An Overview of Directional and Slant Drilling for Natural Gas Development in the Great Sand Hills, Saskatchewan

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Background

The Great Sand Hills Land Use Strategy Review Report and Recommendations (The Great Sand Hills Land Use Strategy Review Committee, 2004: 33) recommended natural gas developments minimize ‘footprint’ by “encouraging the use of special drilling techniques such as multi-pad and/or directional drilling as appropriate to avoid unnecessary environmental damage”. Currently, the Great Sand Hills Regional Environmental Study (GSH RES), as part of the selection of a preferred scenario with recommendations, is reviewing natural gas development with the perspective of potentially reducing surface disturbance. Gas studies for the Review Area (Figure 1) were initially undertaken for the Scientific Advisory Committee (SAC) by Penner, L.J. et al. (2006), who completed a historical review of gas development, production and reserves within and around the Great Sand Hills (GSH) Review Area. Approximately 70 percent of the Review Area is currently leased for gas development. Vertical wells predominate and a typical design comprises a single vertical well on a pad and each land section requiring 8 wells with 8 surface leases or well pads.

GLJ Petroleum Consultants Ltd (2006) were contracted to provide a more in-depth forecast of reserves and future development per legal section of land in the Review Area. Their work identified 1,559 existing gas wells. Using well logs, GLJ Petroleum Consultants Ltd estimated reserves by proven, probable and possible classification on developed and undeveloped lands. Considering all three reserve classifications within the Review Area, GLJ Petroleum Consultants forecast a 15 year development period with up to 2,568 new wells in the Milk River formation and 109 new wells in the Second White Specks formation. A study by Golder Associates Ltd. (2006) reviewed gas technology and management practices covering upstream activities to planning and impact mitigation.

With a study goal of reducing surface disturbance, attention was focused on future activities associated with step-out and in-fill gas developments. Questions centered on the forecast number of surface leases or well pads per section and the accompanying extent of roads and trails. One alternative strategy that could reduce disturbance, but still allow full access to gas reserves, would be to employ directional, slant and vertical drilling technology from a multi-well pad on a surface lease. A follow up investigation was undertaken to determine efficacy of directional and slant drilling using multi-well pads in the Great Sand Hills.

Objectives

Objectives of this overview are to (1) describe existing directional and slant drilled wells and well pads in the Review Area; (2) describe differences in surface disturbance (via road and trail density) for areas with multi-well operations (vertical, directional and slant drilled) versus a single vertical well per pad; (3) independently provide a prototype directional well design specific to gas reserves in the Review Area; and (4) review economic and ecological (e.g. surface
disturbance) cost-benefit factors for directional and slant drilling with multi-well pads versus a single vertical well and pad in the GSH Review Area.

**Approach**

GLJ Petroleum Consultants Ltd were contracted to determine directional and slant drilled wells and to provide surface locations for existing multi-well pads. These locations were matched by Bob MacFarlane (GSH RES Project Manager, Canadian Plains Research Center, University of Regina) to mineral leaseholders and contact was made with gas companies to determine background on the drilling and current operations. On Management Ltd with Bob MacFarlane undertook a cursory review of directional and slant drilled well records; described characteristics of the drilling and production; and provided guidance for typical costs to develop a vertical, directional and slant well in the Review Area. The Golder Associates Ltd (2006) report; *Review of Gas Technology and Practices in the Great Sand Hills* was considered with respect to the Report’s review of directional and slant drilling and multi-well pads. Dr. Scott Nielsen (Ecologist, Conservation Planning Institute) plotted all existing well pad locations and compared associated road and trail density for those land sections with directional and slant wells versus vertical wells and no gas well development. Chinook Directional Services Inc. were contracted to consider the GSH and propose a typical design drawing for using multi-well pads and directional wells in the Review Area.

