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Big Bore Well Drilling in New Zealand – A Case Study

John Bush and Christine Siega

Mighty River Power Ltd, Hamilton New Zealand

John.Bush@mightyriver.co.nz; Christine.Siega@mightyriver.co.nz

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ABSTRACT

A typical standard geothermal well in New Zealand is a 9-5/8" cemented production or injection casing completed with a 7" perforated liner in an 8.5" hole. In 2006, one geothermal operator began looking at big bore completions as a way to improve the cost per megawatt of its drilling operations by reducing the number of wells required per field. After an initial review, it was concluded that a big bore well completed with 13-3/8" cemented casing and 9-5/8" perforated casing could increase the productivity or injectivity of wells by 66% for a cost increase of 17% and minimal additional risk. Starting in 2007, big bores were included in the drilling program in the Mokai, Kawerau and Rotokawa geothermal fields.

Nine standard wells and twelve big bore wells, both production and injection, were drilled from 2007 to the beginning of 2009. The results of the drilling and testing program show that big bore wells can successfully reduce drilling costs as well as the number of wells required, but are dependent on the characteristics of the field.

1. INTRODUCTION

Standard bore geothermal production well KA 41 was completed in the Kawerau Geothermal Field in December 2005 (Figure 1 – Taupo Volcanic Zone – North Island New Zealand). Subsequent modelling of the well indicated production was wellbore limited and that increasing it from a 7" to a 9-5/8" big bore perforated liner would increase the production capacity by 66% for a 17% increase in cost and a 7% increase in time to drill. The investigation predicted no impact on well spacing due to well interference. Additional benefits for big bores included added flexibility during drilling if hole problems were encountered and increased wellbore scaling allowance in injection wells.

Potential drawbacks included decreased wellbore velocity from pressure or enthalpy decline in later years inducing wellbore slugging over the long term and a larger standby capacity required in case a large bore well needed to be withdrawn from service on short notice.

Increased capacity would be partially offset by the need to maintain greater idle production or injection capacity necessary for full generation in the event that any one well was lost but this would be more than offset by the delay needed for makeup drilling.

There would be no impact on production well spacing at Kawerau (where the first well was to be drilled) with minimal additional drawdown of reservoir pressure affecting the big bore flow rate.

Any long term decrease in well bore velocity requiring a re-sleeving of the wellbore would be well in the future and be more than offset by the increase in production.

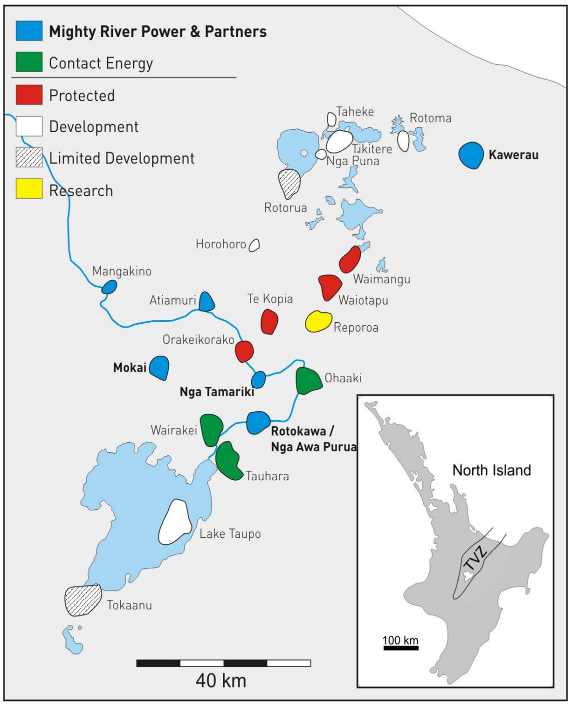

Figure 1: Taupo Volcanic Zone – North Island New Zealand.

Slightly longer drilling times would be required handling the increased volume of top hole cuttings and handling the bigger tools and casings. This would be partially offset by increased bit life and better penetration with the larger bits in the reservoir hole section.

