POWERWAVE WATERFLOOD ALBERTA, CANADA

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Wavefront Technology Solutions

Location	Alberta, Canada
Operator	Intermediate Size Oil & Gas Company
Formation	31% porosity Sandstone
Reservoir Fluid	18.5° API Oil
Objective	Improve Sweep Efficiency
Tool used	Dragonfly 3.75"
Date installed	Sept/Oct 2007 – Still in operation

1. EXECUTIVE SUMMARY

Powerwave has been employed in three injection wells for 24 months to improve oil recovery from this field. Excellent results have been realized from the significant production and economic oil volume benefits that have been realized during this period:

Overall Project Results

- **68% drop in Oil Production Decline.** Oil production decline from the three production patterns dropped from a pre-Powerwave value of 3.4% per month to 1.1% per month with Powerwave. This represents a 68% reduction in the decline rate.

- **170% Increase in Oil Production.** Oil production from three production patterns (16 oil production wells) increased by 85 barrels of oil per day over the established base production decline trend of 50 barrels of oil per day.

- **Over 51,700 barrels of incremental oil to date** has been attributed to the Powerwave installations.

- **240% Increase in Oil Cut.** The average oil cut after 24 months of Powerwave stimulation has increased to 3.54% compared to 1.05% on the previously established decline trend.

Pattern 1 Results

The Northern pattern was unaffected by any change in operating conditions and represents a true test of Powerwave:

- The production increased to 52.3 barrels of oil per day from a baseline decline of 18.8 barrels of oil per day. Giving 33.5 barrels of oil per day or 175% increase.
- The production decline for this pattern has been reduced from 4.1% per month to 1.1% per month, or over 70%.
- Total production benefit for this pattern was 18,800 barrels of oil.
- The aggregate oil cut for the pattern producers was at 2.56% compared to the decline trend of 0.85%, an increase of over 200%.

Pattern 2 and 3 Results

Two of the three production patterns (centre pattern and southern pattern) had new injectors that came on line approximately 1 ½ - 2 months after the start of the Powerwave project. This has affected the results from these patterns, but a Powerwave response had already started to be seen in some of the offset production wells and significant work was carried out together with the Operator to filter out the effects of the new injectors.

General Comments

Following the very positive production response to Powerwave injection, the Operator is considering plans to work over up to seven producers near the Powerwave injectors and reinstating them to production.

This analysis has been carried out jointly with the Operator and the figures quoted are approved numbers.

The injection rate in the Powerwave injectors has been kept relatively constant during the 24 month period in order to ensure representative results to pre Powerwave conditions.

2. INTRODUCTION

The ultimate success of oil recovery using fluid flooding depends on how effectively the flooding agent pushes oil to production wells. Oil and fluid viscosity, together with the size of the pore space between rock or sand grains determines the path oil and flooding agents take through the reservoir. See Figure 1

2.1 Powerwave Flood Improvement

Oil fields exhibit heterogeneous permeability created both from the basic sedimentary layering processes and also from subsequent tectonic activities that bend or stress rock and can open natural fractures. Areas of high permeability absorb disproportionate fluid volumes and cause the flooding agent to penetrate poorly through less permeable material giving rise to poor conformance.

The Powerwave process uses a downhole system to generate fluid displacement waves in the reservoir that improves the effectiveness of how water moves through the reservoir rock. This leads to more oil being pushed towards production wells, leading to increased production and reserves over time.

3. FIELD PRODUCTION AND INJECTION ISSUES

In this field, the oil viscosity is high enough to create an adverse mobility ratio between the oil in the reservoir and the water injected to push the oil towards production wells. This results in the water tending to push past the oil causing recovery of the mobile oil to be very slow. Waterfloods, such as the one documented here, tend to produce recoverable oil at very high water fractions (over 90%).

4. POWERWAVE INSTALLATION

To effectively impact the movement of water in the reservoir, Powerwave systems need to be deployed directly in the well, in proximity to the perforated or screened interval.

In this field, three water injection wells were outfitted with Powerwave systems. A typical downhole system configuration can be seen in the left margin on page 1 and a typical surface set-up is shown in Figure 2.

5. DISCUSSION OF RESULTS

5.1 Field Area

Three injection well patterns were equipped with Powerwave systems in Sept/Oct 2007. These patterns were chosen because of their long term injection and well defined production decline.

The field is a high quality sandstone reservoir with 18.5 degree API oil. The reservoir has a single pay zone that has a net thickness of 4.3 metres (14.1 feet) thick. The reservoir is laterally continuous and vertically homogeneous. The total pattern area has been calculated to be 82 acres in extent and reservoir in these three patterns contain Original Oil In Place (OOIP) of 2.23 million barrels of oil. Figure 3

5.2 Water Injection

The injection into the pattern Powerwave injectors was kept relatively constant in order to ensure the validity of the results. The Operator specifically wanted to keep the injection in the Powerwave injectors constant in order to demonstrate if an improvement in sweep efficiency could be achieved. This is shown for each of the patterns in Figure 4 – 6.

It was planned to keep the overall injection in the surrounding injectors as constant as possible, but for Pattern 2 and Pattern 3 this was not possible due to two injector conversions that happened during the Powerwave project. The new injectors can be seen marked with a blue solid dot and a red circle on the map in Figure 4.

The total injection into the wells surrounding Pattern 1 is shown in Figure 7. As shown, the peripheral injection has been constant at around 3,000 barrels of water per day (± circa 10%) from the Powerwave system was installed until the end of 2008. Since then, however, injection has been dropping, gradually through the first half of 2009, but after July 2009, a drop in injection of approximately 25% is apparent.

Pattern 1 was not affected by changes in the surrounding area that would lead to increased production from the pattern producers.

Injection into the injectors surrounding Patterns 2 and 3 are shown in Figures 7 and 8 respectively.

5.3 Analysis Method

The well data was analysed using well test information gathered since September 2005, two years prior to the start of the Powerwave project. This enabled the establishment of a high quality base decline on a well-by-well basis, which the production following implementation of Powerwave could be compared with.

In order to minimize production increases that were not directly attributable to Powerwave a rigorous analysis was undertaken in close collaboration with the Operator. The details of this analysis are shown in the Appendix.

5.4 Project Production Benefits

Powerwave production benefits were assessed using the net production profiles for the project and for each pattern. The net production profiles were generated using 'Powerwave Base Production' data aggregated to the appropriate level. The 'Powerwave Base Production' data was calculated as described above.

The total net oil production for the 16 oil production wells is shown aggregated by pattern in Figure 10. Well by well production for each pattern is shown in Figures 9 through 11. The vertical lines on the charts indicate when each Powerwave system was installed.

Prior to Powerwave the total combined net oil production from the three patterns was showing a stable exponential decline of around 3.4% per month as shown in Figure 10. Apart from the significant production increase, it is worth noting the marked drop in oil production decline to 1.1% per month during the Powerwave project. This represents an almost 70% reduction in the pre project decline and signifies that Powerwave is gaining access to significant new economic oil volumes.

