Proposed South Pierson Unit No. 2

Application for Enhanced Oil Recovery Waterflood Project

Lower Amaranth/Mission Canyon

Pierson, Manitoba

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Canadian Natural Resources Limited
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Summary</td>
<td>1</td>
</tr>
<tr>
<td>Reservoir Properties and Technical Discussion</td>
<td>2</td>
</tr>
<tr>
<td>Geology</td>
<td>2</td>
</tr>
<tr>
<td>Original Oil in Place Estimate</td>
<td>3</td>
</tr>
<tr>
<td>Historical Production</td>
<td>3</td>
</tr>
<tr>
<td>Primary Recovery</td>
<td>3</td>
</tr>
<tr>
<td>Secondary Recovery</td>
<td>4</td>
</tr>
<tr>
<td>Unitization</td>
<td>5</td>
</tr>
<tr>
<td>Unit Name</td>
<td>5</td>
</tr>
<tr>
<td>Unit Operator</td>
<td>5</td>
</tr>
<tr>
<td>Unitized Zones</td>
<td>5</td>
</tr>
<tr>
<td>Unit Wells</td>
<td>5</td>
</tr>
<tr>
<td>Unit Lands</td>
<td>5</td>
</tr>
<tr>
<td>Tract Factors</td>
<td>5</td>
</tr>
<tr>
<td>Working Interest Owners</td>
<td>6</td>
</tr>
<tr>
<td>Waterflood Development</td>
<td>6</td>
</tr>
<tr>
<td>Waterflood Operating Strategy</td>
<td>6</td>
</tr>
<tr>
<td>Reservoir Pressure</td>
<td>6</td>
</tr>
<tr>
<td>Waterflood Surveillance and Optimization</td>
<td>7</td>
</tr>
<tr>
<td>Injector Conversions</td>
<td>7</td>
</tr>
<tr>
<td>Injection Rates and Pressures</td>
<td>7</td>
</tr>
<tr>
<td>Notifications</td>
<td>8</td>
</tr>
<tr>
<td>List of Figures</td>
<td>9</td>
</tr>
<tr>
<td>List of Tables</td>
<td>10</td>
</tr>
<tr>
<td>List of Appendices</td>
<td>11</td>
</tr>
</tbody>
</table>
Introduction

The Pierson field, located in Townships 1-3 Ranges 28 and 29 west of the prime meridian, first produced in 1985 (Figure 1). The main target in this area is the Lower Amaranth (Spearfish) formation although some Mission Canyon (Alida) production exists throughout the field. In 1993 Home Oil, as operator of the area, unitized a portion of the field and implemented a 40 acre waterflood. The unit was named South Pierson Unit No. 1. Canadian Natural Resources Limited (CNRL) acquired the lands in 2002 and received approval to down space the unit to a 20 acre waterflood in 2004. The majority of the injector conversions for the 20 acre waterflood were completed between 2007 and the first six months of 2008. Since that time, the flood has proven to be effective by observing the flattening production decline.

Based on the results of the existing South Pierson Unit No.1, it is proposed that a new unit be created directly offsetting it to the northwest. The new unit would be named South Pierson Unit No. 2 and would consist of two full sections and three partial sections for a total of three sections of land or 48 legal subdivisions (LSD’s) (Figure 2). Currently there are 29 producing or suspended vertical wells, 1 abandoned well and one dual leg horizontal well existing within the boundaries of the proposed unit. To complete the 40 acre spacing in the proposed unit boundaries, CNRL would proceed with drilling 19 vertical locations over three to four years once the unit has been approved. With the recent success of horizontal drilling in the Spearfish formation, CNRL plans to develop the unit with horizontal producers and convert the vertical wells to injectors in four phases. This development strategy is expected to see similar results to the South Pierson Unit No.1 under a 20 acre waterflood.

Summary

1. The proposed South Pierson Unit No. 2 (SPU No. 2) will include 29 existing vertical wells, 1 dual leg horizontal well and 1 abandoned well that are completed in the Lower Amaranth (Spearfish) and/or the Mission Canyon (Alida) formations.

2. The proposed unit will include 48 legal subdivisions (LSD’s), of which 34 are developed and 14 are undeveloped. The boundaries of the proposed unit will be adjacent to the northwest part of existing South Pierson Unit No. 1.