Big bore completions would allow added flexibility during drilling with more room for re-drills, casing repairs, and fishing jobs and the option to drill ahead with 8.5" hole for additional production.

In injection wells, a big bore completion provides an increased scaling allowance.

Approval was given in April 2006 to go forward with the program and the first big bore well MK 17 spudded in the Mokai Field in Jan 2007.

This paper will highlight the drilling program and drilling results for the standard and big bore wells followed by the testing results and the conclusions drawn by the analysis of drilling and testing.

2. WELL DESIGN DRILLING PROGRAM AND DRILLING RESULTS

2.1 Standard Well Design

A standard well design starts with a 30” precollar or conductor cemented at 15-20 m at the time the location is built followed by 20” surface casing cemented at 100 m in 26” hole, 13-3/8” anchor or intermediate casing cemented at 400 m in 17.5” hole and 9-5/8” production liner cemented in 12-1/4” hole into the top of the production reservoir at about 1000 m and hung from the shoe of the anchor casing. The 9-5/8” liner is then cemented back to surface with a tieback string. The 8.5” production hole is drilled to total depth of the well usually in the range of 2000 m to 2500 m and completed with 7” perforated liner set on bottom.

The hole is drilled with low solids bentonite mud in the cemented sections and drilled with water and polymer sweeps in the production zone utilizing blind drilling once returns are lost into the producing zones.

Major problems include lost circulation and down-hole equipment failures. Air drilling was not utilized in the productions zones as it offered no increased productivity or reduced hole problems and it increased well costs and reduced bit life.

Five inch grade G drill pipe was used to drill the wells sometime limiting total depth due to torque and drag limitations. Most wells were directional, but presented no exceptional problems. Cuttings build-up in the lower sections of the well sometimes limited the depth. In holes where these problems were experienced, the perforated liner was run and hole size reduced to 6” to get additional depth before running 4.5” perforated liner. This hole reduction offered only limited success as additional depth and productivity were usually limited.

Initial well testing during drilling includes rig pump injection into the well to measure an injectivity index which is correlated to an estimate of production or injection capability. Water is continually pumped into the well once returns are lost to keep the well from heating up and trying to flow as well as keep producing/injection zones open.

2.2 Big Bore Well Design

A big bore well design starts with a 40” precollar cemented at 15- 20 m at the time the location is built followed by 30” surface casing cemented at 100 m in 36” hole, 20” anchor casing cemented at 400 m in 26” hole and 13-3/8” production liner cemented in 17.5” hole into the top of the production reservoir about 1000 m and hung from the shoe of the anchor casing. The 13-3/8” liner is then cemented back to surface with a 13-3/8” tieback string. The 12-1/4” production hole was drilled to total depth of the well usually in the range of 2000 m to 2500 m where 9-5/8” or 10-3/4” perorated liner is set on bottom.

Casing and hole sizes were kept to most of the same sizes as the standard bore design to minimize the down hole tool, casing and bit size changes so the big bore wells could be started on a short schedule with minimal tool size changes. The 9-5/8” perforated liner was originally planned until 10-3/4” perforated casing was procured.

Planned drilling mud properties and blind drilling in the production hole section would be similar to the standard hole. Hole cleaning properties in the upper sections would require additional viscosity. It was anticipated lost circulation would be more costly to cure with the larger hole size and torque and drag would increase as the hole size increased.

Until a 29.5” blowout preventer (BOP) was available, the 26” hole for the anchor string was drilled under 24” line pipe surface casing with a 21-1/4” BOP stack by piloting 17-1/2” hole and then opening it with an under-reamer to 26”. The 20” casing was run with special clearance couplings and no centralizers to fit through the 21-1/4” BOP stack consisting of an annular, blind and pipe rams. Under-reaming the hole section proved problematic and as soon as available, the rig rotary table was upgraded to a 37-1/2” table and the 26” hole was drilled conventionally under the 30” casing with the 29.5” annular preventer thus eliminating the 24” line pipe. The “rotary table” was set in the rig floor, but was not functional. Rotary was provided by a top drive.