The total production at the beginning of October 2005 was approximately 270 barrels of oil per day. By the time the Powerwave systems were installed in Sept/Oct 2007, this had declined to approximately 115 barrels of oil per day. At the end of September 2009, the production from the project area wells totalled 135 barrels of oil per day.

The results from the first 24 months of operation have been a great success. The total oil production benefit attributable to Powerwave from the three patterns was circa 85 barrels of oil per day at the end of September 2009 based on a detailed well-by-well review.

This represents an increase in production over the base production trend of circa 170% as presented in Figure 11.

The incremental production volume has been calculated to be over 51,700 barrels of oil.

Figure 12 shows the total oil, water and fluid off-take from the project area pattern producers.

Worth noting is gross fluid off-take being continuously increased during the pre-Powerwave period in order to offset production decline. The gross fluid production following the start of the Powerwave has been more or less constant. The impact of this increase in gross fluid rate is to artificially bolster oil production rate, and as a result the true oil decline for the project area is likely to have been underestimated by the analysis carried out here. This makes the notable increase in oil production achieved with Powerwave even more significant.

Figure 13 shows the oil cut development for the project area wells before and during the Powerwave project. As depicted, the oil cut was following a well developed trend prior to the Powerwave project implementation.

Based on the established oil cut decline trend, the oil cut at the end of September 2009 would have approached 1.05%, instead, the actual oil cut in the project area was 3.54%, or almost two and a half times the pre Powerwave forecast. Figure 13

5.5 Pattern 1 Production Benefits

Pattern 1, Figure 14, was unaffected by any other factors during the period from September 2006 through September 2009. As a result, Pattern 1 provides the mose accurate representation of Powerwave benefits in this field without having to allocate production increases between Powerwave and new injectors as the case was for Patterns 2 and 3. For this reason, the full suite of data charts previously shown for the Powerwave project will also be shown for Pattern 1 alone.

Pattern 1 production is made up of 8 wells, and prior to Powerwave the total net pattern oil production was showing a relatively stable exponential decline of approximately 4.1% per month. Production decline during the Powerwave project was 0.85% per month, a reduction of over 70% from the pre Powerwave decline.

Production from Pattern 1 at the beginning of October 2005 was slightly less than 140 barrels of oil per day. By the time Powerwave was initiated on September 25, 2007 production had declined to approximately 54 barrels of oil per day. At the end of September 2009, production totalled 52 barrels of oil per day, almost the same as when the Powerwave commenced 24 months earlier and declining at a slower rate. Total production benefit to date attribute to Powerwave from this pattern has been over 18,800 barrels of oil.

Overall Powerwave benefit after 24 months was approximately 29 barrels of oil per day above the base decline (12 barrels of oil per day), representing a production increase of over 200% compared to the do nothing case.

Figure 15 shows the total oil, water and fluid offtake from the producers in Pattern 1.

It can be seen that there has been a gradual increase in the gross fluid during the period leading up to Powerwave implementation to offset production decline. Gross fluid production following the start of the Powerwave has been more or less constant.

The impact of this increase in gross fluid rate could artificially bolster the oil production rate prior to the start of the Powerwave project. This has not been accounted for in the analysis carried out here.

Figure 16 shows the oil cut trend for Pattern 1. Based on the established oil cut decline trend, the oil cut at the end of September 2009 would have been approximately 0.85%. With Powerwave the actual oil cut in the project area was 2.56%, or over two times the pre project forecast.

As mentioned, the results from Pattern 1 can be seen as a true and representative test of the Powerwave process. The calculated oil production benefits from the other two patterns will, therefore, be compared to the Pattern 1 results as an additional validation of the analysis work carried out to filter out the non- Powerwave incremental production.

5.6 Pattern 2 Production Benefits

Pattern 2 Figure 17 oil production is derived from 4 wells and prior to Powerwave the total net pattern oil production was showing a relatively stable exponential decline of around 2.4% per month.

Production from Pattern 2 at the beginning of October 2005 was approximately 43 barrels of oil per day. By the time the Powerwave system was installed on September 27, 2007 production had declined to just over 24 barrels of oil per day. At the end of September 2009, production totalled 41 barrels of oil per day; not far from the production level two years prior to when the Powerwave systems were installed.

Oil production benefit after 24 months for Pattern 2 has been calculated to be approximately 29 barrels of oil per day above the base decline (12 barrels of oil per day), representing a production increase of over 200% compared to the do nothing case.

5.7 Pattern 3 Production Benefits

Pattern 3 Figure 18 oil production is derived from 5 wells and prior to Powerwave the total net pattern oil production was showing a relatively stable exponential decline of around 3.0% per month.

Production from Pattern 3 at the beginning of October 2005 was approximately 86 barrels of oil per day. By the time the Powerwave system was installed on the 13th Oct 2007, this had declined to 42 barrels of oil per day. At the end of September 2009, the production had remained almost flat at 41.5 barrels of oil per day.

The overall benefit after 24 months for Pattern 3 has been calculated to be approximately 22 barrels of oil per day above the base decline (20 barrels of oil per day), representing a production increase of over 100% compared to the do nothing case.

Production increases calculated after removing incremental production from sources other than Powerwave is roughly in line with that observed from Pattern 1, so the assumptions made in the analysis can be taken to be close to the true values.

5.8 Longer Term Benefits

The results are validating the claims that the Powerwave injection process is improving the waterflood efficiency, which over time would be expected to give a higher total oil recovery for the field.

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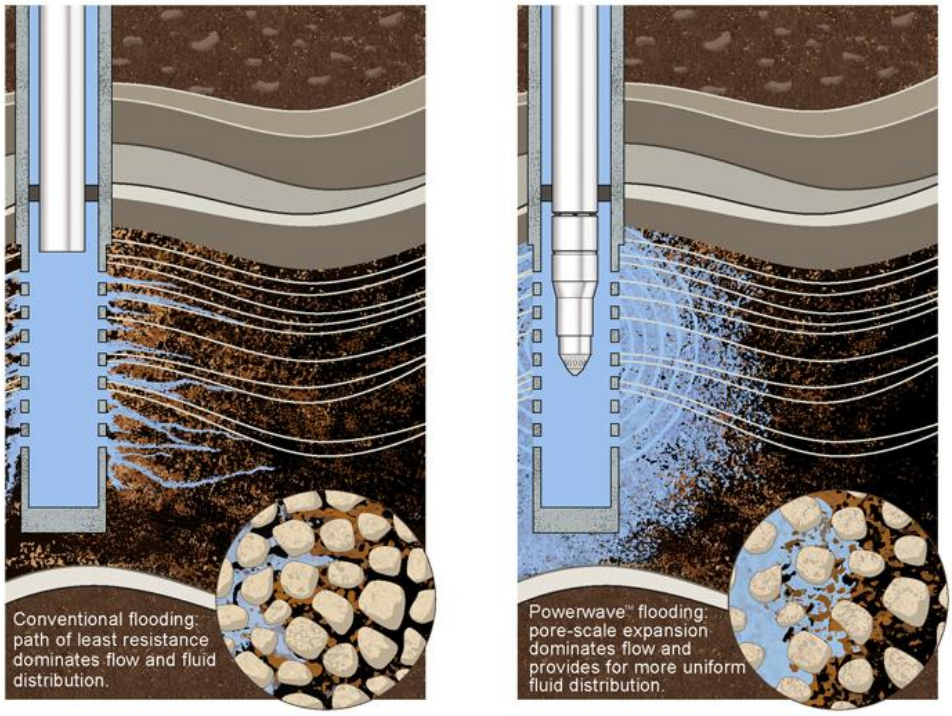