3. The original oil in place (OOIP) for the proposed unit is 2,898 e$^3$m$^3$ or 60.4 e$^3$m$^3$/LSD on average.

4. Cumulative production from the proposed unit up until the end of March, 2010 is 133.9 e$^3$m$^3$, which represents a 4.6% recovery factor of the total OOIP within the proposed unit boundary.
5. The estimated ultimate recovery (EUR) of oil on primary production within the proposed unit boundary using decline analysis and a vertical type well for the undeveloped lands is 239.0 e$^3$m$^3$, with 105.1 e$^3$m$^3$ remaining reserves as of April 1, 2010. This equates to an average recovery factor of 8.2% of the total OOIP.

6. Peak production from the proposed unit was 42.1 m$^3$/day of oil in August, 1995, or 2.63 m$^3$/day per well of oil from 16 wells. The most recent production rate from March 2010 was 14.7 m$^3$/day of oil or 0.64 m$^3$/day of oil per well from 23 wells, with a relatively stable water cut of about 30%.

7. Initial pressure of the reservoir is approximately 11 MPa and has been depleted to 6.56 MPa based on recent pressure data collected (Appendix 11).

8. The existing South Pierson Unit No.1, which is directly offsetting the proposed unit, can be used as an analogy to predict the expected recovery factor for the proposed development plan. The development with horizontal producers should behave similarly to a 20 acre waterflood, therefore it is estimated that up to a 23% recovery factor will be achieved or 668.0 e$^3$m$^3$.

9. The development plan includes drilling 24 horizontal producers; to be completed with multi-stage hydraulic fractures over a time span three and a half years. There will be 19 infill vertical wells drilled that will be converted into injectors along with the existing vertical wells for a total of 48 injectors or 1 injector per LSD for an effective 20 acre waterflood.

Reservoir Properties and Technical Discussion

Geology
The main target for the proposed South Pierson Unit No. 2 is the Spearfish formation, although the Alida formation is perforated or penetrated in several of the existing wells. The Spearfish is a dolomitic siltstone to fine sandstone with slightly calcareous but mainly anhydritic cement. It was deposited in a tide dominated delta environment and sits unconformably above the Mississippian beds. In Appendix 1 a stratigraphic cross-section of the Spearfish and Alida within the proposed unit boundaries and into the South Pierson Unit No.1 is included to show the extent of both formations throughout the units. A subsea structure map on the top of the Spearfish Sandstone is provided in Appendix 2 illustrating the slight dip of the beds to the southwest. The Spearfish pay interval is defined between the Spearfish Sandstone (as seen on cross-section) and the Mississippian Unconformity. Spearfish pay was determined using a cutoff of 12% porosity, roughly equivalent to 1.0mD of permeability. An average porosity of 14% and an average initial water saturation (Swi) of 45% were used in calculating the product of porosity and net pay (Phi*h) and the product of Phi*h and Swi (Hydrocarbon pore volume or HCPV). Alida pay was determined using a 7% porosity cutoff on rock below the effective cap rock and above the interpreted oil water contact, with an Swi of 29% and an average porosity of 13.9%. Contoured maps detailing the net pay, Phi*h, and HCPV are attached.
for both formation intervals in Appendices 3-5, 7-9. Based on the behavior in the South Pierson Unit No.1, there is no obvious directional Spearfish permeability trend. Included in Appendix 6 is a map detailing the product of permeability and net pay ($K^*h$) for the Spearfish Formation, which depicts a relatively consistent permeability throughout the reservoir of the proposed unit, with a weak north-south trend, making the area an ideal candidate for waterflooding.

From these maps it is evident that the South Pierson Unit No. 1 is the same reservoir as the proposed unit and is of similar quality. With this information it is concluded that South Pierson Unit No. 1 can be used as a direct analogy to the proposed South Pierson Unit No. 2 and should respond in the same manner to tighter well spacing and waterflooding.

**Original Oil in Place (OOIP) Estimates**

Volumetric calculations were done to determine the OOIP for the Alida and Spearfish formations using CNRL internally created maps. Based on these calculations it was estimated that the Alida has $181.8 \times 10^3$ m$^3$ (1,144 mbbls) of OOIP and the Spearfish has $2,717 \times 10^3$ m$^3$ (17,087 mbbls) of OOIP for a total of $2,898 \times 10^3$ m$^3$ (18,230 mbbls) of OOIP. The tabulated parameters for each LSD used in these calculations can be found in Table 6.

