Success of Multiple-leg Well Completions at the San Jacinto-Tizate Geothermal Field, Nicaragua

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Keywords: Drilling plan, multiple-leg well, cost-benefit, decision tree, whipstock, inflatable packer.

ABSTRACT

In 2010 Ram Power commenced a drilling programme to secure additional field production and injection capacity required for the San Jacinto 72 MWe expansion project. This involved the drilling of 5 new production wells and 1 new injection well to provide the total steam (598 t/hr) and brine injection capacity (1,520 t/hr) required.

In late 2010 SKM completed a review of Ram Power drilling results, leading to recommendations for changes to the well targeting strategy, and drilling and well testing procedures. As a follow on task, SKM assisted Ram Power in developing and implementing a drilling plan which had the primary objective of securing the remaining steam and injection capacity in the most cost effective manner and in the shortest possible timeframe.

The Drilling Plan identified an opportunity to enhance the capacity of a number of existing wells using either chemical or mechanical workover techniques. One component of the San Jacinto Drilling Plan that was particularly successful was the use of multiple-leg well completions in certain situations, which resulted in an estimated cost saving of US$6M and a 10 week saving on schedule.

This paper provides case studies for the use of “forked” wells for production (well SJ12-2) and injection (well SJ11-1) applications. It describes a number of key considerations that need to be taken into account as part of well design, implementation and long-term operation, and provides a cost-benefit assessment of the single vs. multiple leg approach.

1. INTRODUCTION

1.1 Project Background

The San Jacinto-Tizate geothermal project is located in northwestern Nicaragua approximately 20km northeast of the city of Leon and centrally located among a series of active volcanoes (Figure 1).

The first major exploration of the resource began in 1993 with a Russian company, Intergeoterm. The initial phase of exploration drilling concluded in 1995 with the completion of 6 wells and the partial drilling of a 7th, and confirmed the presence of a relatively low gas (<0.4 wt %) liquid-dominated neutral chloride resource, with a temperature range of 260°C – 300°C in the central upflow area.

In 2003 the project was acquired by Polaris Energy Nicaragua S.A., who was assisted by SKM in evaluating the resource potential and in developing and implementing a strategy for the commercial development of the resource. A 10 MWe back pressure plant was commissioned in 2005 using the existing wells. The first stage of resource expansion required additional drilling during 2007-08. This new phase of drilling confirmed that the wells with excellent production (>20 MWe) and injection capacity (>500 t/hour) could be successfully constructed.

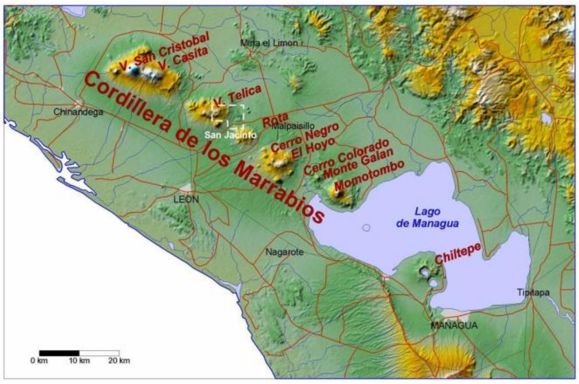

Figure 1: San Jacinto project location.

1.2 Phase 1 and 2 Expansion Project

Following the acquisition of Polaris by Ram Power in 2009, a drilling program was initiated by Ram Power in 2010 to increase the project generation capacity to 72 MWe net using 2 x 36 MWe Fuji Electric steam condensing turbines, to replace the existing 10 MWe back pressure plant. Phase 1 was successfully commissioned in December 2011, with Phase 2 expected to be on line in late 2012.

This paper describes some of the key drilling initiatives that resulted in successfully securing the additional production and injection capacity required for the expansion of the San Jacinto-Tizate Geothermal Project.