Figure 1

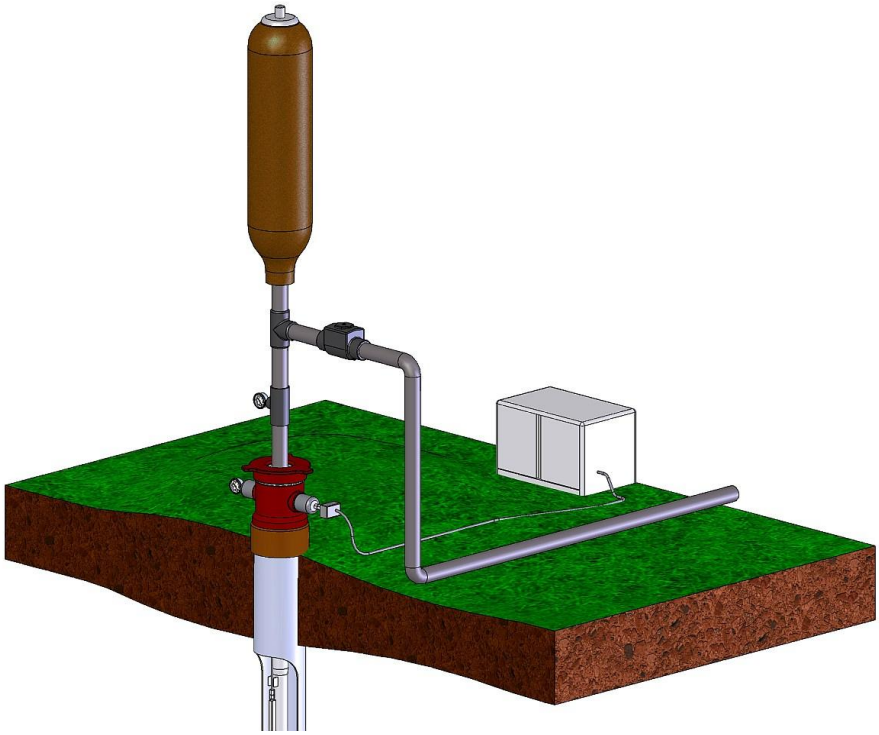

Figure 2– Typical Powerwave Surface Set-Up

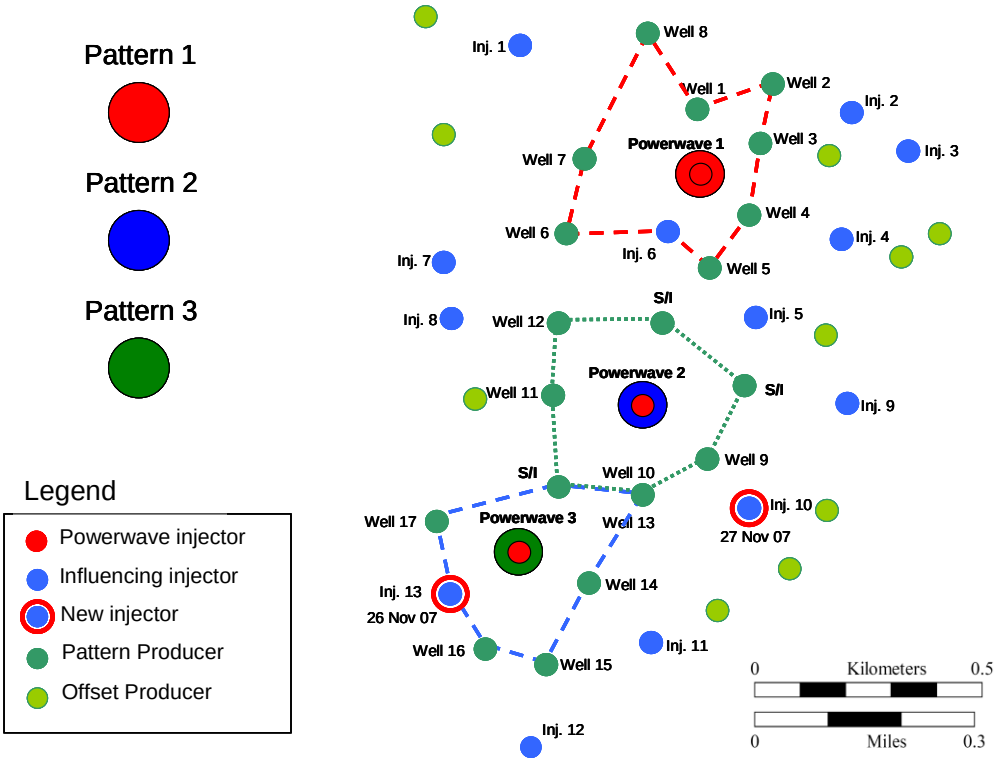

Figure 3 – Powerwave Project Area Map

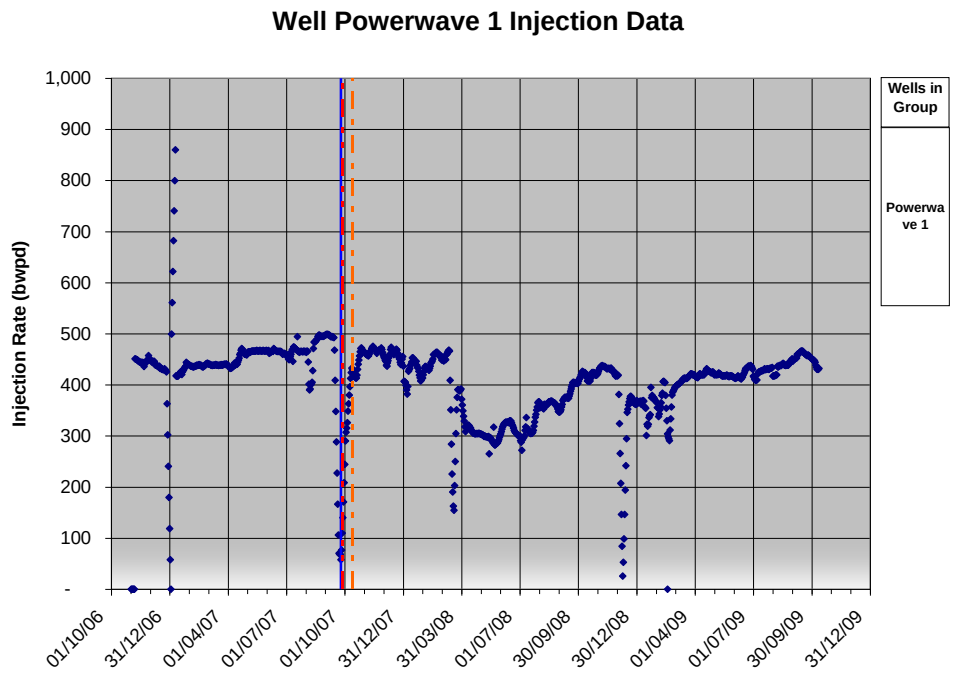