Other “problems” were not anticipated with big bore drilling. It was anticipated that surface casing would take longer to run as it was welded together instead of threaded and that all operations would take longer due to the increase size of tools, larger volumes of mud and cement for drilling, casing cementing and lost circulation. Rate of penetration would be reduced in the upper hole sections as a larger volume of cutting would be handled, but penetration and bit life in the reservoir section might improve due to improved performance of 12-1/4” bits versus the 8-1/2” bits.

Once the concept was proven that big bore drilling was successful, many optimization programs could be conducted in the area of casing sizes, bit section, mud motor usage, etc. In instances where hole problems developed, the 10-3/4” liner (perforated or cemented) could be run allowing continued drilling to total depth without the problems associated with picking up a smaller drill string and reducing hole size to 6”.

2.3 Actual Drilling Results

2.3.1 New Standard Wells

Nine standard wells drilled during the time of the study were mostly trouble free ranging from 23 days to 42 days to drill with the average of 33 day to drill from spud to rig release. The depths of the standard wells ranged from 1950 m to 2707 m with an average of 2306 m. Trouble time on the wells ranged from 0 to 4 days with an average of under 2 days. The wells included one injector, six producers and two step-out wells that turned out to be dry holes.

Drilling costs per well ranged from NZ$3.3 million to NZ$6.0 million with the average of NZ$4.2 million to drill from spud to rig release. Costs exclude rig move and location costs as well as excessive injectivity testing prior to rig release and are clouded by well cost increases of 22% over the two year period and fluctuations in the NZ$/US$ exchange rate. Well costs are affected by many variables. They are presented in this study in a general sense, but are the primary driver of drilling decisions along with well productivity and safe operations.

2.3.2 Big Bore Wells

There were 10 big bore wells drilled during the time of the study ranging from 31 days drill to 71 days with an average of 51 days to drill from spud to rig release. The depths of the big bore wells ranged from 1833 m to 3100 m with an average of 2456 m. Trouble time on the wells ranged from 0 to 16 days with an average of just under 8 days.

Drilling costs per big bore ranged from NZ$4.9 million to NZ$9.1 million with the average of NZ$6.9 million to drill from spud to rig release. Costs exclude rig move and location costs as well as excessive injectivity testing prior to rig release as in the standard wells.

Two big bores were left out of the study as they turned out to be exceptionally problematic taking 158 days 90 days to drill: one to 3200 m due to a twisted off a mud motor that couldn't be fished, washed out the tool joint on an open hole whipstock, three unsuccessful attempts to set a whipstock inside casing and then one whipstock that failed as it could no be re-entered, and the second one drilled to 2992 m with a key seat that could not be cleaned up and subsequent damaged casing that needed to be sleeved.

In the final drilling, the big bores covered a wide range of depths and drilling conditions. In order to better look at the range of outcomes, the data was additionally narrowed. If we look big bore wells less 2450 m in depth, it catches the four wells that were mostly trouble free and it is seen that outcome is an average of 39 days to drill to 2087 m at a cost of NZ$5.45 million. This might be a more normal cost of big bores. The deeper big holes wells could have made better use of the ability to set an additional liner to reach to 3000 m.

Taking a look at big bore wells deeper than 2450 m, the results are not nearly as good. This group covers the eight wells drilled deeper ranging from 2484 m to 3147 m at an average depth of 2794 m in 75 days at a cost of NZ$9.8 million.

If we further refine the numbers by dropping out the exceptional well that took 158 days to complete and normalize the remaining seven wells to 2150 m the averages become 52 days to drill to a big bore costing NZ$6.7 million.

While the standard bore wells were essentially trouble free, the big bore wells experienced a number of problems, but mostly at depths below 2450 m. The four best big bore wells at an average depth of 2087 m experienced only one tool failure when a drilling jar parted and one well had exceptionally high lost circulation. There was no nearby standard well in the in the study to compare losses. These wells were all in the Mokai and Kawerau fields.