2. REVIEW OF 2010 DRILLING RESULTS

During 2010 Ram Power embarked on drilling campaign to secure the additional production and injection requirements for the Phase 1 and 2 expansion projects. In late 2010 after a succession of commercially unsuccessful wells Ram

Power commissioned SKM to undertake a detailed review of these drilling results, and provide some recommendations for increasing the probability of future success (SKM, 2010). This review identified a number of improvement opportunities which were then implemented on subsequent wells. These actions were described by Lawless *et. al*. (2011), and included:

- Replacing the use of bentonite mud with water for drilling the production sections of the wells;
- Re-analysis of geological data and downhole logging results to develop a revised well targeting strategy;
- Implementation of additional field surveys to assist with well targeting. These included magnetic, gravity, and soil gas flux – shallow temperature surveys;
- Improvements on water supply to the rig;
- Retention of big hole well design;
- Use of continuously slotted liners for the entire production section;
- Replacement of S-shape well profiles with conventional J-shape profiles for improved targeting of steeply dipping structural permeability and to minimise drag during drilling;
- Removal of directional mud motor at the earliest opportunity, enabling increased flow rates for hole cleaning;
- Performing well acid stimulation work on one well which was clearly mud damaged;
- Identification of workover opportunities to enable cost-effective improvements to well productivity. This included sidetracking of subcommercial wells, and forked completions to preserve moderate production found in the original leg; and
- Adoption of a more thorough completion test and well discharge testing procedures for better resource understanding.

3. PRODUCTION AND INJECTION DRILLING PLANS

Following the succession of unsuccessful wells leading to the review of drilling results, Ram Power commissioned SKM to develop and implement a production drilling plan (SKM, 2011a) and an injection drilling plan (SKM, 2011b) to secure the remaining production and injection requirements for the project. This plan was developed in conjunction with the Ram Power technical team with the primary objective of obtaining the necessary additional steam supply and brine injection capacities in the most cost effective and time efficient manner.

Decision trees were developed for each of the drilling plans to help define the criteria for well completion and drilling success, and to determine the most appropriate sequence for subsequent wells (Figure 2, see attachment at rear).

The drilling plans considered opportunities for well workovers to expedite production enhancements in wells that were either subcommercial or only marginally productive. In the latter case, two wells were completed using multiple-leg methodology so that the production obtained in the original leg could be maintained. Case studies for the use of multiple-leg well completions for production and injection well applications are discussed in this paper.

Currently, there are thirteen active wells at the San Jacinto project, including nine producers, and four injectors. The borefield configuration comprises a central production area with injection sectors to the north and south (Figure 3).

4. APPLICATION AND DESIGN OF MULTIPLE-LEG WELLS

The cost of drilling production and injection wells is one of the major and most variable capital investments associated with developing geothermal projects, and can strongly influence the economic viability of developments. Optimising well design to best exploit reservoir conditions, while minimizing cost is a fundamental component of overall project commercial success. One option for reducing drilling cost is to drill multiple-leg wells.

The use of multiple-leg wells is relatively uncommon in the geothermal industry, compared to other workover techniques such as sidetracking. It has been previously used with success, most notably by Chevron in South East Asia (Stimac et al., 2010), and at the Geysers Field in the USA (Yarter et. al., 1991).

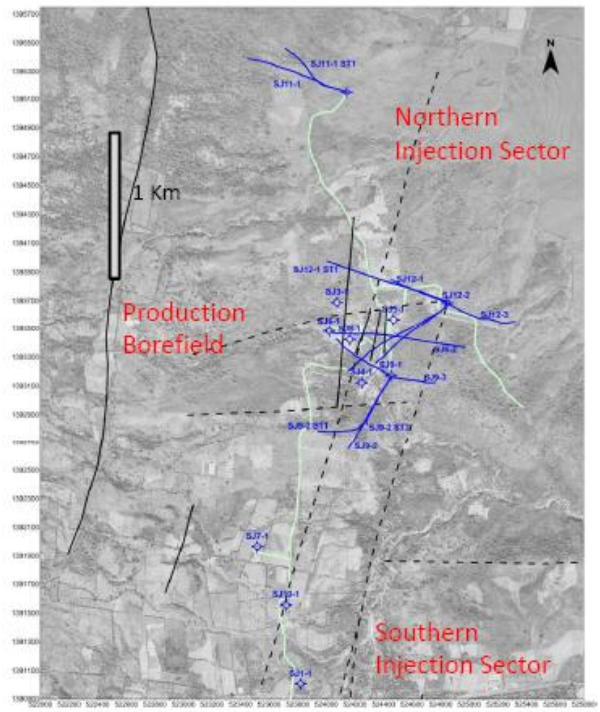

Figure 3: San Jacinto Production and Injection Borefield, and main structures (black).