Figure 4 – Powerwave Pattern 1 Injection

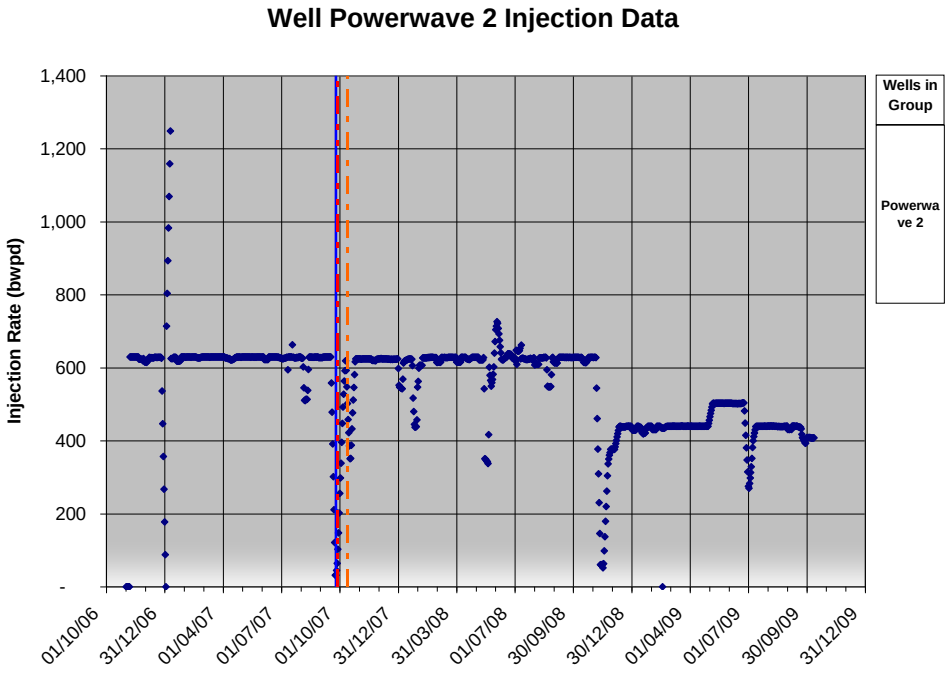

Figure 5– Pattern 2 Powerwave Injection

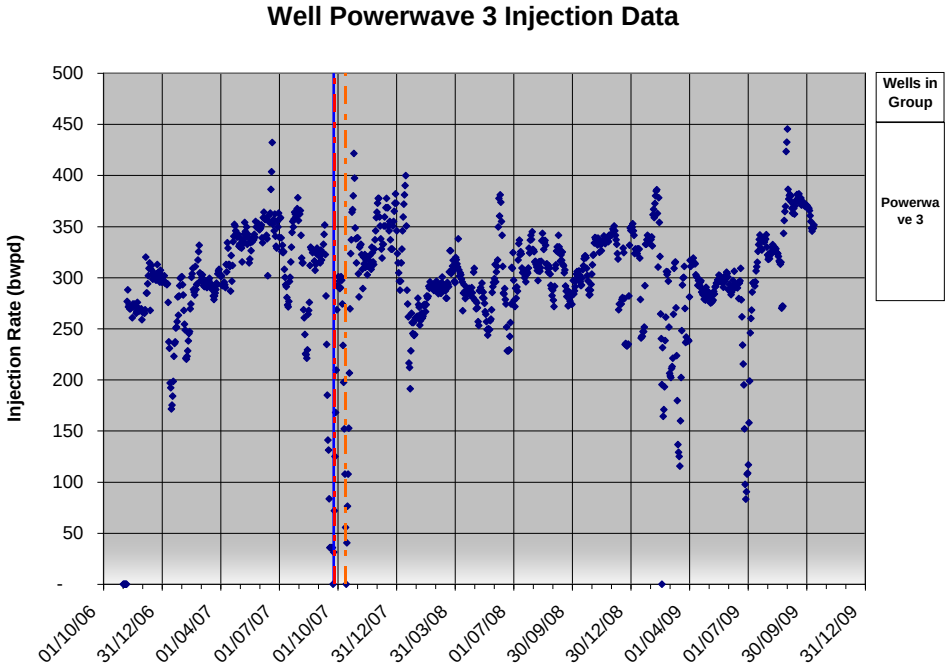

Figure 6– Pattern 3 Powerwave Injection

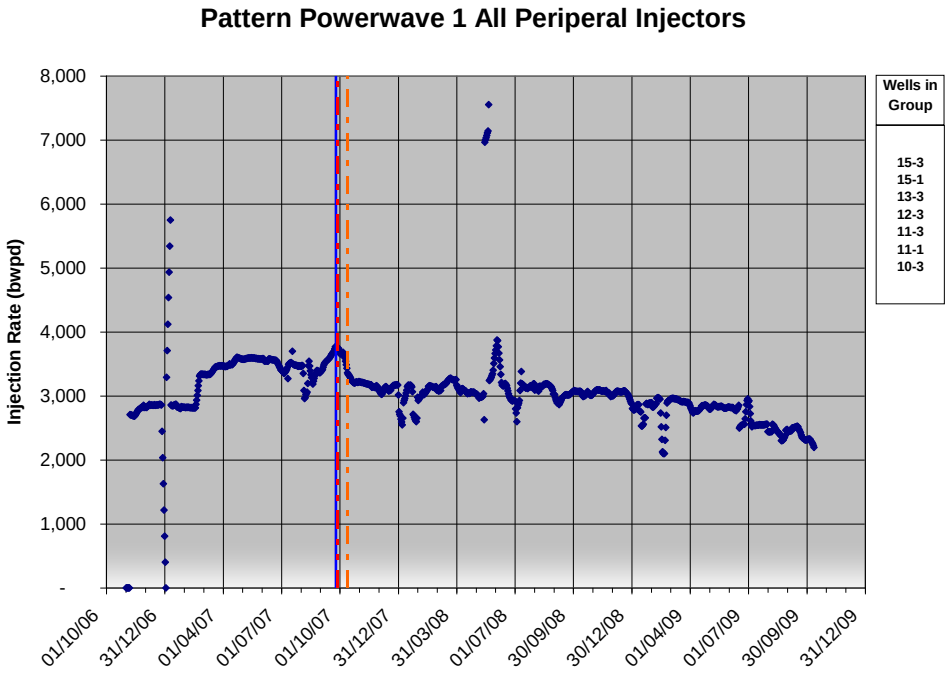

