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Technical Report

Uncertainty Related to Gas Field Subsidence Predictions and Associated Environmental Impacts of the Proposed Mackenzie Gas Project

Submitted to:

Joint Review Panel for the Mackenzie Gas Project

By:

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Background

Kendall Island Bird Sanctuary (KIBS), located in the Mackenzie River Delta in the Northwest Territories, is an important breeding and staging ground for a wide variety of waterfowl and shorebirds. The presence of this important bird habitat prompted Environment Canada to create the KIBS in 1961. Two of the three proposed Mackenzie Gas Project (MGP) natural gas anchor fields, Taglu and Niglintgak, are situated within and underlie part of KIBS.

Reservoir compaction and associated surface subsidence will occur as gas is extracted from the reservoir bedrock system. Surface subsidence in this outer deltaic environment will result in permanent submergence and/or flooding of part of the adjacent KIBS land area. Given the environmental sensitivity of the surface ecosystem it is important for the Joint Review Panel (JRP) to determine the level of uncertainty associated with the predictions of the magnitude of surface subsidence for each anchor field. In addition, the environmental impact of surface subsidence can be quantified by examining the relationship between the magnitude of the surface subsidence and the size of the area of KIBS and associated land and surface water areas that will be permanently submerged and/or flooded by surface subsidence that is directly related to hydrocarbon extraction.

Evaluation of the degree of uncertainty of surface subsidence predictions

For the purposes of this discussion, we note the difference between reservoir compaction and surface subsidence. For a reservoir of infinite lateral dimensions, surface subsidence will essentially be equal to reservoir compaction. In reality, every gas reservoir has finite dimensions and, depending on the extent of the arching phenomena in the overburden rock above the reservoir, surface subsidence will be lower than reservoir compaction. This difference between reservoir compaction and surface subsidence is essentially a function of reservoir depth and the lateral extent of the reservoir (as mentioned in reference 1) as well as the material properties of the overburden. The degree of uncertainty of surface subsidence predictions is thus associated with:

- i) the degree of uncertainty in the reservoir compaction prediction; and
- ii) the degree of uncertainty in the prediction of the amount of arching in the overburden rock.

Uncertainty in reservoir compaction prediction

Reservoir compaction is the change in rock formation thickness that is associated with an increase in effective stress (total stress minus the pore-water or gas pressure) as reservoir fluid or gas pressure decreases with possible additional contributions due to the removal of fines or suspended solids when the producing hydrocarbon reservoir is unconsolidated or semi-consolidated sand, and some fines are produced with the hydrocarbons. In general, the increase in effective stress is equal to the decrease in gas pressure. The reservoir compaction may, at first approximation, be calculated as the product of the initial formation thickness, H, the formation compressibility (the relationship between the change in formation thickness and the change in effective stress), C, and the change in effective stress, $\Delta\sigma'$, which is equal to the change in reservoir gas pressure, ΔP:

$$\Delta H = H \times C \times \Delta\sigma' = H \times C \times \Delta P \qquad \text{eqn (1)}$$

Uncertainty in reservoir compaction predictions arises from several factors. These factors include: uncertainty or discrepancies in the thickness of the rock formations that will be impacted or involved in the reservoir compaction process; uncertainty in the measured or calculated compressibility values assigned to the different bedrock units in the geological column of the reservoir and its inter-bedded units; and, differences between the actual and proposed changes in gas pressure(s) for each of the producing formations, inter-bedded formations and adjacent formations, over the life-time of the project.

The following sections of our report highlight issues related to the uncertainty in each of the above factors, particularly as they relate to the Taglu and Niglintgak anchor gas fields.

Uncertainty in the thickness of the reservoir rocks that are impacted by gas depletion

The rock formations in the Mackenzie delta consist of interbedded sand and shale layers. Gas is generally produced from the sandstone or sand units. Uncertainty in choosing a representative reservoir thickness may arise from the fact that gas extraction over a 30-year period will also affect, at least partially, the shale formations.