**Results and Discussion**

**Objective 1:** Describe existing directional and slant drilled wells and surface pads in the GSH Study Area

Slant and directional drilling as opposed to a vertical well may be undertaken to avoid a topographic or environmentally sensitive feature such as a water course or a steep dune; to reduce surface disturbance and; to meet economic reasons. Golder Associates Ltd (2006: 8) described key differences between directional and slant drilling. “Directional drilling usually involves starting off in a vertical wellbore path and then deflecting or deviating horizontally (usually 70º or less hole angle) to a subsurface target or desired bottom-hole”. “Slant drilling differs from directional drilling in that the drill angle starts at the surface and not from a vertical wellbore. Essentially the angle is calculated for the wellbore to leave the surface and terminate at the desired target or down-hole location.”

Regulatory well spacing and number of surface leases or well pads per legal section control the design of horizontal reach for directional and slant wells in both in-fill and step-out developments. Having a block of adjoining surface leases held by the same gas company enables more flexibility on the design and layout of reach for both directional and slant drilling. A spacing of 8 wells and 8 surface leases per land section characterizes the GSH Review Area.

Drilling experience is well developed in the Milk River formation of Alberta and Saskatchewan. GSH gas reserves are accessible shallow deposits, typically found in sandstone and shale deposits at 400 m. Cost of development and economics of gas production also determine gas companies’ decisions on the design of reach. While slant drilling in the Review Area had reaches varying from 100 m to 1,100 m, Golder Associates Ltd (2006:8) offer an opinion that 200 m to 600 m best represented the reach that reflected a gas company’s choice for reason of economics and production in the Review Area. Similarly with directional drilling, Golder Associates Ltd
To the maximum reach of the GSH RES Directional & Slant Drilling Report January 3, 2007 (2006:8) report “industry members that were contacted stated that maximum reach that they would try into the Milk River formation would be 200 m to 250 m”.

Of the 1,559 existing wells reported for the GSH Study area, 254 wells or 16 percent were found to be directional or slant (GLJ Petroleum Consultants Ltd. 2006). All directional and slant wells are located in the Milk River formation. The reporting does not distinguish between the numbers of directional versus slant wells. Year 1989 was the first record of a directional or slant well and there is evidence of increased directional and slant drilling in the past six years. From year 2000 to June 2006, 40 percent of the reported 254 directional and slant wells were drilled in the Review Area. Completed well records show that after year 2000, directional and slant drilling has by requirement only occurred under frozen ground conditions. Of known drilling activity in winter 2006-2007, plans call for an additional 34 slant wells as part of an in-fill development, to be drilled by the City of Medicine Hat.

A review of well locations and mineral leases confirmed that directional and slant drilled wells are currently owned and operated by Canadian Natural Resources Ltd., City of Medicine Hat and EOG Resources Canada Inc. Both Canadian Natural Resources Ltd. and the City of Medicine Hat undertake directional and slant drilled wells within an Environmental Assessment Approved Project Area, approved by the Saskatchewan Minister of Environment following an Environmental Impact Assessment.

On completed directional and slant wells in the Review Area, the number of wells per pad ranges from two to seven. Newer drilling programs typically have the lowest number of well pads per section and the highest number of wells per pad. Wells drilled in 2005 by Anadarko Canada Ltd. and now owned and operated by Canadian Natural Resources Ltd. typically consist up to six slant drilled wells and one vertical well per pad. This design employed as few as one well pad per land section. The City of Medicine Hat typically uses two directional or slant drilled wells and a vertical well per pad. By design these well pads are located immediately adjacent to a common land section boundary, average one pad per land section and share common trail access. Directional and slant wells of EOG Resources Canada Inc. have two to three wells per pad and the density is typically two pads per land section.

Characteristics of the directional and slant drilled wells were checked by a cursory review of three completed wells from wells operated by the City of Medicine Hat, EOG Resources Canada Inc. and Canadian Natural Resources Ltd. The query by On Management Ltd. (November 1, 2006) was made to confirm age, production and characteristics of the depth and reach for a range in well age and ownership. The three wells chosen were:

a. **Well location 91/11-29-14-24W3** (surface pad unique well identifier (UWI): 100142001424W300) is operated today by the City of Medicine Hat and it was drilled in July 1989 by North Canadian Oils. Considered an early directional or slant drilled well, it continues to operate after 17 years with an average daily production of 30.0 mcf. (0.8 m³/day) (June 2006). The well pad consists of two directional or slant wells and a vertical well. This specific well has a true vertical depth of 459.4 m (1,507.3 feet), measured depth of 1,091.0 m (3,579.6 feet) and a horizontal reach of approximately 1,000 m (3,281 feet). By design two well pads in land section 20 supports a total of six wells in land section 20 and 29. No well pads are located in land section 29.