**Historical Production**

The first well within the proposed unit boundaries was drilled in 1987 and wells continued to be drilled in the area relatively steadily until 1994. The majority of these wells penetrated the Alida formation, but many were only perforated in the Spearfish formation. In 2008 an additional eleven wells were drilled targeting only the Spearfish; all of their initial production rates were below expectations.

Peak production rate of $42 \text{ m}^3/\text{d}$ was reached in September, 1995. Production declined steadily until the new wells were drilled in 2008 and production reached a maximum of $27 \text{ m}^3/\text{d}$. It is believed that the poor inflow of the wells drilled in 2008 is due to pressure depletion in the area, which was observed from a recent pressure survey of three wells within the proposed unit boundary. In order to continue with further development, it is desirable to implement a waterflood and increase the reservoir pressure so that initial production is higher and long term declines are shallower.

**Primary Recovery (current)**

Cumulative production within the proposed unit boundaries is $133.9 \times 10^3$ m$^3$ (840 mbbl) of oil and $189.8 \times 10^3$ m$^3$ (1,193 mbbl) of water to the end of March, 2010 (Figure 3). This production is equivalent to a 4.6% recovery factor of the total OOIP. The most recent production rate from March 2010 was $14.7 \text{ m}^3/\text{day}$ of oil and $6.4 \text{ m}^3/\text{day}$ of water or $0.28 \text{ m}^3/\text{day}$ of water per well from 23 wells, with a relatively stable water cut of about 30%. Note that water production dropped significantly in 2008 when the 100/05-30-002-29W1/0 Alida well was shut in.
Based on decline analysis and a type well for the undeveloped lands, the estimated ultimate recovery (EUR) for the proposed unit on primary production is 239.0 e$^3$m$^3$ (1,503 mbbl), which results in a recovery factor of 8.2% of the total OOIP. In Figures 4 and 5 the thickest lines represent the production forecast for the existing wells on primary production and the next thickest line is the forecast if the undeveloped lands were also drilled and produced on primary production. The difference between the primary EUR for the fully developed proposed unit and the cumulative oil production to the end of March 2010 is 105.1 e$^3$m$^3$ (661.1 mbbl), which is the remaining recoverable oil from primary production.

**Secondary Recovery (proposed)**

South Pierson Unit No.1 (SPU No.1) was initially developed under 40 acre spacing on primary production. The main target was the Spearfish formation however there was some Alida production within the area. In 1993 the area was unitized and started on a 40 acre waterflood. In 2004 a down spacing application was done to infill drill for a 20 acre waterflood. The majority of the infill wells were drilled in 2005 and 2006; some of these wells were converted to injectors in 2007 and the first half of 2008 to complete the line drive patterns. In Figure 6, the progression of SPU No. 1 from the Spearfish primary production to 20 acre waterflood can be seen. Within the last year, the decline from the existing unit has become more stable and it is predicted in Figure 7 that the ultimate oil recovery from SPU No. 1 will be about 1,000 e$^3$m$^3$ (6,289 mbbl), which is equivalent to a 23.0% recovery factor of the 4,339 e$^3$m$^3$ (27,288 mbbl) of OOIP calculated internally by CNRL.

Geology supports the belief that SPU No. 2 and the existing SPU No. 1 are the same reservoir and therefore, the performance of SPU No.1 under waterflood can be used as a direct analogy for how the SPU No. 2 will perform when it is developed as an effective 20 acre waterflood. Using a 23.0% recovery factor from the existing unit’s Spearfish formation and applying it to the SPU No. 2’s total OOIP , it is expected that the ultimate oil recovery from proposed unit could be 668.0 e$^3$m$^3$ (4,202 mbbl) (Table 2). The forecasted production for the proposed unit is represented by the thinnest lines in Figures 4 and 5 and takes in to account the timing of the development plan.