For example, Natural Resources Canada (NRCan) in its September 8, 2006, response to the Joint Review Panel's Information Request (IR) JRP_R4_11 on subsidence estimates gave both the assumed thickness of the reservoir that will be subject to compaction and the source of their information: "Niglintgak Field Project Description: 123 m (this estimate corresponds to highlighted yellow units on the well log for the Niglintgak Field as shown in the Proponent's response to IR JRP_ R2_44)".

For the Taglu field reservoir thickness, NRCan notes: "Reservoir thickness – used sum of pay zones as listed in Table 2.6 of Taglu Field Project Description: 216 m (this estimate corresponds to the yellow and red highlighted units on the well log for the Taglu Field as shown in the Proponent's response to IR JRP_ R2_44)".

Using the above values for reservoir thickness in each of the two gas fields, NRCan obtained surface subsidence levels that were consistent with the Proponent's surface subsidence predictions. Clearly, if the thickness of the zones that would be impacted by gas depletion in each reservoir system increases there would be a corresponding increase in the reservoir compaction and the associated surface subsidence over each gas field. It should be noted that the geomechanical model for the Taglu gas field considered 11 layers with a total pay zones of 555 m, i.e. 2.6 times larger than the thickness used by NRCan.

The anticipated formation compaction at Taglu could thus be close to a factor of 2.6 greater than the compaction computed by NRCan.

For Parsons Lake (reference 1) it is noted that, "*… two scenarios considered to take into account the possibility that the interbedded shale horizons* (shale layers between other rock layers such as sandstone or sands – inserted by the authors of this report) *will drain during reservoir depletion…"* For these two scenarios, when the shale layers were allowed to drain, the maximum reservoir compaction increased from 7.0 cm to 30 cm, i.e. a four-fold increase in the magnitude of the reservoir compaction.

According to the Proponent's response to IR JRP_R4_08, "*…the shale layers at the Niglintgak field are not expected to be affected by the gas extraction."* However, the Proponent does not appear to have presented any laboratory data on the porosity, permeability and compressibility of the shale units, other than log-derived values that would support this conclusion.

For the Taglu field, the Proponent's approach is more difficult to analyze since the computer model layers do not appear to have a one-to-one match with the geological layers and it appears that some of the shale and siltstone layers have been averaged with the sand layers. It is therefore difficult to extract data pertaining solely to the shale units since the reservoir at Taglu consists of 11 distinct sand layers, based on sand type and expected pressure depletion.

In reference 4, section 2.3.5, the Proponent states that the Taglu reservoir intervals comprise interbedded successions of sandstone, siltstone and shale. In section 2.4, the Proponent gives Taglu's reservoir properties by unit in Table 2-6. This information is summarized in Table 1.

Reservoir interval	A	B2	UC	LC	LC2
Gross pay average (m)	79.4	14.4 (?)	61.5	52.5	8.3

Table 1. Taglu reservoir average pay thickness by unit

In response to IR JRP_R4_09, Table 4.09a-1 gives the layer description used by the Proponent to model subsidence at Taglu. Again, this information for the Taglu field is summarized and presented in Table 2.

Layer description	Layer thickness at point of maximum subsidence (m)	Reservoir Interval	Total thickness (m)
A00 – A06	22		
A06-A08	5.7		
A08-A10	10.7		
A10-A30	3.8		
A30-A44	54.9	A	97.2
Clino	102		
B00-B10	101.7		
B10-B20	0		
B20-B38, B38-C00	43.9	B	145.6
C00-C28	187.9	UC+LC	187.9
C28-C29	6.1	LC2	6.1

Table 2. Numerical model layer thickness at Taglu

Except for reservoir interval B, the ratio between average gross pay (the gas producing section of the unit) and total unit thickness ranges from about 60% for unit C to 82% for unit A. This is thought to represent the shale and siltstone fractions that are present in these reservoir units.