b. **Well location 91/03-31-14-23-W3** (surface pad UWI: 1001543001423W300) was drilled in January 2006 by Anadarko Canada Corporation and is now owned and operated by Canadian Natural Resources Ltd. This is a new generation directional or slant drilled well that is part of
a multi-well pad comprising six directional or slant drilled wells and one vertical well. Current average daily production is 56 mcf (1.6 m³/day) (June 2006). This specific well was drilled to a true vertical depth of 505 m (1,657 feet), measured depth of 768 m (2,520 feet) and a horizontal reach of approximately 500 m (1,640 feet). The well pad density for this land section is one multi-well pad.

c. **Well location 91/02-09-16-24-W3** (surface pad UWI: 100160401624W300) was drilled in June 1994 by EOG Resources Canada Inc and continues to be operated by same. This 12 year old directional or slant drilled well produces 25 mcf (0.7 m³/day) (June 2006). The well pad consists of one directional or slant drilled well and one vertical well. This specific well was drilled to a true vertical depth of 459 m (1,506 feet), measured depth of 778 m (2,553 feet) and a horizontal reach of approximately 620 metres (2,034 feet). The well pad density for this section is three multi-well pads.

Of the three companies operating directional and slant drilled wells in the Review Area, the City of Medicine Hat and Canadian Natural Resources Ltd participated in a follow up telephone interview or personal meeting.

A telephone interview with Brian O’Dell (City of Medicine Hat) on November 1, 2006 confirmed that the City of Medicine Hat employs slant and directional drilling as a condition of their Environmental Assessment Approved Project Area. Brian O’Dell stressed that minimal disturbance practices of winter drilling and no site leveling are followed. As per directional and slant drilling, the advantages noted were lower surface lease costs with multi-well pads and lower pipeline and flow line costs. A common access road is employed for the well pads. Disadvantages included more operational issues with removal of water plus limited availability and higher cost of slant drill rigs. Compared to the costs to drill a typical vertical well, slant drilled wells were estimated to be 2 times more expensive and directional wells were estimated to be 1.4 times more expensive.

An interview was held with Terry Forkheim (formerly with Anadarko Canada Corporation and now with Canadian Natural Resources Ltd) and Darlene Sakires (Canadian Natural Resources Ltd) on November 2, 2006. Drilled originally by Anadarko Canada Ltd and now owned and operated as of November 2, 2006 by Canadian Natural Resources Ltd, the 2005-2006 wells were confirmed as slant drilled wells. The discussion confirmed that these multi-well pads typically comprise seven slant wells and one vertical well. A prior environmental impact assessment had been undertaken and the drilling was within an existing Environmental Assessment Approved Project Area. Monitoring of the wells is undertaken remotely by a SCADA (supervisory control and data acquisition) system and this further reduces frequency of on-site inspection. Of note during the 2005-2006 drilling operations, Anadarko Canada Ltd experienced surface disturbance issues related to access and trail rutting that resulted from equipment movement during a mid-winter thaw coupled with ground disturbance from a pipeline explosion during a pressure test. Reclamation efforts were subsequently undertaken.

**Objective 2:** Describe surface disturbance characteristics as measured by road and trail density associated with multi-well pads of vertical, directional and slant drilled wells versus a single vertical well and pad.

Roads and trails are a visible indicator of surface disturbance resulting from any human use. With multi-well pads using a combination of directional, slant and vertical wells, researchers queried
whether the associated road and trail density would be lower than in areas where a single vertical well and pad were located.

As part of the GSH RES study, a GIS layer of roads and trails was overlain on the Review Area and a density of these lineal features was computed and proved useful in zoning the level of development. The road and trail database while valuable is limited by the lack of information on the degree and type of use. During the 2005 ground-truthing for the SPOT image classification and 2006 field surveys for birds and plants, it was found that some trails showed little use and in some cases were not discernible.