It is anticipated that the Alida will contribute only a small amount of production to the total ultimate recovery because the OOIP is so small. However, the Alida is supported by an active natural aquifer drive and similar recovery factors to the Spearfish are observed in the Alida just to the west in the Gainsborough field.
Unitization

The basis for unitization is to implement a waterflood to optimize the recovery of oil from the Spearfish and Alida formations. Without unitization, drilling new wells in the area will be more difficult due to lower initial production rates and reserves on primary production without any pressure support.

Unit Name
Canadian Natural Resources Limited (CNRL) proposes that the name of the new unit shall be South Pierson Unit No. 2.

Unit Operator
CNRL will be the Operator of South Pierson Unit No. 2.

Unitized Zones
The unitized zones to be waterflooded will be the Lower Amaranth (Spearfish) and the Mission Canyon (Alida).

Unit Wells
The 31 existing wells to be included in the proposed South Pierson Unit No. 2 are outlined in Table 3 with their current status. The development plan found in Table 4 includes the existing wells, the 19 proposed vertical locations and the 24 horizontal infill wells that will be drilled upon approval of the unit in addition the timing of the proposed injector conversions.

Unit Lands
The South Pierson Unit No. 2 will consist of several LSD’s in sections 18, 20 and 31 as well as all of the LSD’s in sections 19 and 30 of Township 2-29W1. The total number of LSD’s included in the unit will be 48. Based on the current development of 40 acre spacing there will be 48 tracts. CNRL has 100% working interest in the proposed unit and therefore will have 100% working interest in each tract. The lands are outlined in Table 5.

Tract Factors
The South Pierson Unit will consist of 48 tracts based on the total OOIP from the Spearfish and Alida using the maps created internally by CNRL and subtracting the cumulative production to date for each LSD. The production from the dual leg horizontal well was divided according to the existing production allocation agreement.

The variables used in the calculation of the tract factors can be found in Table 6 for each individual LSD.
Working Interest Owners
CNRL is 100% working interest owner in all of the lands included in the proposed unit boundary and therefore will have 100% working interest in the proposed South Pierson Unit No. 2. This is summarized also summarized in Table 5 for each of the tract factors.

Waterflood Development

The South Pierson Unit No. 2 will be developed in four phases over the next three to four years. First, a number of existing vertical wells will be converted into injectors to start addressing the current pressure depletion in the area. Once these wells have been converted into injectors, two horizontal Spearfish wells will be drilled. Pending the success of these horizontals, the development plan will continue in a similar fashion, as outlined in the development plan timing, which can be observed in Figure 8 and summarized in Table 4. Each year several vertical locations will be drilled and converted to injectors to prepare for drilling the infill horizontal producers. At the end of the development plan there will be 48 vertical injectors, 24 horizontal producers and one dual leg horizontal producer.

Waterflood Operating Strategy
South Pierson Unit No. 2 will be tied into the South Pierson Unit No. 1 injection system. Pierson's current injection system uses mainly produced water from the Alida and Spearfish formations with makeup water from a licensed source well at 102/03-16-002-29W1 that is perforated in the Tilston formation. All the production is sent to the Pierson battery at 14-09-002-29W1 where the water is separated, filtered and distributed to the injection system. A simplified process flow diagram of the current system with modifications to include the proposed unit can be found in Figure 9.

It is felt that compatibility testing for the injection water is unnecessary because it is mainly produced water from the formations that will be injected into. Also, there have been many years of successful waterflooding with no compatibility issues in the South Pierson Unit No. 1.

All surface facilities and wellheads will have cathodic protection to prevent corrosion. All producing and injection flowlines and tubing will be made of fiberglass so corrosion will not be an issue. Injectors will have a packer set below the top of the injection formation, and the annulus between the tubing and casing will be filled with inhibited fluid. Refer to Appendix 10 additional corrosion control details.

Reservoir Pressure
Pressures from three shut in wells were collected in April 2010 ranging from 6,309 kPa to 6,748 kPa, averaging 6,555 kPa (Appendix 11). The wells were shut in between 5.3 and 15.1 years, so it is suspected that they represent the current reservoir pressures fairly accurately. The original reservoir pressure of the area was approximately 11,000 kPa and the saturation pressure (bubble point pressure) from PVT analysis done for 6-19-2-29W1 is 4,551 kPa. The plan is to increase the current reservoir pressure closer to the original reservoir pressure by maintaining an instantaneous voidage replacement ratio (VRR) of
approximately 1.5 until a cumulative VRR of 1.0 is reached and assuming surface pressures stay below the maximum allowable wellhead pressures.