In view of these data, it is not unreasonable to consider that the interbedded shale layers may also undergo compaction during reservoir depletion at the Niglintgak field. For the Taglu field, it is unclear how the presence of these interbedded shale layers were accounted for in the expected pressure depletion since the computer model or code that the Proponent used is deemed by the Proponent to be proprietary and has not been shared with the Joint Review Panel.

Unless the Proponent can demonstrate clearly that shale drainage was considered adequately in the reservoir compaction predictions, it is not unreasonable to consider that additional reservoir compaction would be induced if the effective stress in the shale layers increases as well. This, in turn, would likely lead to an increase in surface subsidence in both gas fields that are located within the Kendall Island Bird Sanctuary, similar to the shale draining scenario that was produced for the Parsons Lake gas field.

<u>Uncertainty in reservoir compressibility</u>

Reservoir compressibility is related to the reservoir material properties, which, in turn, depend in part on the geological history, included loading and unloading history, and internal processes such as stress corrosion (pressure-related chemical effects due to stress changes at the grain-to-grain contacts within a rock unit) and related mineral dissolution and deposition. Compressibility is, by far, one of the most difficult parameters to determine, particularly on the rock mass scale, and the degree of uncertainty will be higher when the number of samples are small and are restricted to a few zones of the reservoir.

For example, the rock property data that were reported, but appears to have been subsequently discarded, for five core samples collected from the Taglu reservoir rock units approximately 35 years ago (see Proponent's response to IR JRP_R4_08 dated May 30, 2006 – Attachment JRP 4.08-1), show a range of modulus values and a range of responses to loading. In addition, the geophysical laboratory measurements on these rock cores gave higher modulus values than the classical rock mechanics tests. Finally, the rock properties (such as the relationship between stress and strain and the relationship between transverse strain and axial strain) that were used either directly or indirectly in the computer model(s) to determine the reservoir compaction and the surface subsidence are higher than any of the stress-strain moduli that were determined from the laboratory tests on the rock cores that have been reported for these reservoir rock units.

Part of the uncertainty in the response of the reservoir rocks to pressure depletion is related to whether the reservoir units are normally consolidated, where the vertical effective stress (the total vertical stress minus the pore-water pressure or gas pressure) is consistent with the actual pressure due to the weight of the overburden, or if the reservoir is a pre-consolidated rock formation, in which the current effective vertical stress is less than the effective pre-consolidation stress (the historical maximum effective vertical stress). In the latter case, additional loading due to increases in the effective stress would result in relatively small compaction until the effective vertical stress becomes larger than the pre-consolidation stress, on the rocks, and enters into the normally consolidated domain. This is where compaction is governed by the virgin (the original, before the additional loading was imposed on the rock) compressibility at the corresponding stress level. However, it is important to note that over long time periods a condition of static equilibrium (where the forces or stresses within a rock are balanced, including the grain-to-grain contacts and the fluid/gas pressures) is re-established as the grain-to-grain contacts in the reservoir formations are modified by the internal processes discussed above, restoring part of the original or virgin compressibility of the formation.

Niglintgak

In response to IR JRP_R4_08, the Proponent for the Niglintgak field states that the compressibility used in their prediction is based on the virgin stress loading data. This is a conservative assumption since the reservoir formation may be over-consolidated based on the geological history of this area. To illustrate the point let us assume that the maximum burial depth of the sands during the Oligocene exceeded the current depth by about 1100 metres. In this case, the effective pre-consolidation stress would be about 10 MPa (mega Pascal, 10^6 Pascals) greater than the current effective vertical stress. As well, if the area was also covered by up to a kilometre of ice during the most recent glacial period (see response to IR JRP_R4_08) this would produce an added vertical stress of about 9.2 MPa. These two loads, however, are not cumulative. Since the depletion at Niglintgak will only be about 9.6 MPa at most, i.e. less than 10 MPa, the reservoir, even at full depletion, would still be at a stress level close to its historical maximum.