Length and density of road and trails for the Review area, (2,029 km²), was 3,130.1 km length with a linear density of 1.5 km/km². For the GSH Representative Areas Ecological Reserve (RAER) (373.4 km²) where there currently exists agricultural use but no gas development, the road and trail length was 453.8 km with a linear density of 1.2 km/km². For the developed zone of the Review Area and exclusive of the RAER and all land sections with multi-well pads, the area amounted to 424.2 km² and here researchers found road and trail length at 1,106.1 km with a linear density of 2.6 km/km². This developed zone reflects agricultural use plus vertical gas well and pad development. Comparatively, multi-well pads with a combination of directional, slant and vertical wells referred to collectively as directional wells in Figure 2 were divided into a South zone (87.5 km²) coloured green and a North zone (98.2 km²) coloured yellow. The South zone wells comprised those multi-well pads operated by Canadian Natural Resources Ltd with up to seven wells per pad and one pad/section and by the City of Medicine Hat with typically three wells per pad and one pad/section. The North zone wells comprised those multi-well pads operated by EOG Resources Canada Inc with two or three wells per pad and two pads/section. Results for the multi-well pads indicated those in the South zone had a road and trail length of 95.1 km and a linear density of 1.1 km/km². Comparatively, in the North zone the multi-well pads had a road and trail length of 87.5 km² and a linear density of 2.3 km/km².

These analyses demonstrate that where multi-well pads operated by the City of Medicine Hat and Canadian Natural Resources Ltd. are at a density of one pad/section, associated road and trail density was quite low at 1.1 km/km², less than half that observed for areas with single vertical wells and pads (2.6 km/km²) and comparable to road and trail densities in the RAER (1.2 km/km²). However, as the multi-well pads/section increased to 2+ pads/section for EOG Resources Canada Inc. in the North Zone road and trail density increased to 2.3 km/km². Particularly worth noting is the use by the City of Medicine Hat of an innovative design in placement of their multi-well pads to service wells into two adjoining sections plus use of a common surface access trail.

**Objective 3:** Independently provide a prototype directional well design specific to gas reserves in the GSH Review Area

Chinook Directional Services Inc was contracted to provide a design for a typical directional drilled well for the Review Area. On Management Ltd provided input on development and feasibility for the design.

With a well spacing for up to eight wells per section, the proposed design for a typical land section proposes up to four multi-well pads, each with two directional wells drilled. The reach was limited by the well spacing, number of surface leases and the cost and economics of production. Appendix A. (Chinook Directional Services Inc. 2006) provides one example from a series of design schematics that illustrates a directional well drilled to approximately 400 m (1,312 feet) depth and 280 m (919 feet) in horizontal displacement from the pad center. As the
elevation for the well pad location increases, the opportunity for a suitable angle increases and thus a longer horizontal displacement or reach can be achieved.

A design of four well pads per section with two wells per pad is achievable and an improvement in environmental surface conditions (via reduced surface disturbance from reductions in roads and trail development) over that of eight vertical wells and pad per land section. Moreover, from a review of wells completed to date there is evidence to suggest that one or two pads per section are cost-effective and feasible resulting in even more substantial reductions in surface disturbance.

**Objective 4:** Review economic and ecological (e.g. surface disturbance) cost-benefit factors for directional and slant drilling with multi-well pads versus a single vertical well and pad in the GSH Review Area.

