bottom plug will effectively abandon the lower section of the well and more importantly isolate the section to be perforated. Next the perforating gun will be run into the well and set off at the proper depth. There will be the need for multiple shot runs, because the length of the perforation section is longer than the average perforating gun. After the shots have been made, the wellbore will need to be circulated in order to clean out all debris created during the perforation process. Once this is completed, the new section of the well can be tested and evaluated. After evaluation, a slotted liner could be run through this section, though it may not be needed due to the design size of the perforations. If the perforations are small enough then a slotted liner will not be required. The last operation would be to remove the temporary abandonment if required. This is optional as the original bottom hole section did not show significant long term production in all of the Asal wells. A step by step procedure has been included in this report as Appendix 2 – Perforation Program. The "Perforation Program" is written about ASAL 1 well. The only difference in the other wells would be depth and in a couple of wells the casing size changes from 7" to 9-5/8". However, all other information contained in the program will be applicable to all other Asal wells. There are several items that need to be specifically designed and engineered per well. Those items are: shot depth into formation, perforation diameter (entrance diameter), shot phase angle (shot pattern), perforation density (# of shots per meter), and perforation flow efficiency. Once the decision is made to proceed with perforating, all specific design parameters will be engineered for each well for optimization. Additionally, as it refers to equipment, each program in this report has a basic list of equipment to complete each method. The rig that is currently owned by ODDEG would be capable of performing this operation.

Sidetracking wellbores occurs in all areas of drilling. Usually a drilling operation will begin sidetracking wells if an obstruction or debris is located in the wellbore. If the debris cannot be removed, then the rig will sidetrack the well around the obstruction. However, sidetrack are also drilled to be second legs of production. This type of operation was considered as a recompletion method for the Asal wells. In order to successfully recomplete a well via a sidetrack leg, certain steps are required to take place. Similar to perforating and in fact all other considered methods, the bottom portion of the hole should be temporarily or permanently abandoned. In this case permanent abandonment is more likely due to the nature of setting and removing a whipstock into the wellbore. After the bottom portion is abandoned, the whipstock will be lowered and set into the well at the predetermined depth. This whipstock is essentially a ramp used to direct the mill at the casing. The mill will cut a window into the steel casing allowing it to pass through freely. Once the window is made, the rig will switch to a standard bit and begin drilling new formation utilizing directional tools. These directional tools will steer the bit away from the original hole and towards a predetermined target. Once the sidetrack is drilled and the target is reached, the rig can test the sidetrack leg. If the program was planned to re-open the bottom portion of the well after the sidetrack is drilled, then the whipstock would be removed and the bottom plugs drilled out. This will effectively open the bottom of the well back up for production. However, if the bottom portion of the well was unproductive (reason to recomplete) then the whipstock and bottom plugs can stay in place. Finally if the whipstock is to stay in the well and the sidetrack leg shows good production, then a slotted liner may be run into the new leg and hung from the casing. A step by step procedure has been developed for Asal 1 sidetracking. That procedure can be found in Appendix #3 – Sidetracking Program. Included in this program is an equipment list that may be needed to complete the operations. According to depth capacity, the ODDEG rig could perform this work. However, more examination would be needed because drilling a sidetrack leg may require abilities that the rig does not possess. For instance, the rig may not have enough torque capacity to cut the window or drill at an angle with directional tools. Sidetracking in most of the Asal wells will take place inside of a dual casing string because the window needs to be cut high enough above the potential production zones to allow for the sidetrack leg to have enough spacing between it and the original wellbore. For instance, the program supplied has the sidetrack window being cut through the 7" casing, 9-5/8" casing and the cement that exists both between and outside of the casing strings.

Section milling is a technique that has been around for a long time. In fact drillers used to mill out a section of casing instead of cutting a window for sidetracks. However, the whipstock assemblies and window mills have been improved over the years to make section milling for sidetrack purposes obsolete. Casing section milling is still a viable solution to remove casing as well as expose formations that are behind cemented casing strings.