Figure 7 – Pattern 1 Offset Injection

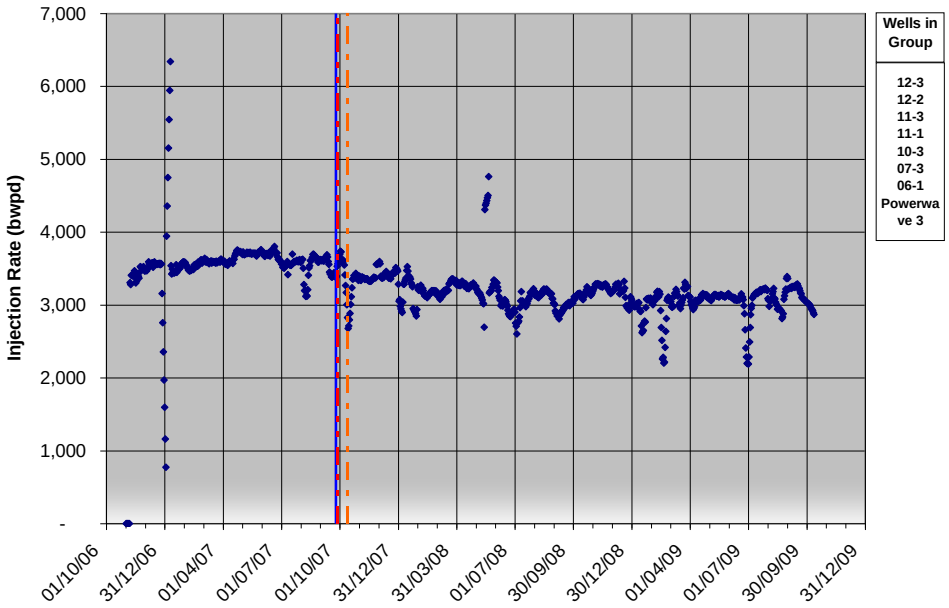

Figure 8– Pattern 2 Offset Injection

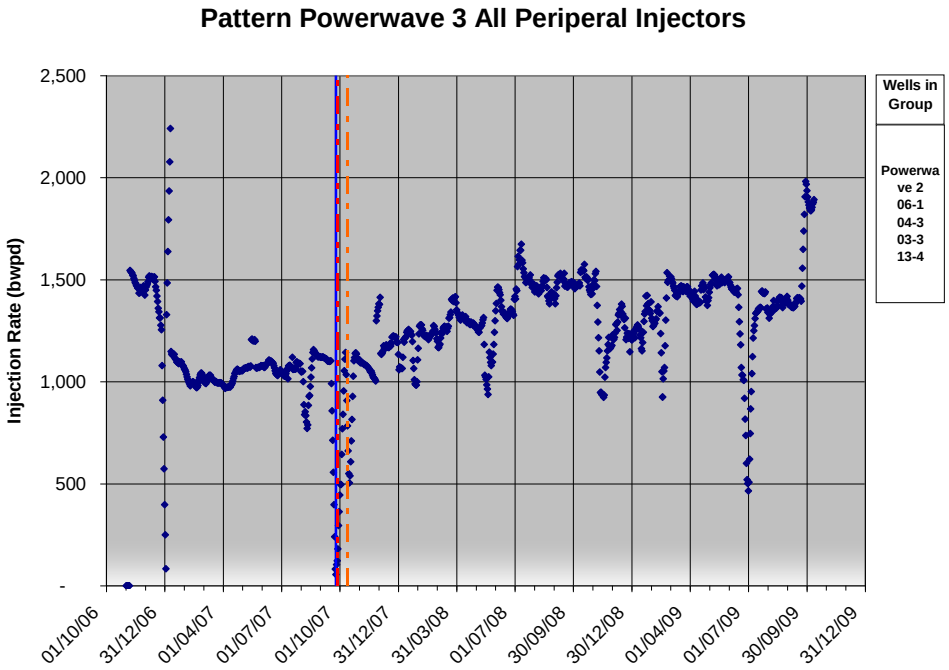

Figure 9- Pattern 3 Offset Injection

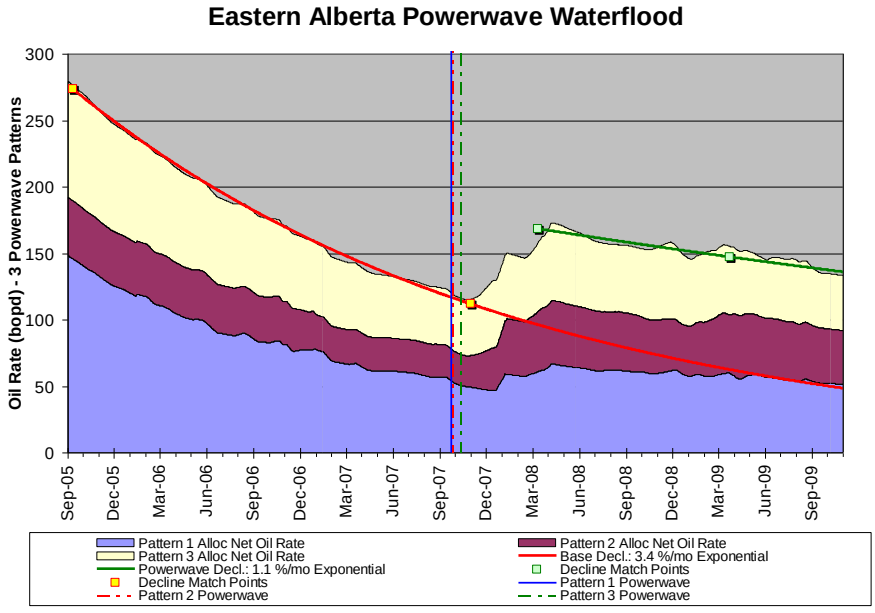