4.1 Advantages of Multiple-Leg Wells

There are a number of benefits to drilling multiple-legs or forks when planning and implementing a drilling programme. The major advantages include:

1. There is a significant improvement and impact on the overall project schedule and budget management. Multiple-leg wells are completed sooner and at less cost than an equivalent number of new wells.
2. Drilling and finding costs ($/MW) are minimised resulting in more efficient reservoir exploitation.
3. There are reduced costs associated with rig moves and skids.
4. Fewer surface locations are needed resulting in less wellhead equipment and more efficient use of surface drilling sites. There is an environmental benefit in reducing the number of surface locations and associated well pad infrastructure.
5. Pipeline and construction costs are reduced with fewer well tie-ins to the production/injection system.
6. Marginal production or injection is preserved and still utilised after drilling a second leg.
7. The knowledge gained from the original leg means resource related risks (e.g. temperature and permeability) in the second leg are significantly reduced with large potential upside.

4.2 Potential Constraints and Key Considerations

There are many considerations which need to be assessed prior to and during the implementation of multiple-leg well completion. Some of these are regarded as potential constraints, or perceived disadvantages, and include:

1. Risk of failure due to various mechanical aspects of the wellbore completion. These include successfully installing and retrieving the equipment required to drill the fork leg, the possibility of damage to the integrity of the casing surrounding the 'window' milled for the fork leg, and the potential of formation collapse within a short section of unlined wellbore required for the initial section of the fork leg.
2. Requirement for directional drilling and detailed understanding of geometrical relationship of well track and target(s) to minimise interference effects between legs.
3. Increased complexity of multiple-leg completion requires necessary equipment and expertise to implement effectively the operation and minimise downtime.
4. Consideration needs to be given to any future remedial work, re-entry and well monitoring. It is very difficult to re-enter the fork leg following the removal of the whipstock assembly. This increases the importance of thoroughly characterising each leg with well completion tests (e.g. PTS surveys and injection testing) before whipstock removal occurs.

The final objective and desired results are to end up with two or more separate legs producing or injecting from a common wellbore, both completed with perforated liners and both drilled to specific targets to facilitate well spacing. There are several challenges, but with proper job design, equipment, technology and expertise, the risks are minimal and the potential rewards very significant.

5. GENERAL PROCEDURES FOR DRILLING MULTIPLE LEG WELLS

The general procedures applied for the drilling and testing of the two multiple-leg wells at San Jacinto included the following steps:

1. A suitable forking interval is selected. This is typically near the production casing shoe (PCS) and should be located where:
   (a) There is an interval of strong formation to reduce the risk of formation collapse within the short unsupported openhole section.
   (b) There are no permeable zones. This is to enable effective cement placement around the milled section, minimise drill fluid losses while milling the window, and also minimise the potential for inducing steam entry into the window interval.
   (c) The whipstock can be located at the appropriate depth such that the window can be completed in between casing couplings for ease of milling and to avoid damage to the couplings.
2. The original well is isolated with an inflatable packer followed by a layer of sand and cement. The layer of sand (usually 3-5m) is to provide a safety buffer on top of the packer and prevent the cement from interfering with later retrieval. The cement layer provides a base to set the whipstock and anchor assembly.
3. The cement is cleaned out to a calibrated depth with respect to the casing collar locations. If available, a casing collar log provides better depth control. This depth control for placement of the whipstock is to facilitate efficient milling and sidetracking operations.
4. A retrievable whipstock assembly (Figure 4) is run and oriented to a desired direction with the objective of facilitating immediate directional separation when initiating the new leg. A Measurement While Drilling (MWD) tool is recommended for this orientation. It is more precise and controllable.