Golder Associates Ltd (December 2006: 8-9) reports from their industry consultation, that directional drilling is useful to overcome landscape conditions like topography or a waterbody which “make placement of a surface lease for a vertical well impractical or costly to prepare”. Additionally, directional drilling can be employed “to mitigate impacts by reducing the number of individual surface well leases and associated access corridors within a landscape area”. Limitations noted were as follows:

- as the angle increase, down-hole equipment can get stuck;
- depending on the softness or hardness of the formations, steering the drill collar and bit can make steering and reaching the down-hole target difficult;
- natural bedding planes and faults can make directional control difficult and require correction runs;
- hole drag can pose significant problems to the tensile capacity of the drill string;
- in soft formations, rotary torque may increase to unacceptable high levels;
- as hole angle increase, the collar weight on the drill bit decreases, thus limiting the negating buoyancy forces and cause penetration rates to become slower;
- additional equipment is often required such as measurement while drilling assemblies, down-hole motors, and stabilizers;
- increase potential in hole instability or sloughing;
- additional equipment may necessitate the requirement of a larger surface lease;
- a longer on-site drilling period is required;
- product recovery can be impaired or low; and cost to directional drill can increase drilling costs by 10% to 50% over a vertical well. On large horizontal displacements, costs can increase by 200% to 400%.”

With slant drilling, Golder Associates Ltd (2006: 9) reported similar advantages to directional drilling. Concerns were expressed that for reaches greater than 700 m there was reduced gas production. “The reduced gas production was attributed to the inability to establish good down-hole stimulation, the distance the gas has to travel to reach the surface and the associated frictional drag from the walls of the production pipe”. Further concerns are potential health and safety issues related to gas migration to the surface when there is a failure to achieve a “good cementing of the conductor and surface casing”.

The limitations described by Golder Associates Ltd (2006) for slant and directional drilling are one perspective. On Management Ltd suggests the described limitations generally apply on the broader scale of drilling; moreover, the development history within the GSH and the nature of the
shallow gas fields of the Milk River formation has shown that directional and slant drilling has worked. On the concern regarding gas migration, On Management Ltd (2007) noted that this is rare and less of an issue for the GSH wells with shallow depths and lower pressures plus the surface casing is relatively short at 80 m (262 feet). Drilling operations today use stabilizers to ensure that the pipe is centered and thus allow for cementing of the casing to be complete. This author is not aware of any reports of gas migration causing health or safety concerns for directional and slant drilled wells operational since 1989 in the Review Area. Mr. Todd Han, Assistant Director Petroleum Development, Petroleum and Natural Gas, Saskatchewan Industry & Resources noted (October 16, 2007 interview with author) that directional drilling in a gas migration prone area may worsen the problem. He went on to clarify that gas migration had not been recorded in the GSH Review Area but rather to the north in an area referred to as Miry Creek.

For multi-well pads, Golder Associates Ltd (December 2006: 10) notes that the number of wells per pad is limited by both the horizontal reach and the surface lease available. As previously mentioned, regulatory well spacing is the over-riding factor and this combined with the need for sufficient flat ground for set up of a drill rig plus costs and economics of production together are controlling factors. With a view of only the spatial needs plus minimum disturbance that includes winter drilling and no site clearing, a flat area of 150 m (492 feet) x 150 m would enable a multi-well pad of three to five wells.

On Management Ltd (December 13, 2006) provided a cost-estimate of gas well development in the Review Area. A typical vertical well, drilled to 400 metres, is estimated to cost $175,000 (exclusive of mineral lease costs) and this estimate is based on a 50 to 100 well drilling program. The vertical well costs include: site survey, surface lease payment, drilling, casing and a short tie-in flow line, environmental project proposal, environmental monitor and out-of-pocket site expenses and on-site staffing. Comparatively, the same well drilled directionally would cost $200,000 (with a short tie-in flow line) and for a slant drilled well would cost $260,000. The cost differences reflect the specialization of equipment, time and labor. Bringing a well to operation also requires a compressor station for approximately every 5.0 mmcf/day (5.0 million cubic feet/day). The cost to build a compressor station is between $300,000 and $400,000. From the compressor station, the gas is transported through a high pressure sales pipeline to a main pipeline. The sales pipeline cost is $100,000 per mile.

**Summary**

Directional and slant drilled wells from a multi-well pad is one strategy that can reduce ground disturbance from roads and trails, yet still provide access to gas resources. This investigation identified that directional and slant drilling with multi-well pads have been undertaken in the Great Sand Hills Review Area since 1989. Approximately 16% or 254 wells of the total 1,559 wells within the Review Area are directional or slant drilled. Of only those directional or slant wells, 40% percent were drilled since year 2000.