Figure 10– Project Production By Pattern

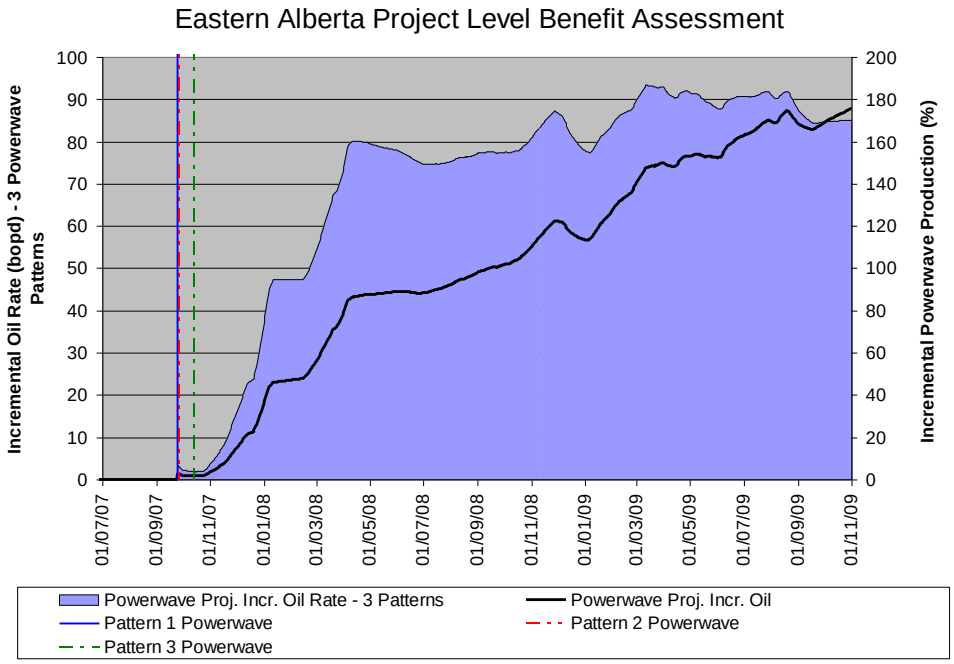

Figure 11 – Powerwave Incremental Oil Rate

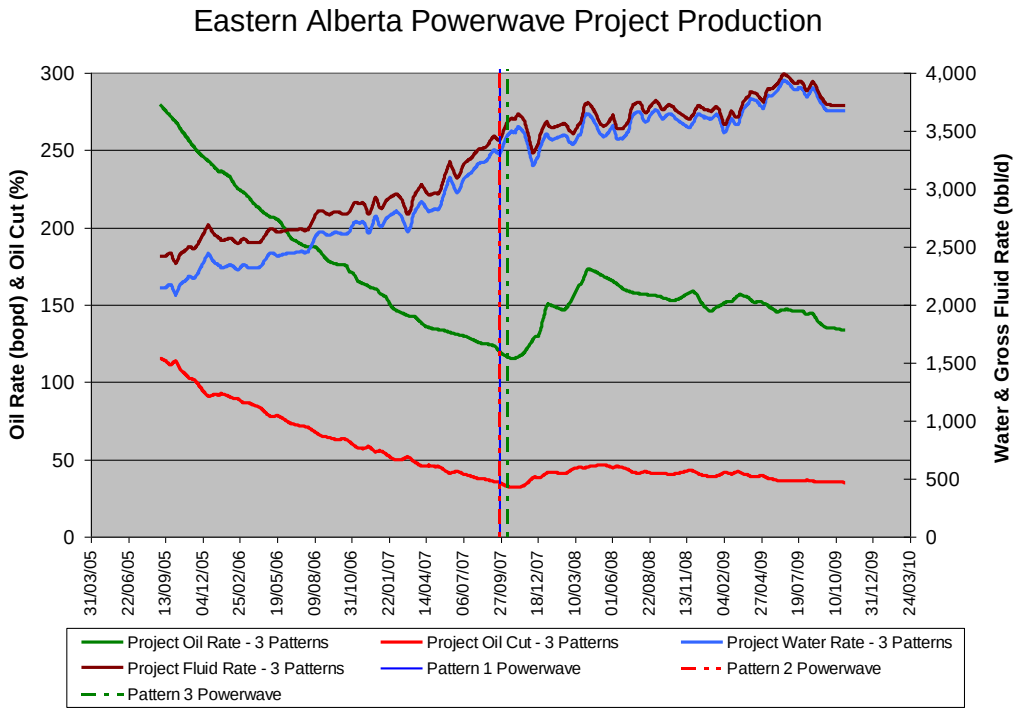

Figure 12 – Pattern 1 Oil Rate By Well

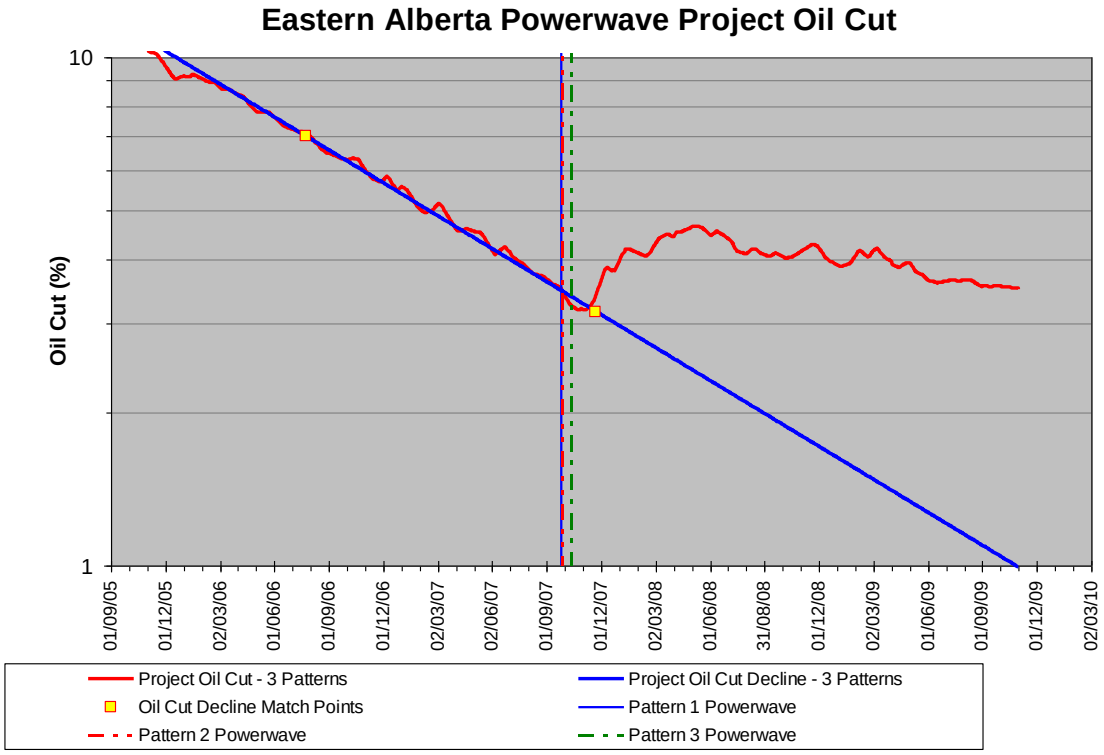