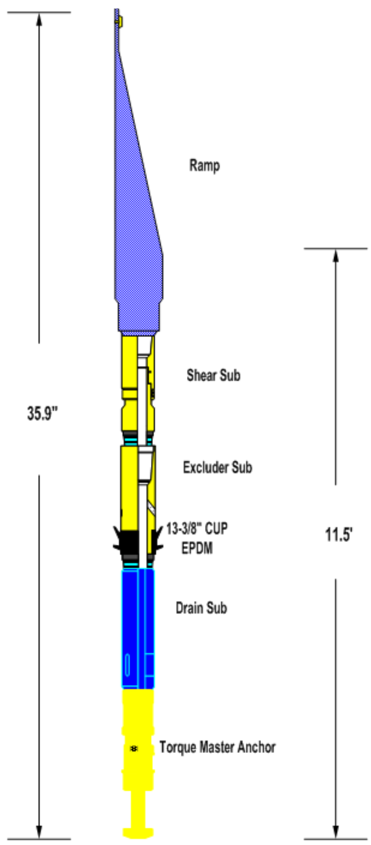

Figure 4: Schematic of retrievable whipstock assembly.

5. The anchor assembly is set on top of the cement. The milling assembly is then disengaged from the whipstock ramp (Figure 5) and casing milling is initiated. Multiple milling assemblies are used to establish a complete "window" in the casing and initiate a new hole into the adjacent formation.

Figure 5: San Jacinto whipstock ramp.

6. A separate leg is directionally drilled from the production casing to a desired reservoir target.
7. A new perforated liner is installed. It is very important during placement that the top of the liner is 5 to 6m below the bottom of the whipstock ramp to allow for any thermal expansion of the liner after the whipstock has been removed and the well is exposed to flowing temperatures. However, the liner installation can be problematic if any fill is encountered at the bottom. Diligence is necessary when preparing the wellbore prior to running the liner and making sure any hole sloughing is mitigated.
8. Injectivity testing and/or production logging are performed to evaluate and assess the new leg.
9. The whipstock assembly is retrieved. A fixed lug retrieving tool and stabilized assembly is used. A retrieval slot on the whipstock ramp is located and engaged. Overpull is applied to shear the disconnect and then the whipstock and anchor assembly are recovered.
10. The cement and sand are cleaned out to the top of the packer. The packer is latched, released and recovered. The original leg is re-opened as an active wellbore.
11. Well completion and production discharge testing and analysis are conducted for the combined wellbore.

6. CASE STUDY – PRODUCTION WELL SJ12-2

Drilling of the initial leg of the SJ12-2 well was completed by Ram Power in January 2011. The well encountered moderately good permeability but was terminated earlier than planned at a measured depth of 2,288m due to a stuck drill string that was eventually left in the hole.

Well output testing confirmed production capacity of 4 MW, which was lower than expectations but with evidence that the fish left in the hole was restricting steam flow. In early 2011 a decision was made to return the rig with the objective of preserving the existing production and drilling a second leg toward a new reservoir target.

After successfully setting the packer and whipstock assembly a window was milled in the lower part of the 13 3/8" production casing. Three milling runs were required to complete the window.

The forked leg was drilled to 2,207m with a 10° azimuth change and 23° increase in deviation (Figure 6). The intended reservoir target was achieved with intersection across a productive fault system and significant permeability encountered.

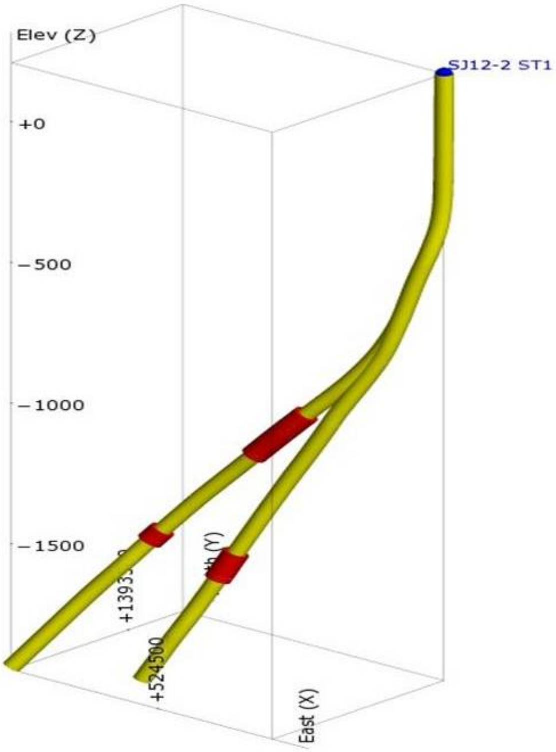

Figure 6: 3-D Illustration of SJ12-2 with main permeable zones shown in red shading.