The six big bore wells drilled deeper than 2450 m experienced a number of issues associated with big bores including under-reamer problems on the earlier wells and problems with the larger liner hanger not seen with the standard bore version. Many of the problems were associated with pushing the wells to maximum depths (tight hole with stuck pipe) and extended reach to pass a legal boundary with subsequent key-seat when the hole was dropped back to vertical. Most of these wells were for injection drilled on a difficult ridge to get to deep injection with an extended reach.

Drilling Cost and Times are summarized in Table 1.

3. TESTING RESULTS

3.1 Observations on Performance of Existing Standard Sized Well

After drilling, the permeability and the production/injection performance of the wells are measured by an injection testing. For production wells, a further discharge testing is conducted.

Tables 2, 3, and 4 summarize the results of these tests on the standard wells drilled at Kawerau, Rotokawa, and Mokai.

The Kawerau reservoir appears to have a uniform and very high permeability throughout the entire field. Wells drilled in the field to the same depth show consistent production and injection flows for a particular casing size design.

Almost all of the wells showed very high permeability during injection testing; the injectivity index calculated ranging from 50 t/h.b to 300 t/h.b. At these values injection or production flows are limited by the casing size of the wells.

Unlike Kawerau, Rotokawa has non-uniform permeability. The permeability ranges from poor to moderate, although there are some parts of the field that show high permeability.

Production wells drilled at Rotokawa, even with the same casing size, show a wide range of production flow rates depending on permeability (Table 3).

Table 1: Drilling Cost and Time Summary.

Wellbore Description	Days	Depth (M)	Problem Days	Cost NZ$	Remarks
Standard Wells					
Original Standard Well Estimate	37	2150	0	$3.8 million	Contained no trouble contingency.
Nine Standard Well Average	33	2306	2	$4.2 million	Rates/material costs up 22% over two year study as drilling time decreased.
Big Bore Wells					
Original Big Bore Well Estimate	39.4	2150	0	$4.5 million	Contained no trouble contingency.
Ten Big Bore Well Average	51	2456	8	$6.9 million	
Four Big Bore Wells < 2450 M	39	2087	4	$5.5 million	
Six Big Bore Wells > 2450 M	59	2702	10	$7.8 million	
All 12 Big Bore Wells Drilled	63	2558	17	$8.3 million	Includes two wells > 90 days

Table 2: Testing Results of Kawerau Wells.

Well Name	Well Type	Well casing	Deepest permeable zone, m	Injectivity Index, t/h/b	Productivity Index, t/h/b	Injection Capacity (t/h) at 10barg WHP	Production Flowrate (t/h) at commercial WHP (22 barg)
PK6	production	std	2100	90	36	-	494
PK7	production	std	2100	40	15	-	411
KA41	production	std	1910	60	110	-	516
KA42	production	std	2000	300	411	-	522
PK4A	injection	std	1600	100	-	530	-
PK5	injection	std	2500	20	-	394	-
PK3	injection	Std w 7" & 4.5" liner	1600	46	-	436	-

Table 3: Testing Results of Rotokawa Wells.

Well Name	Well Type	Well casing	Injectivity Index, t/h/b	Productivity Index, t/h/b	Production Flowrate (t/h) at commercial WHP (30barg)
RK17	production	std	200	38	538
RK5	production	std	50	7	343
RK25	production	std	23	1	85
RK26	production	std	101	Not tested yet	Not tested yet
RK27	injection	std	13	Not tested yet	Not tested yet

Table 4: Testing Results of Rotokawa Wells.

Well Name	Well Type	Well casing	Injectivity Index, t/h/b	Productivity Index, t/h/b	Injection Capacity (t/h) at 10barg WHP	Production Flowrate (t/h) at commercial WHP
MK5	production	std	100	170	-	405
MK3	production	std	32	4.2	-	130
MK14	production	std	35	-	-	240
MK16	production	std	30	-	-	310
MK18	explo	std	0.4	-	-	Nil
MK19	explo	std	0.5	-	-	Nil
MK21	explo	std	8.9	-	95	-
MK20	Injection	std	35	-	300	-
MK17	Injection	bb	20	-	400	-

The most permeable production well, RK17, has very high injectivity (~200 t/h/.b) and the flow is wellbore limited. Wells with moderate permeability, like RK5 (50 t/h.b injectivity index), have flows of about 343t/h. Tight wells, like RK25 (23 t/h.b injectivity index), have flows at about 85t/h.