According to the response to IR JRP_R4_08, the maximum reservoir compaction at the top of the A1 sand unit was 0.537 m, which, in turn, corresponds to a relative compaction, $\Delta H/H$, of 0.43% considering the gross pay of 124.4 m of the A sands. This is consistent with the assumed compressibility value of 0.5 GPa^{-1} and eqn (1) yielding a compaction value of 0.57 m.

According to references 5 and 6, the relative compaction for a vertical stress increment from 10 MPa to 20 MPa in an oedometric test conducted on samples recovered at Niglintgak B-19 in 1977 was about 0.88% for first loading (virgin) and 0.5% during second loading after unloading the sample. The value of 0.5% corresponds thus to the over-consolidated domain, i.e. for stresses less than the pre-consolidation stress. The values inferred from the laboratory data in the over-consolidated data are close to the value assumed for the compaction prediction. However, it does not appear to be a value that corresponds to virgin loading as stated by the Proponent. This, in turn, makes the Proponent's compaction prediction for Niglintgak less conservative than stated.

Taglu

The Taglu gas field is in close proximity to the Niglintgak field and it is reasonable to consider that the geological history of the Taglu field is similar to that at the Niglintgak field. Consequently, it is reasonable to assume for the purposes of this discussion that the reservoir is also pre-consolidated by about 10 MPa. However, because the reservoir is located at a greater depth than Niglintgak, the change in effective stress during reservoir depletion is much larger. In reference 7, Table 2, the average pressure depletion in the different layers of the Taglu reservoir range from about 8 to 29 MPa as shown below:

Layer description	Layer thickness at max subsidence (m)	Pressure Depletion (MPa)
A00 – A06	22	0.6
A06-A08	5.7	0
A08-A10	10.7	23.4
A10-A30	3.8	0
A30-A44	54.9	7.8
Clino	102	9.1
B00-B10	101.7	15.7
B10-B20	0	0
B20-B38, B38-C00	43.9	12.3
C00-C28	187.9	15.2
C28-C29	6.1	29.3

Table 3. Predicted pressure depletion at Taglu

For several layers, the maximum change in vertical effective stress is larger than the added stress from geological loading or ice loading. This suggests that the reservoir rock may enter into the normally consolidated domain as gas extraction proceeds. Hence, reservoir compaction is anticipated to be larger than that which was predicted using material properties corresponding to the over-consolidated domain.

In our analysis, we also compared the predicted maximum reservoir compaction at Taglu in terms of relative settlement considering that the total reservoir thickness is 555 m. According to Table JRP 4.08-8 from the Proponent's response to IR JRP_R4_08, ΔH at the top of the reservoir is 0.92 m, which yields a relative compaction of $\Delta H/H = 0.92/555 = 0.17\%$. It is noted that this relative compaction is 2.5 times smaller than that predicted at Niglintgak. In the over-consolidated domain, one might expect little effect of confining stress on material properties. This means that it would be reasonable to use the same compressibility value at Taglu as that used at Niglintgak, at least until gas pressure depletion reaches 10 MPa.

Considering that: (a) at Taglu the rock is likely to reach the normally consolidated state, at least in some layers, and (b) that the compressibility used in the prediction at Taglu is 2.5 times lower than that used at Niglintgak, the compaction at Taglu may be significantly larger than the Proponent's predicted value of 0.92 m.

<u>Uncertainty in gas pressure depletion values</u>

For the Niglintgak and Parsons Lake gas fields, the maximum pressure depletion is almost equal to the initial reservoir gas pressure. The predicted gas pressure depletion values for Taglu are given in Table 3 of this report and are generally significantly smaller than the initial reservoir gas pressure, which appears to be about 30 MPa in A layers and 32 MPa in C layers (see reference 2, Figure 3-1).