A 9⅝" liner was installed and stopped with the liner top about 1m below the bottom of the whipstock. Some difficulty was initially encountered re-entering the liner. A drill pipe assembly was run inside the liner and the bottom of the wellbore was cleaned out allowing the liner to settle to the bottom. This placed the top of the liner approximately 7m below the bottom of the casing window. The final well completion of SJ12-2 is shown in Figure 7.
Prior to whipstock retrieval well completion testing was performed to evaluate and characterise the reservoir parameters. This was particularly important given that this leg of the well could not be easily accessed by logging tools once the whipstock had been removed.

During retrieval of the whipstock, the anchor assembly became separated and was left in the hole. Fishing tools were run to recover the anchor tool. It was discovered after examining the tool that a part of the assembly was packed with metal cuttings preventing any pull on the anchor and resulting in the safety sub shearing. The lesson learned was that more attention should be given to proper hole cleaning when milling operations are being performed. This can be accomplished with proper drilling mud maintenance and pumping high-viscosity sweeps following the casing milling.

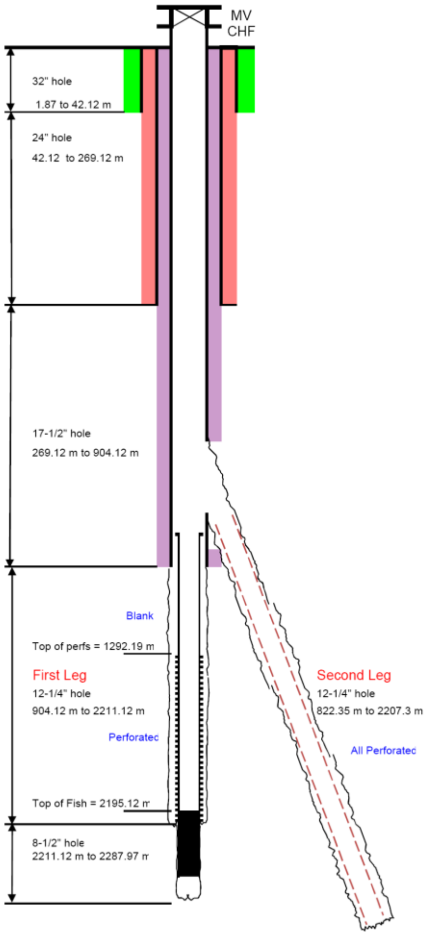

Figure 7: SJ12-2 well completion details.

A successful forked completion was achieved using Baker Hughes packer and whipstock tools. The directional target and desired well spacing were achieved as planned. A long-term discharge test was performed and the estimated power production capacity with combined flow of both legs was almost 20 MWe. This represented almost a 400% improvement in power production capacity compared to the original well. Compared to drilling a separate new well on this same site, the total benefit of drilling a secondary leg was a cost savings of approximately US$2.3M and a schedule reduction of almost 4 weeks. Production from SJ12-2 has not been commissioned and is still waiting final completion of the Phase 2 power plant construction, which is expected in late 2012.

7. CASE STUDY – INJECTION WELL SJ11-1

This well was planned and successfully completed as a dedicated injection well in 2011. The well is the first and only well drilled in the northern injection sector at San Jacinto. A second leg became necessary to achieve the target injection capacity while also helping to meet a very tight power plant commissioning programme.

Very slow drilling rates and significant lost circulation were encountered in a thick sequence of hard andesitic lava flows that dominated the upper cased section of the well and added many unscheduled days to the completion of the original well. Given this knowledge and experience, the plan to drill a second leg became even more cost effective rather than drilling a second new well from the same site. Also, there was good permeability identified in the initial leg, so it became a strategic opportunity to maximize injection capacity with a second leg and meet target requirements for the project.

The first leg was drilled to a measured depth of 2,003m T.D.) and completion testing indicated an injectivity index of 15.5 t/hr/bar. While this equated to a relatively good hot injection capacity of 400 t/hr at a delivery pressure of 15 barg, it remained well short of the maximum theoretical capacity based on the large diameter casing design, and also the overall field needs.

A Schlumberger Formation Micro Imaging (FMI) survey was undertaken to confirm the lithological and structural characteristics of the 9 5/8" production section of the well. A failure with the inclinometry measurements meant that a comprehensive assessment of the permeability controls in the original leg was not possible. As a consequence it was decided to 'twin' the original leg of the well by drilling a subparallel welltrack approximately 150m north of the original leg (Figure 8).