Mokai wells also have varying permeability (Table 4). The permeability ranges from poor to moderate.

What is common among the very permeable wells with standard-sized casing is that the maximum flow is not more than 540t/h due to the wellbore friction.

3.2 Evaluation of Standard Bore Test Data and Expected Output of Big Bore Wells

Further evaluation of the existing data from standard wells was done to determine the increase in injection or production flows if these wells were completed with larger diameter casing.

For injection wells, a straight forward calculation was done involving pressure drop along the casing and liner, and the injectivity index value. The aim of the calculation is to determine the difference in injection capacity at 10barg WHP for the standard, and the big bore sized well at different injectivity index. The 10 barg WHP was chosen, as this is usually the maximum operating WHP when the injection wells are online to the station. The permeable zone depth and casing/liner setting depths in the calculation are based from a single well (PK4A) for uniformity.

Figure 2 shows the result of the calculation. The result suggests that a big bore well will generally have a similar injection capacity to a standard well at low injectivity index 5-10 t/h/b. The difference is greater at higher injectivity index.

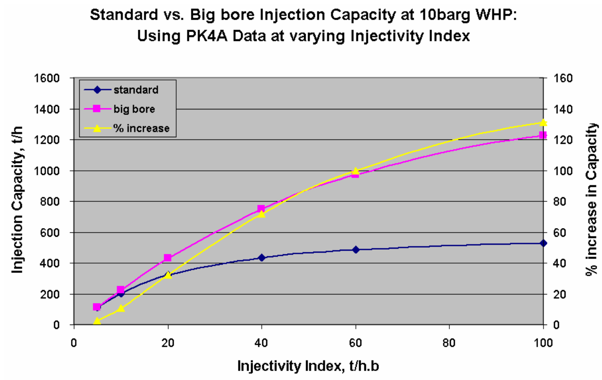

Figure 2: Standard vs. Big bore Injection Capacity at 10barg WHP.

Applying the standard drilling cost of NZ$4M for standard wells and NZ$5.6M for big bore wells, Figure 2 is again plotted in terms of increase in injection capacity of a big bore well from a standard well per $M of drilling cost. Another set of data using higher cost (NZ$6.7M) of big bore drilling is plotted, to determine the change in % increase per million for wells that are drilled longer. The resulting plot is on Figure 3.

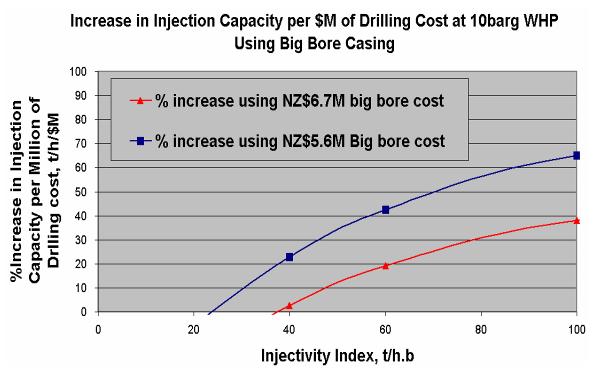

Figure 3: % Increase in Injection Capacity of Big Bore over standard bore per $M.

Figure 3 shows that at usual 10 bg operating WHP, the use of a big bore for injection wells is only justified when the injectivity index is at least 23 t/h.b. At this injectivity index value, the injection capacity per $M of drilling cost is the same for both the standard and the big bore well. However if there is an increase in the cost of drilling due to longer drilling period, the minimum injectivity index requirement also increases. In Figure 3, for a drilling cost of NZ$6.7M, the big bore is only justified if the injectivity index is at least 40 t/h.b.