Casing section milling can only take place in zones that have one casing string. It would take too much time and increase the risk too much to try and section mill 2 casing strings at the same depth. Because of this some of the wells can be recompleted using a section mill but only if one casing string exists in that interval. For example, ASAL 6 has two casing strings that extend to 388m, the 9-5/8" casing cemented to 388m and the 7" casing cemented from 364m to 919m. This means that the casing section mill will only be applicable to the 7" casing below 388m. In order to section mill the casing certain procedures need to be followed. First, like the other methods, the bottom of the hole needs to be temporarily or permanently abandoned. Then the section mill would be run to a certain depth and an initial cut made using rotation. This cut is then expanded as the rig rotates the tool and adds weight, similar to standard drilling practices. The section mill will effectively grind up the steel casing into shavings allowing it to be circulated from the wellbore. Once the casing has been milled up, the rig can run an under-reamer or hole opener into the well. This tool will allow the rig to ream out the new open hole section to a larger size than the casing above it. This needs to be performed in order to remove any residual cement and part of the newly accessible formations. The reaming of the formation is important as it could be damaged from the original drilling or cementing of the casing. A damaged formation may hinder production or injection due to the closure of permeability or fractures. Once the new open hole section has been reamed out, the rig will be able to test the section. If successful the bottom plugs can be removed which will open up the bottom of the original well or a slotted liner can be run through the new open hole section. These are both optional, but need to be determined prior to the rig showing up on location. A step by step procedure can be found in Appendix #4 – Casing Section Milling Program. This program was written for ASAL 1 as an example. Many of the other wells are very similar to ASAL 1 with the only changes come from depth and possible casing sizes. The program also has a list of equipment needed to complete the technique. It could be possible for the ODDEG rig to perform this work. However, it may be very slow progress during the section milling portion of the operations because the rig will have limited torque capabilities and will only be able to handle a certain amount of weight. When milling casing, excessive torque may be present due to the steel casing being ground up. If this option is selected, further evaluation and analysis would need to be performed to see if the rig is capable of completing the operation. In addition, this option will be a longer process due to the milling of such a long section of casing. Higher risks are present during this operation due to tool failures and malfunctions.

The Spiral Cutting Approach is an experimental method used to remove casing from a wellbore. This method involves the rig utilizing a vertical skate cutter to cut the casing into a spiral, spring-type, shape. Prior to running the cutter, the rig will need to temporarily or permanently abandon the lower portion of the well. Once abandoned, the rig will pick up and run into the well with the spiral cutting apparatus. The rig would rotate slightly as the tool is lifted and lowered throughout the section. The vertical skate cutter will wear grooves into the casing until it is cut all the way through. As one section is cut through tension is pulled on the top of the cut section. This tension will attempt to break the cement bond holding the casing in place. The action of cutting and pulling tension is repeated until the entire section is cut through. At that point the rig will pull a lot of tension on the top of the casing to free it additional from the cement. Once free, the casing will be picked up. As it is picked up the weight of the casing will make it elongate and due to the spiral cuts, the casing OD will be reduced. This will, theoretically, allow the casing to be pulled from the well through similar sized pipe above. If the casing will not be pulled up, there is also the option to push the casing to bottom. This should, theoretically, allow the casing to collapse and be crushed in the bottom section of the well. After the casing is removed the new section can be tested and evaluated. A slotted liner is optional to run through the new open hole section depending on the results of the well test. If the casing was removed from the hole then the bottom plugs could be removed, effectively re-opening the lower portion of the well. However, if the casing was shoved and crushed on bottom, then the plugs will remain and the bottom portion of the hole is considered abandoned. A step by step procedure has been created and can be found in Appendix #5 – Spiral Cutting Program. This program applies the spiral cutting approach to ASAL 1. As other wells are similar to ASAL 1, others will only be able to perform these operations at the bottom of the hole where only one casing string exists. It would be far too difficult and time consuming to try spiral cutting and removal of two strings of casing. The program in Appendix #5 also lists some equipment that may be needed to complete the operations. The ODDEG rig would not be able to perform this technique as the weight capacity of the rig is not strong enough. In order to break the cement bonds, the casing will need to be pulled very hard and the current capacity of the rig (80,000 lbs) would not be sufficient to succeed. This option is the riskiest option of the four provided. Risks and Issues will be discussed later in this report, but some of the risks can be found in Appendix #5.

Now that step by step procedures have been developed for each of the four methods, cost estimates can be created to give a relative picture of budgetary concerns. Each operation requires specialized tools to be utilized to access the formations behind cemented casing strings. These specialized tools all result in specialized costs per application.

4. POTENTIAL RISKS

Whenever a rig is over a well and operations are performed inside of the wellbore there are some inherent risks that will always be of concern. Damage to casing, wellbore and wellhead are prime examples of risks that may occur at any time. The risks are typically lower when working inside of casing because the volatility of some formations have been removed from the situation. For this exercise, we did not focus on typical risks associated with drilling or workovers; rather focus was placed on specific risks that would arise during the recompletion methods studied. Each major risk associated with each recompletion method can be found in the individual programs found in Appendix 2 through Appendix 5. This section will focus on the major issues that may befall each or all of the recompletion methods.

<u>Lost Circulation:</u>

All the methods have similar risk in certain areas for instances lost circulation is a common risk in most of the methods. When removing the casing in methods which call for milling a section conventionally or with spiral cuts or sidetracking the well out a window, lost circulation can be a major problem. Lost circulation hinders the hole cleaning ability of the mud, therefore formation cuttings and metal chips or shavings will not be removed properly from the hole making it very difficult to complete the milling distances required. Proper hole cleaning is necessary for re-completion of the well. If lost circulation becomes a major issue during operations, then it is recommended to switch from a mud system to an aerated water system. The method of perforating the casing into the formation through the casing does not have a problem with lost circulation therefore it presents only a minimum risk.