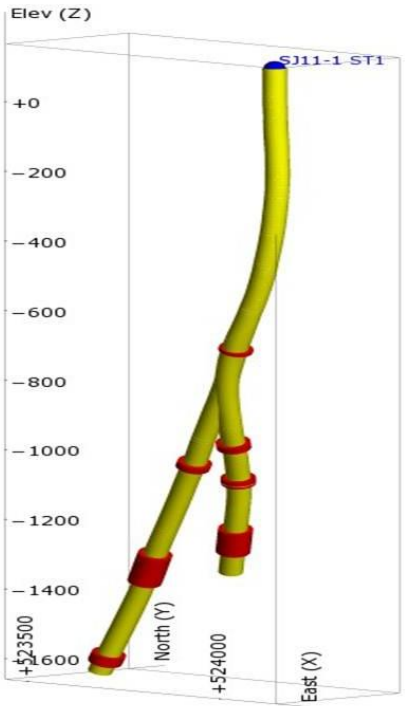

Figure 8: 3-D Illustration of SJ11-1 with main permeable zones shown in red shading.

The construction details of the SJ11-1 forked completion are provided in Figure 9.

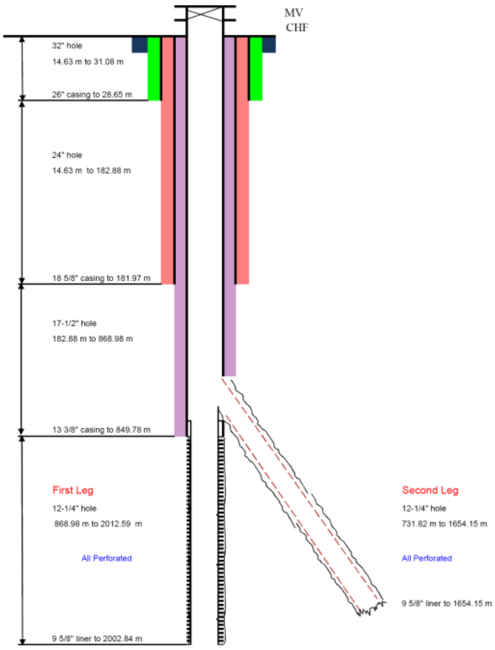

Figure 9: SJ11-1 well completion details.

Following the completion of drilling, an injectivity test was performed on the combined legs and resulted in a similar result of 47.5 t/hr/bar. The second leg completion resulted in almost a 300% improvement in measured injectivity. Compared to drilling another new well from this same site and encountering similar problems in the upper section, the total benefit of drilling a secondary leg provided a cost saving of approximately US$3.7M and a schedule reduction of almost 6 weeks.

After a 25 day shut-in period, a pressure temperature survey was conducted in the original leg, which showed a down flow of fluids from the forked leg into the original leg. The hot injection capacity for this well was estimated at 825 t/hr for the combined legs at a targeted delivery pressure of 15 barg. The well is currently the highest capacity injector for the field and the multiple-leg completion has provided the necessary capacity that would have otherwise required another separate new well. The SJ11-1 well has been in service since the commissioning of Phase 1 in December 2011 and is maintaining injection performance as tested.

8. CONCLUSIONS

A review of 2010 Ram Power drilling results and the implementation of modified practices in drilling and well testing provided a positive impact in securing the additional production and injection capacity required for project expansion.

Drilling and completing multiple-leg wells using retrievable packer and whipstock systems proved to be a very practical and cost effective technique for optimising well performance and enabling the San Jacinto expansion project to achieve the established commissioning targets.

The estimated savings in cost and time to the overall project resulting from the forked completions of SJ12-2 and SJ11-1 totalled almost US$6M and 10 weeks. This resulted in a very significant benefit to project budgeting, scheduling, and financial viability.

Baker Hughes equipment, technology, and expertise proved to be very reliable and instrumental to the project success and in minimizing the risks associated with completing multiple-leg wells.

SKM contributed a vital role in well targeting, advocating drilling production intervals with water, and post-well evaluation and analysis to optimise well performance and reservoir management.