The production flow difference between big bore and standard bore wells were computed using wellbore simulation. Again, data from a common well configuration is used for uniformity. The wellbore configuration of Rotokawa well RK5 was used to determine the change in flows for a standard and big bore casing at different productivity index. The flows are computed at 30 barg WHP as this is the operating WHP of the wells at Rotokawa.

The result is plotted on Figure 4. Consistent to the result of Figure 2, the production flow of the big bore well is higher than the standard well starting at 5 t/h.b productivity index. The difference is again higher as the productivity index increases.

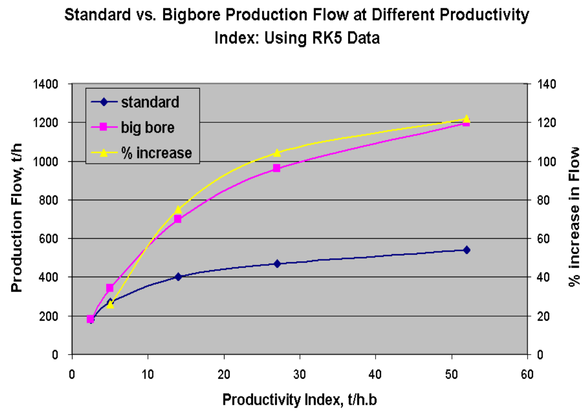

Figure 4: Standard vs. Big bore Production Flows at 30barg WHP.

In terms of increase in production flow per $M of drilling cost (Figure 5), the use of a big bore for production wells is justified when the productivity index is at least 7 t/h.b. This is for a normal drilling cost of NZ$5.6M for big bore. At higher drilling cost, NZ$6.7M for example, the minimum productivity index requirement becomes 14 t/h.b.

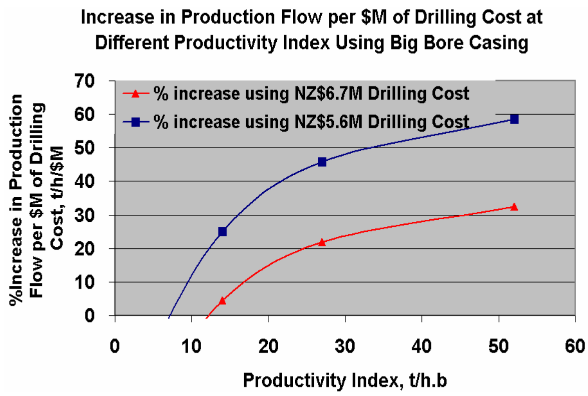

Figure 5: % Increase in Production flow of Big Bore over standard bore per $M.

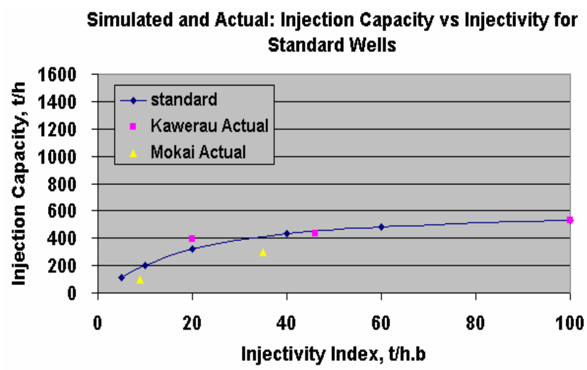

Figure 6: Simulated and Actual Injectivity vs. Injection Capacity.

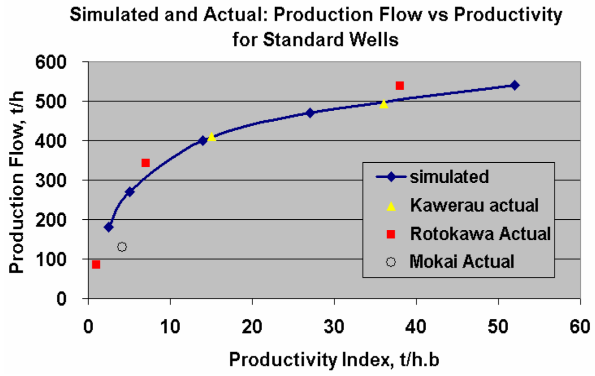

Figure 7: Simulated and Actual Productivity vs. Flow.