Since a proprietary reservoir simulator was used to provide pressure predictions for the Taglu gas field and the Joint Review Panel has been unable to access this model, we, as technical advisors to the Panel, are unable to determine why this difference in gas pressure depletion values exists. We assume that this variability in gas pressure depletion may be due to the averaging of the sand and shale hydraulic properties in the numerical model layers. If this is the case, the model would underestimate the actual gas pressure depletion over the life of the reservoir.

Unless the Proponent can demonstrate that their proprietary simulator provides a conservative estimate of reservoir pressure it is clear that a conservative approach would have to consider, as was done for the Niglintgak and Parsons Lake gas fields, full depletion with a pressure change of about 30 MPa. This would move the effective stress levels in the entire Taglu reservoir higher than the pre-consolidation stress level and thus the compressibility and compaction would be governed by the normally consolidated rock stress versus compaction relationship.

Considering the above, anticipated surface subsidence induced by reservoir compaction at Taglu may be significantly larger than the 0.38 m predicted by the Proponent if the proprietary pressure simulator does not predict the correct final pressure depletion values.

<u>Creep or time dependent rock properties</u>

Predicted reservoir compaction at all three gas fields were not calculated using time-dependent material properties (for example where the rock would continue to deform under a constant load). Taglu's Proponent simply states: "*Time dependence (creep behaviour) was not measured during laboratory testing or considered a critical variable for the geomechanical subsidence model.*" Examination of the rock mechanics data that were provided for the Taglu reservoir rocks suggests that the rock samples continued to deform when the load was held constant on the post-failure part of the stress-strain curve – indicating time-dependent deformation. In addition, extensive research in Japan has shown that creep cannot be neglected in sedimentary rocks, especially over the stress range found in the gas reservoirs (reference 8, Hayano *et al*., 2001). Since gas extraction is planned for at least 30 years, creep may contribute to an increase in reservoir compaction both during the active gas extraction phase as well as for some time after gas extraction has been terminated.

For Niglintgak, the Proponent states: "*… the modelling work done was conservative and was designed to predict maximum subsidence impacts. The aspect of time delay was not considered, as it does not affect the ultimate magnitude of the predicted subsidence*." The Proponent has provided no evidence supporting this last statement.

Creep must be included in any reservoir compaction prediction model. Failure to do so will under-estimate the level of reservoir compaction during the gas depletion phase and for some time after active gas depletion has ceased.

<u>Uncertainty in predicting the amount of arching in the overburden rock</u>

As discussed above, arching will reduce surface subsidence relative to the magnitude of the reservoir compaction but this reduction depends primarily on reservoir geometry and depth. Other factors should also be considered such as the material properties of the overburden.

In reference 1, the Proponent performed a generic numerical modelling analysis for the Parsons Lake reservoir that established a relationship between subsidence (s) and compaction (ΔH), as a function of the ratio between reservoir depth and reservoir width.

Table 4 of this report shows the subsidence to compaction ratio obtained by the Proponent for each of the three gas fields: Niglintgak, Parsons Lake and Taglu.

Gas field	s / ΔH predicted from geomechanical models	s / ΔH generic model	D m	W m	D/W
Niglintgak	0.442 / 0.537 = **0.82**	**1.0**	1000	7000	0.14
Parsons Lake		**0.8 – 0.95**			0.5
Taglu	0.38 / 0.92 = **<u>0.41</u>**	**0.95**	N-S direction		0.4

Table 4. Subsidence to compaction ratio (predicted vs. generic modelling)

Table 4 demonstrates that the subsidence to compaction ratio for Taglu is considerably different from the ratio calculated for Niglintgak and Parsons Lake. Taglu's Proponent does not give any justification for this significant difference considering that the generic model does not predict a major difference in the arching mechanisms at each gas field. If a subsidence to compaction ratio of 0.8 to 0.9 is used for Taglu, all other parameters being unchanged, the maximum surface subsidence at the Taglu gas field would increase from 0.38 m to about 0.8 m.

Summary of the subsidence analysis

At this stage of our analysis, we are concerned that the Proponent's maximum subsidence values at each gas field, but especially at the Taglu field, do not represent the maximum value and may not be as conservative a value as stated in the EIS.