Figure 13 – Powerwave Oil Cut Development

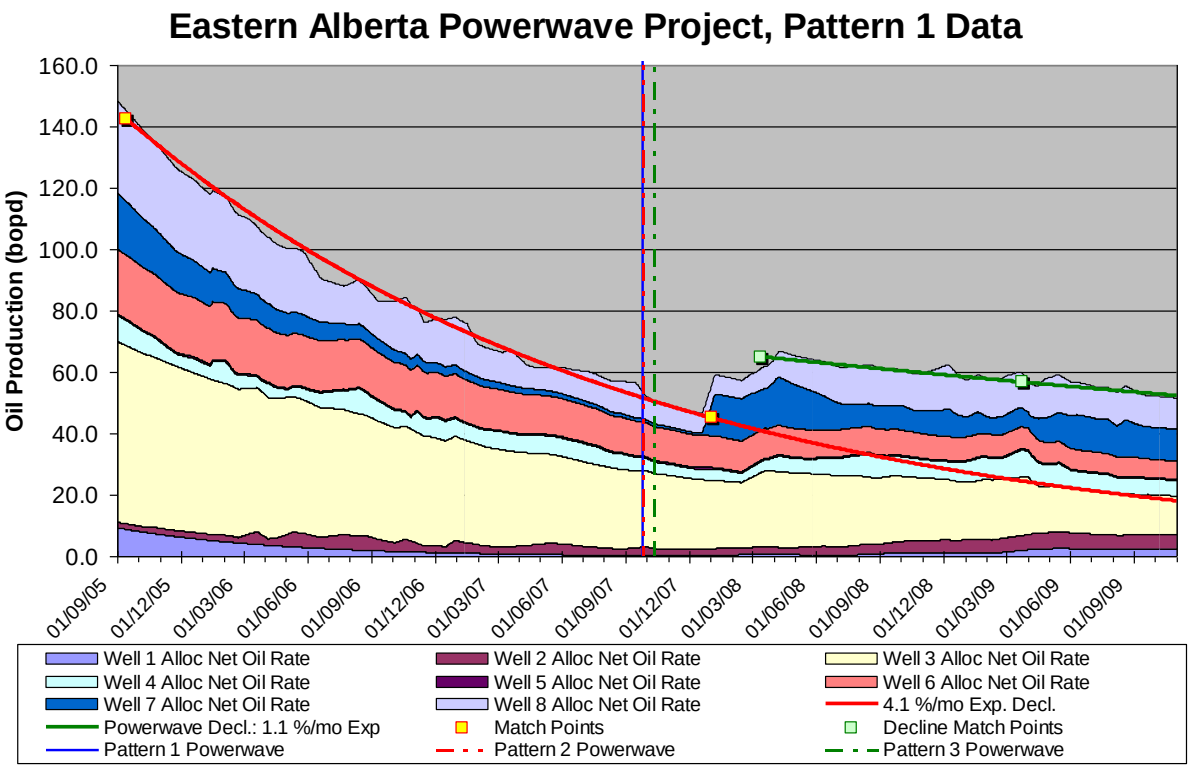

Figure 14 – Pattern 1 Oil Rate By Well

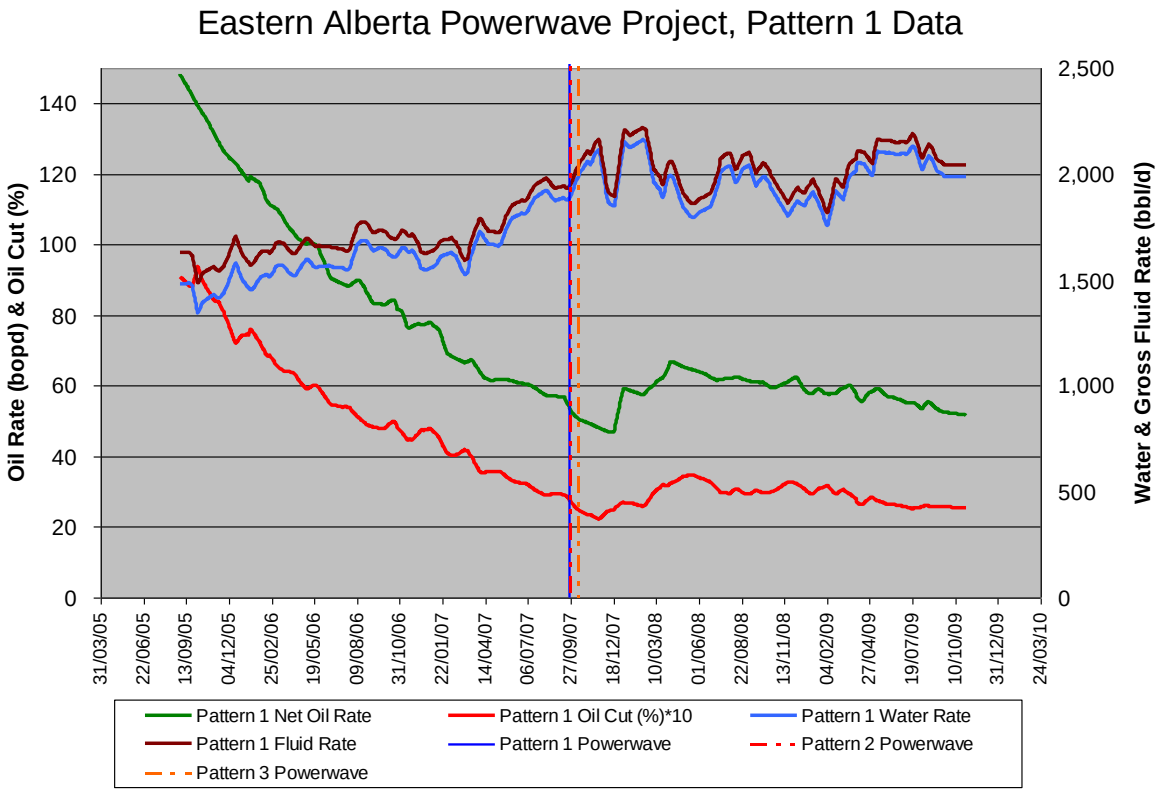

Figure 15 – Pattern 1 Oil, Water And Fluid