Figures 6 and 7 are the comparison of the simulated flows and permeability with the actual data for standard wells. Both plots show that the actual data are consistent to the simulated.

3.3 Actual Performance of Big Bore Wells

Table 5 shows the performance of the big bore wells drilled by Mighty River Power.

There are 3 production and 2 injection big bore wells drilled in Kawerau. As expected, all of them have high permeability that resulted in high production and injection flows. The fullbore production flows of KA45A and KA46 have never actually been measured because the flow is beyond the capacity of the well test equipment. Wellbore simulation of these wells shows that at full opening, they can produce 840 t/h and 1200 t/h, respectively. The performance of the big bore wells at Kawerau has justified the use of a big bore casing in this field.

The big bore injection well drilled at Mokai has a moderate permeability with injectivity index of 20 t/h.b. This injectivity index value almost meets the minimum requirement of 22 t/h.b to justify the use of the big bore casing.

In Rotokawa, 4 out of 6 big bore wells were able to meet the minimum injectivity index requirement of 22 t/h/b.

Figure 8 is a plot showing the consistency of the simulated and actual injection capacity vs. injectivity index for big bore wells.

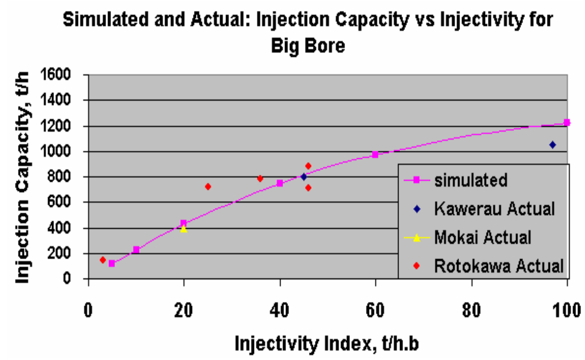

Figure 8: Simulated and Actual Injectivity vs. Injection Capacity.

4. CONCLUSIONS AND RECOMMENDATIONS

The use of big bore is highly recommended in a moderate to highly permeable reservoir. The resulting production/ injection performance of the wells with this permeability will justify the cost of drilling the big bore well.

The longer the duration of well drilling compared to a standard well, the higher is the over-all cost of drilling and the lesser the gain that can be benefited from using a big bore.

Big bore is not recommended to low permeability reservoir. There is also greater risk of using big bore to reservoir with non-uniform permeability or to reservoir with unknown permeability.

Table 5: Big Bore Performance.

Well Name	Well Type	Well casing	Injectivity Index (t/h/b)	Injection Capacity (t/h) at 10barg	productivity Index, t/h/b	Production Flowrate (t/h) at commercial WHP
Kawerau						
KA45A	production	bb	43	-	35	841*
KA46	production	bb	45	-	260	1183*
KA47	production	bb	220	-	84	1171*
KA43	Injection	bb	45	800	-	-
KA44	injection	bb	97	1050	-	-
Mokai						
MK17	Injection	bb	20	400	-	-
Rotokawa						
RK19	Injection	bb	1.2	-	-	-
RK20	Injection	bb	25	723	-	-
RK21	Injection	bb	36	781	-	-
RK22	Injection	bb	46	880	-	-
RK23	Injection	bb	3	140	-	-
RK24	Injection	bb	46	711	-	-

*** Computed using Wellbore Simulation**

The best big bore wells in the study cost approximately 30% more and took 20% more time to drill than a standard bore well which was drilled to a slightly deeper depth.

Using big bore, a lesser number of wells is needed. This consequently saves cost on well testing and other infrastructure.

If there is a need to sleeve the production casing in case there is casing damage, a reasonable opening is still left inside the wellbore. Big bores give an additional casing string to run if wellbore problems are encountered. Field experience is required to know when to run the additional string.

Under-reaming the surface hole to reach the required casing depth was very problematic and this practice changed.

Additional gains can be made by optimizing bit and hole size with the casing design by using slim line casing

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