At this time, we are also unable to comment on the confidence levels of the predicted subsidence at the anchor fields as the Proponents have not provided this information. The Proponents should provide confidence bounds on their predictions of maximum surface subsidence and show clearly how these confidence bounds were calculated.

Gas field subsidence and environmental impacts

As geo-technical advisors to the Joint Review Panel, our main areas of responsibility with respect to gas field subsidence matters are focussed on an analysis of the surficial and sub-surficial geological elements of the proposed gas field developments. An analysis of the features of these proposed developments that relate to reservoir subsidence logically leads to an analysis of how changes in the sub-surface could lead to changes in the land surface and the bio-physical environment that encompasses the proposed developments.

Gas field subsidence and land inundation at Taglu

Our analysis of the environmental effects of gas field subsidence is limited to a cursory discussion of the potential effects of gas field subsidence on land inundation in the Taglu area. We anticipate other technical experts will, either through letters of comment to the Joint Review Panel or in presentations and discussions at future public hearings, provide their interpretation of the potential effects of gas field subsidence on specific areas of environmental concern. These areas of concern might include, but are not limited to, potential effects on vegetation and on birds and wildlife and their habitats, especially as they relate to the Kendall Island Bird Sanctuary.

To illustrate the potential surficial effects of gas field subsidence, NRCan (reference 9) provided an estimate of the change in the area of inundation with increase in lake elevation (or subsidence) at Taglu (near Big Lake). These estimates were based on 2003 LiDAR data and are summarized in Table 5.

Lake elevation (msl)	Estimated change to area of inundation after 30 years (square km)
0.2 m	0.48
0.3 m	1.34
0.4 m	2.75

Table 5. Estimated changes in land inundation with increased lake elevation or subsidence at Taglu (near Big Lake)

Based on our desktop analysis using the Taglu elevation profiles, a subsidence of 0.8 m at the Taglu field could produce an increase in the area of inundation of about 25 square kilometres within the KIBS boundaries. Furthermore a subsidence of 1.6 m would correspond to the top of the Kuluarpak channel banks and the inundated area may then be very substantial. Owing to the relatively flat topography in the Taglu area, typical of the outer Mackenzie delta, doubling the depth of the subsidence does not result in a two-fold increase in inundated area. It is important to note that our desktop analysis showed that a doubling of subsidence depth at Taglu (from 0.4 m to 0.8 m) could result in approximately a ten-fold increase in the inundated area within KIBS.

Based on our analysis, we believe an increase in surface subsidence beyond that predicted by the Proponent of the Taglu gas field in the EIS and subsequent information filings would have a significant impact on the total area of the Kendall Island Bird Sanctuary that would be inundated as gas extraction proceeds.

<u>Gas field subsidence and potential mitigation measures</u>

The Joint Review Panel has also directed us to investigate potential mitigation measures related to gas field subsidence. We would suggest the following measures could be undertaken for each of the three anchor gas fields:

- **Additional samples of all of the primary reservoir rock, underburden, and overburden rock units can be obtained during initial reservoir development and the coupled hydraulic and mechanical properties of these rock units can be determined through laboratory testing. This, in turn, would allow the Proponent to predict surface subsidence with greater confidence than the current data set can support.**

- **Effective mitigation of surface subsidence concerns would also include the implementation of an independent, third party, monitoring system. Surface subsidence can be effectively monitored using current satellite GPS technology once the appropriate benchmarks and reference points have been established.**

- **As mentioned by the Proponent in reference 1, one of the most common and cost effective means of control over reservoir compaction and associated subsidence is through the control of reservoir pressure decline by injecting water into the reservoir. This is an effective means of controlling reservoir subsidence and thus an effective mitigation measure to control or abate surface subsidence. However, we are cognizant of the fact that the Proponents of the three gas fields have not included this feature in their respective proposed gas field operational plans.**

From an environmental impact point of view, a threshold or critical subsidence level should be associated with what is considered to be an acceptable loss of land, vegetation and bird and wildlife habitat in the KIBS. At this time, we will defer defining "acceptable" or "threshold" or "critical subsidence level" to the Joint Review Panel and regulators as it is based on a combination of geo-technical, bio-physical, social, economic and cultural valued components.