The City of Medicine Hat, Canadian Natural Resources Ltd and EOG Resources Canada Ltd operate the multi-well pads with a combination of directional or slant wells and vertical wells. Both the City of Medicine Hat and Canadian Natural Resources Ltd, which assumed control of Anadarko Canada Ltd, use this drilling technology in accordance with Environmental Assessment Approved Project Areas. These companies confirmed that their approach to minimal disturbance included a combination of best management practices including: winter drilling, no site leveling, multi-well pads, use of a common road or trail access to well pads and application of remote
monitoring technology that reduces frequency of site inspection. The regulated well spacing and number of surface leases controlled the number of wells and well pads. Each company uniquely designed their number of wells per pad and pad density per land section, ranging from two to seven wells per pad with densities of multi-well pads per section varying from three to one. Maximum reach for directional or slant wells was approximately 1,000 metres (3,281 feet) even for wells drilled in 1989 which continue to be economical to operate.

As a measure of human disturbance, the investigation selected road and trail density. While this database lacks classification on use, it does provide an index of how the landscape can be fragmented as development increases. With no gas development and only agricultural use, the GSH Representative Areas Ecological Reserve currently has 1.2 km/km² lineal density of roads and trails. In developed portions of the Review Area, where individual vertical wells predominated each with a pad, there was an average lineal density of 2.6 km/km² roads and trails. When considering directional and slant drilled wells on multi-well pads, the road and trail density declined to 2.3 km/km² with two and three pads per land section and then it further reduced to a low of 1.1 km/km² where the pad density was one per section.

For the GSH shallow gas deposits, directional and slant drilled wells to approximately 400 metres (1,312 feet) depth can be implemented on four multi-well pads per section with two wells per pad and an individual well reach of approximately 280 metres (919 feet). The preferred multi-well pad density to minimize road and trail density would ideally be one per land section. For in-fill development, the change could simply be a restriction to new wells to be drilled from existing gas well pads. With step-out development, there is an even greater opportunity to permit innovation by the gas companies to design placement such that well pad density is one pad per land section, as demonstrated by both the City of Medicine Hat and Canadian Natural Resources Ltd.

Gas well development represents a high capital cost in drilling and establishment of infrastructure to transport gas from the well to sales pipeline. For instance, a single vertical gas well is estimated to cost $175,000 which includes site survey, surface lease payment, drilling, casing, flow line, environmental project proposal, environmental monitor and on-site staff. Comparatively, the same well drilled directionally would cost approximately $200,000 and $260,000 for a slant drilled well.

Directional and slant drilled wells are not without technical and environmental limitations particularly during the drilling stage. A longer on-site drilling period and larger surface lease to accommodate drilling equipment are two examples.

For conservation planning in the GSH Review Area, multi-well pads with directional and slant drilling give one option that will work to reduce road and trail density. While it is not a remedy for all situations, this drilling technology could be broadened in the Review Area and be applied in those portions of the landscape that show higher environmental biodiversity requiring protection. Gas companies should be encouraged to continue design innovation and achieve an environmental goal to reduce fragmentation of the habitat, potentially reduce some gas development costs, such as surface leases and yet still enable development of future gas reserves.
Figure 1

Great Sand Hills Regional Environmental Study May 2006
Figure 2

Directional Wells includes directional and/or slant drilled wells that may or may not be combined with a vertical well on a multi-well pad

Appendix A
GREAT SAND HILLS
Regional Environmental Study
Deep Pad 741 Ground Level
South East Well
References


Interviews

September 27, 2006. Andy Hill, President, Chinook Directional Services, Calgary, Alberta


October 16, 2006. Todd Han, Assistant Director of Petroleum Development, Petroleum and Natural Gas, Saskatchewan Industry and Resources, Regina, Saskatchewan.

November 1, 2006 Brian O’Dell P.Eng, Engineering Supervisor, City of Medicine Hat, Medicine Hat, Alberta

November 2, 2006 Terry Forkheim and Darlene Sakires, Environmental Managers, Canadian Natural Resources Ltd., Calgary, Alberta