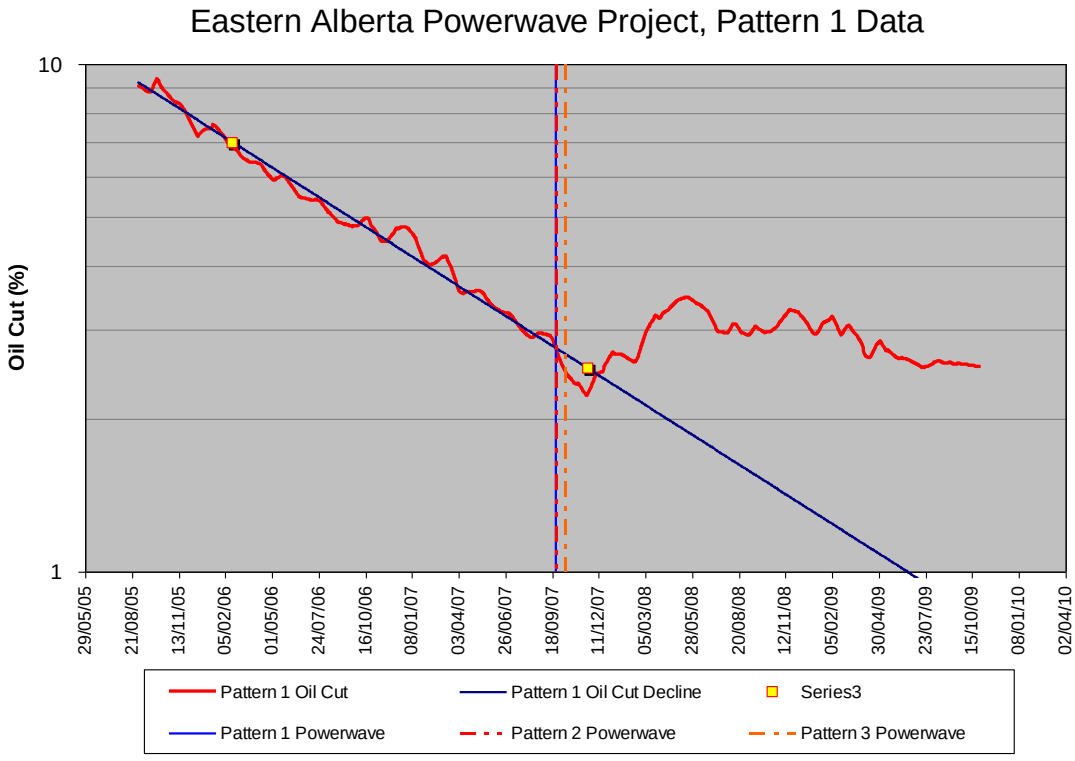

Figure 16 – Pattern 1 Oil Cut Development

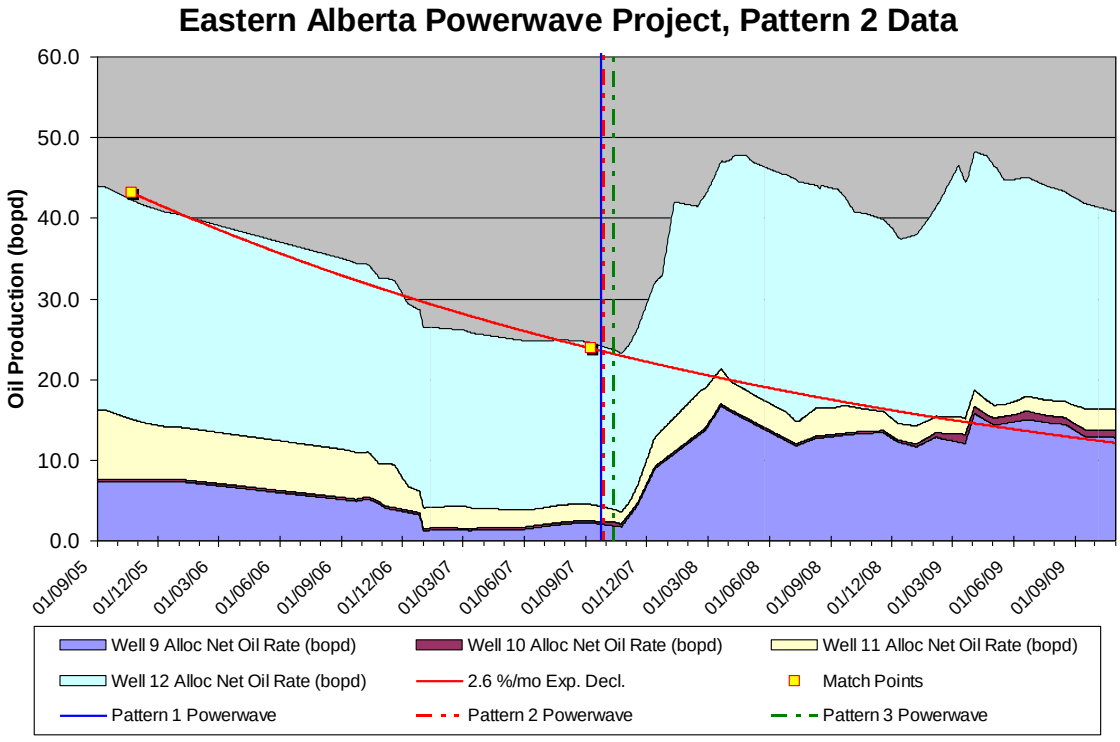

Figure 17 – Pattern 2 Oil Rate By Well

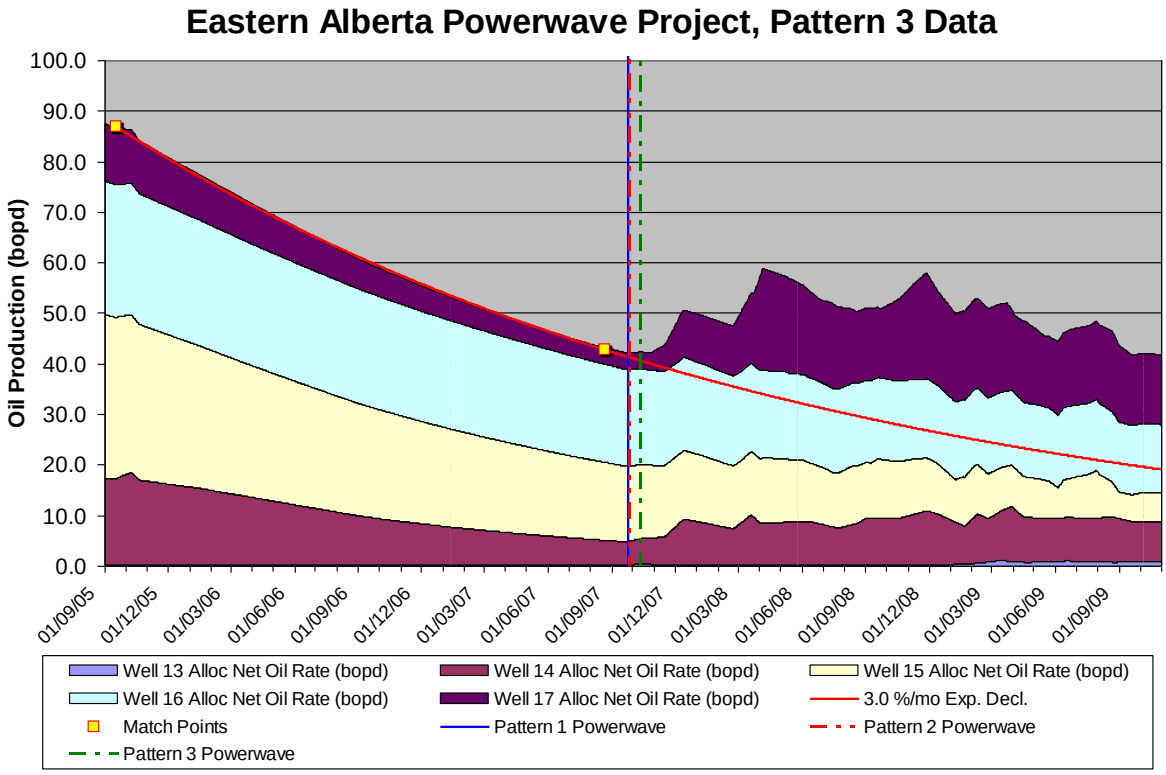

Figure 18 – Pattern 3 Oil Rate By Well