- **Based on "an acceptable loss of land and wildlife habitat in the Kendall Island Bird Sanctuary" and the Proponent's high level of confidence in their predictions regarding gas field subsidence at Taglu and Niglintgak, we would advocate gas**

production could continue to the time of gas field depletion or until the maximum predicted surface subsidence is reached, whichever comes first.

Concluding Remarks

In this report, we have outlined some of the concerns we have, as technical advisors to the Joint Review Panel, regarding the Proponent's predictions of gas field subsidence. These concerns include the use of proprietary geomechanical models and proprietary flow models to compute pore/gas pressures. We have also indicated our concern that, due to the lack of adequate characterisation of the material properties of the productive sands, the interbedded, low permeability bedrock units and the overburden layers as well as the stress history of the reservoir rocks, it is difficult to accurately predict gas field subsidence.

We have also indicated our concern that, in the case of the Taglu field, the rock mechanics laboratory data concerning rock samples from historic well cores does not appear to have been used in the subsidence calculations for that field. As well, for Taglu, there is uncertainty in the thickness of the reservoir units that will be drained by the gas production and uncertainty in terms of the key rock properties that determine reservoir compaction. In the case of Taglu, there is concern that the pressure drop in each of the rock units may be greater than the Proponent's prediction.

Based on information filed to date by the Proponent of the Taglu field, we believe that the prediction of reservoir compaction and surface subsidence due to gas extraction is associated with a high degree of uncertainty. This also leads to uncertainty in predicting the severity of the environmental impact, especially as it may affect the Kendall Island Bird Sanctuary.

This report also provides the Joint Review Panel with the results of our desktop analysis of potential land inundation effects at the Taglu field and includes several measures that should be considered in monitoring and mitigating potential environmental concerns especially as they relate to potential effects within KIBS.

References

1. JRP Public Registry: Exhibit # J-IORVL-0054, "*The evaluation of reservoir compaction and subsidence potential for the Parsons Lake Field, Mackenzie Delta, NWT, Canada*" by N.B. Nagel (updated May 2006) – Attachment to response to Information Request JRP 4.08-2

2. Taglu Development Plan Application: mgp_taglu_dpa_section_3.pdf

3. Taglu Development Plan Application: mgp_taglu_dpa_section_2_part_b.pdf

4. Taglu Development Plan Application: mgp_taglu_dpa_section_2_part_c.pdf

5. JRP Public Registry: Exhibit # J-IORVL- 00689, Response to JRP IR Round 4, Question 9, Part B (JRP_R4_09) Attachment 4.09b-1 (Part 2) (060810_IR_4-09B_resp_attach_1-pt2.pdf)

6. JRP Public Registry: Exhibit # J-IORVL-00690, Response to JRP IR Round 4, Question 9, Part B (JRP_R4_09) Attachment 4.09b-1 (Part 3) (AttachJRP4.09b-1CompacofConsolASandsfromNigB-19part 3.pdf)

7. JRP Public Registry: Exhibit # J-IORVL- 00290, IR Response to NRCan_R2_004, (Attach_2.04-1_Taglu_Surface_Subsidence_Study_Report.pdf)

8. Hayano *et al*. (2001) in "*Characterisation and engineering properties of natural soils*" Volume 2, edited by Tan, Phoon, Hight and Leroueil, Balkema Publishers

9. JRP Public Registry: Exhibit # J-IORVL-00496, Additional information requested by NRCan on February 10, 2006. Attachment 2

10. JRP Public Registry: Exhibit # J-NRCAN-00066, NRCan response to the Joint Review Panel Information Request JRP_R4_11 on subsidence estimates