Consideration of multiple-leg well completions should be included in any field development strategy as a cost effective option for enhancing both production and injection well performance.

ACKNOWLEDGEMENTS

The authors would like to thank Ram Power for the opportunity to present the results of this work. Thanks are also extended to Phil White, Jim Lawless, Aaron Hochwimmer and Paul Groves for their technical review of this paper.

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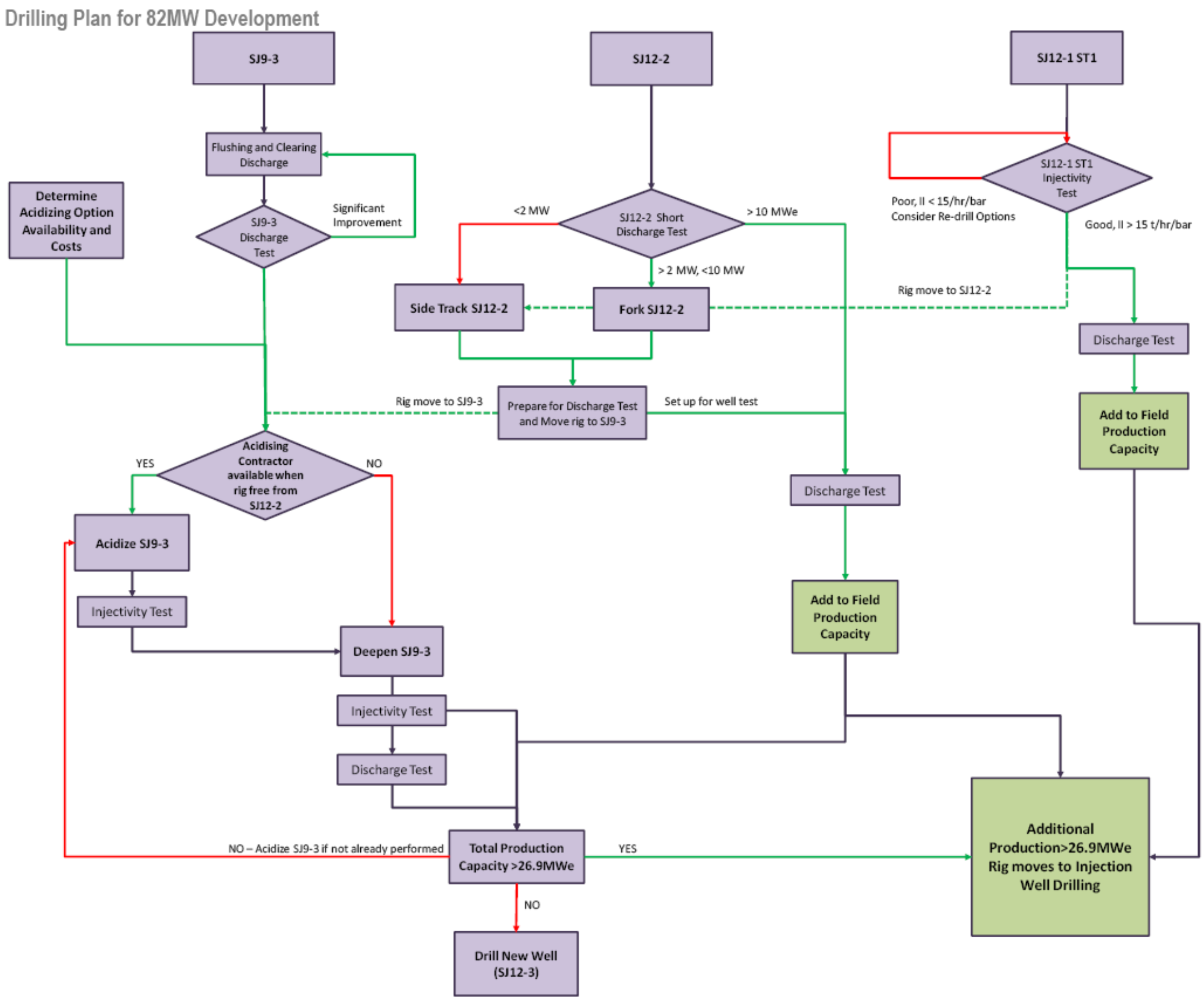

Figure 2: Decision Tree for San Jacinto Production Drilling Plan.

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