**Waterflood Surveillance and Optimization**
The waterflood surveillance of South Pierson Unit No. 2 will consist of the following:

- Regular production well testing to monitor fluid rate and water cut as done in South Pierson Unit No. 1 to watch for waterflood response, breakthrough or viscous fingering
- Comparison of daily injection rates and pressures to targets
- Evaluation of Hall Plots to look for positive or negative skin indicating plugging or channeling/out-of-zone injection, respectively
- Monitor instantaneous and cumulative voidage replacement ratio by pattern and the overall unit
- Injection targets will be sent to the field on a regular basis

**Injector Conversions**
The wells listed in Table 4 will be converted from producing wells to injectors in 2010 through 2013. The tubing and rods will be removed and replaced with fiberglass tubing. See Appendix 12 for a typical injector schematic.

**Injection Rates and Pressures**
CNRL anticipates injecting water into the Spearfish formation for the next several years to re-pressurize it after having been depleted from primary production since 1987. To make up the voidage and pressure depletion from primary production, initial targets for instantaneous VRR will be between 1.25 and 1.75. At peak production rates, total water injection requirements will be between 300 m$^3$/d and 420 m$^3$/d over the entire field. This is equivalent to 6 m$^3$/d and 9 m$^3$/d for each of the 48 injectors. It should be noted that at the peak rates of the horizontal producers it may be difficult to maintain a VRR greater than 1.0 on an individual pattern basis, but overall the VRR should be very close to 1.0. Once the horizontal producers have more stabilized production rates, VRR should increase again to the targeted 1.25 to 1.75 range until the cumulative VRR approaches 1.0. At this point the injection targets will be set based on maintaining reservoir pressure with a VRR of 1.0.

The majority of the wells in the area have been stimulated by fracturing; from this information the fracture gradient is estimated to be 18 kPa/m or approximately 18 000 kPa sandface fracture pressure. The requested maximum injection pressure at the sandface will be 85% of the fracture pressure, which is 15 300 kPa or 5000 kPa at surface.
Notifications

CNRL has notified all surface and mineral owners within the unit and the surrounding 0.5 km of the unit boundary about the unitization and EOR scheme application by mail. A complete listing of the mineral owners within the proposed unit boundary and mineral owners within the notification area will be provided to the Manitoba Government. A copy of the registered mail notifications will be also sent to the Manitoba Government when they are received.
Proposed South Pierson Unit No. 2

Application for Enhanced Oil Recovery Waterflood Project

List of Figures

Figure 1  Pierson Field
Figure 2  South Pierson Unit No. 2 Proposed Boundary
Figure 3  South Pierson Unit No. 2 Historical Production
Figure 4  South Pierson Unit No. 2 Production Forecast – Rate vs. Time
Figure 5  South Pierson Unit No. 2 Production Forecast – Rate vs. Cumulative Oil
Figure 6  South Pierson Unit No. 1 Historical Production
Figure 7  South Pierson Unit No. 1 Production Forecast
Figure 8  South Pierson Unit No. 2 Development Plan
Figure 9  South Pierson Unit No. 2 Injection Facilities Process Flow Diagram
Proposed South Pierson Unit No. 2

Application for Enhanced Oil Recovery Waterflood Project

List of Tables

Table 1  Reservoir and Fluid Properties
Table 2  Original Oil in Place and Recovery Factors
Table 3  Current Well List and Status
Table 4  Development Plan
Table 5  Land Information and Tract Participation
Table 6  Original Oil in Place, Cumulative Oil Production and Tract Factors
List of Appendices

Appendix 1  Stratigraphic Cross Section
Appendix 2  Spearfish Structure Map
Appendix 3  Spearfish Net Pay Map
Appendix 4  Spearfish Phi*h Map
Appendix 5  Spearfish Hydrocarbon Pore Volume Map
Appendix 6  Spearfish K*h Map
Appendix 7  Alida Net Pay Map
Appendix 8  Alida Phi*h Map
Appendix 9  Alida Hydrocarbon Pore Volume Map
Appendix 10  Corrosion Control
Appendix 11  Pressure Survey Data
Appendix 12  Typical Injector Downhole Schematic