<u>Tool failure or malfunction:</u>

Tool failure or malfunction is a very common problem in high temperature geothermal wells. In perforating the well the hole must be full of water to help cool the guns until discharged. This will not be problem after the bottom of the hole has been plug and the casing filled with water. However, tool failure in section mills should be discussed. Section mills and even the spiral cutting mill employ retractable arms that are collapsed into the tool when run in the hole, when in position the pump will then pressurize the tool which deploy and extend the arms. All the arms are dressed with tungsten carbide cutting chips that will cut through the casing initially and then expand out to a given distance. Once completely deployed, it will then proceed downward in a drilling action to mill up the casing stub sticking up. The arms are long enough that it will scrape into the formation removing cement and a small amount of the formation surface. The problem with these tools, much like the under-reamers, is that material cuttings and metal shavings can get under these arms preventing them from collapsing back into the tool body. This will result in stuck pipe. A risk we must always be aware of when milling with retractable blades. Some tool manufacturers have installed shear pins into these arms. So with enough force pulling up, the rig could shear the pin allowing the arms to move freely back into the body of the tool or the arms can be sheared off completely, allowing them to fall to the bottom of the well.

Other tool failures may occur that must also be considered. Bridge plugs and packers may not set properly for sealing off the bottom of the hole. The internal diameter of the casing needs to be scraped or cleaned to get proper sealing. The whipstock orientation in the sidetrack method may also present a problem. Again, the casing where the whipstock is to be set, the casing needs to be scraped or cleaned. Another issue is the whipstock turning after it has been milled off and a sidetrack notch started, this would essentially close the window. Again, clean casing is needed in the area where the whipstock is set. Another problem associated with sidetracking the well is the original cement job just outside the area where the window was cut. If the annulus of that casing does not contain cement, the bit may want the follow that void space alongside the casing making it difficult to perform directional work. All mechanically functioning downhole tools may have relative tool failures, therefore spare parts and spare tools must be available on location to change out or repair.

Unable to break the Cement bond:

When making a spiral cut on the casing, which is a relatively new technique, one must make the spiral cut with a tool that has retractable arms. These arms and the difficulty involved in opening and closing these make it very similar to the section mill, however another problem exist with this method. Once it is cut is made, will the rig be able to pull it hard enough to break the casing's cement bond with the formation. The risk here is if the time is spent cutting the casing can it be pulled free and removed or pushed to bottom. As this is an experimental technique, there currently is not a solution to this risk.

There are risks associated with any wellbore operation and this section has described just a couple of them. Risks such as blowouts, twist offs, and stuck pipe are all normal risks when entering a wellbore. It is absolutely critical that industry standard practices are utilized to reduce the potential for these risks to occur. It is crucial to inspect all tools and equipment before entering a wellbore.

CONCLUSIONS

After reviewing all the information provided and development of planned options, it is evident that these wells can be re-completed at shallower depths. The options range in costs from the simple perforation of the new zones to the most difficult and costly procedure; to cut a window and sidetrack the well to a new bottom hole location. The ODDEG rig should be suitable to perform the tasks required for abandonment of the bottom hole and some of the recompletion methods for shallow zones. Recompletion methods that require higher torques and weights may not permit the ODDEG rig to perform the operations. Prior to the start of any operation the rig and all equipment should be specifically chosen in order to complete the work in a timely and cost efficient manner.

It is recommended to review all data and documents included in this report prior to making any decision to recomplete. Further evaluation needs to take place in order actualize the costs that ODDEG will encounter during any of these operations. In terms of ranking the options laid out in this report; refer to Table 9 – Ranking of Recompletion Techniques. These recompletion methods were ranked by cost, by risk and by success potential. The cost and risk ranking is quite simple. However the success potential measures the potential that the rig will make contact and communicate with the potential productive formations. This does not mean that the formations will contain fluid or generation potential, but it means the success of re-opening a previously sealed off formation for testing.

Table 9 – Ranking of Recompletion Techniques

Ranking	By Cost	By Risk	By Success Potential
1 (Best)	Perforating	Perforating	Sidetracking
2	Section Milling	Section Milling	Section Milling
3	Spiral Cutting Perforating	Sidetracking	
4 (Worst)	Sidetracking	Spiral Cutting	Spiral Cutting

As you can see perforating is by far the cheapest and least risky. The reason is that the drill string or working string never really exits the casing. Instead most work is performed inside of the casing which greatly reduces the potential risks of this operation. However, it does not represent the best success potential because of several factors; the cumulative flow area created by the perforations may not be sufficient to produce enough fluid for electric power generation, the formations in question may be damaged by drilling or cement and may hinder flow, and shot placement may miss the targeted zones.

Sidetracking is the costliest option, but it also provides the greatest potential success because the entire formation with the potential for flow would be exposed to a new wellbore that is drilled. This allows for a 360° field of flow from a previously uninhibited formation. However, this option is somewhat risky due to standard drilling risks during sidetracking.

Prior to the start of the recompletion a determination must be made as to each method will be used on each well. A basic equipment list for each operation has been developed and these items should be located, purchased and sent to the site prior to rig crews beginning to set up the rig. Specialty service personnel should also be on site available to carry out each of the operations as needed. With proper timing and supervision, we feel that these recompletions should be successful.