CUMULATIVE EFFECTS MODELLING OF THE MACKENZIE GAS PROJECT – SCOPING AND DEVELOPMENT

prepared by

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for

Canadian Arctic Resources Committee

A voice for citizens on the Canadian North for more than 30 years

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* Revisions from January 2, 2005 version: Map legends have been simplified and CARC tags have been added to each map

CUMULATIVE EFFECTS MODELLING OF THE MACKENZIE GAS PROJECT –
SCOPING AND DEVELOPMENT

Introduction

On October 5, 2004, Canadian Arctic Resources Committee contracted Cizek Environmental Services to conduct "Cumulative Effects Modelling of the Mackenzie Gas Project – Scoping and Development." Six working days were allocated to this project. This work was to use actual small area examples to review, document, and evaluate the application of dynamic landscape simulation models to assess the cumulative impacts of the Mackenzie Gas Project. The models and/or software that were to be evaluated included:

1. GLOBIO (Global Methodology for Mapping Human Impacts on the Biosphere)[1]
2. IDRISI Dynamic Modelling Module[2]
3. DINAMICA Landscape Dynamics Simulation Software[3]

It was originally anticipated that mapping and modelling cumulative effects of induced natural gas fields would require a probabilistic approach where future gas wells would be identified based on a combination of geological potential and distance to proposed pipeline infrastructure.

On October 7, 2004 the regulatory applications for the Mackenzie Gas Project (MGP) were submitted and released to the public.[4] While the Environmental Impact Statement (EIS) submitted to the Joint Review Panel does not contain any maps showing cumulative effects of induced development,[5] the application to the National Energy Board contains a very detailed natural gas supply forecast prepared by Gilbert, Laustsen, Jung Associates Ltd., Petroleum Consultants, entitled *Mackenzie Gas Project – Gas Resource Supply Study*[6] (GLJ Study). The GLJ Study identifies all the future wells required to supply the MGP until 2049 but does not provide any maps. Instead of pursuing a probabilistic dynamic modelling approach, it was decided to simply map out the induced development identified by the GLJ Study. In addition, a preliminary cumulative effects assessment was conducted using the United Nations Environment Program's "Global Methodology for Mapping Human Impacts on the Biosphere" (GLOBIO).

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[1] http://www.globio.info/
[2] http://www.clarklabs.org/
[3] http://www.csr.ufmg.br/
[4] http://www.ngps.nt.ca/applicationsubmission/
[5] http://www.ngps.nt.ca/applicationsubmission/EIS.html
[6] http://www.ngps.nt.ca/applicationsubmission/GLJ.html

All data were processed using ArcView3.3 (Environmental Systems Research Institute, Redlands CA)[7] Geographic Information System (GIS) software running in WindowsXP on a DellXPS with 3.4GHz CPU, 1GB RAM, 128 MB Video Acceleration, and 100GB Hard-Drive. Digitizing was conducted on a Summagrid IV[8] (GTCO Calcomp, Columbia MD) 36"x48" digitizing tablet.

Kevin O'Reilly of the Canadian Arctic Resources Committee provided many helpful insights and suggestions throughout this project. A review of the final draft of this project by Hal Retzer, Peggy Holroyd, and Chris Severson-Baker of the Pembina Institute also pointed out several areas requiring further explanation and clarification.

Study Area

The GLJ Study (Table 7, p. 50) identifies three general petroleum areas that could supply the MGP:

1. Mackenzie Delta & Beaufort Sea (NWT)
2. Eagle Plains (Yukon Territory)
3. Colville Hills (NWT)

However, the GLJ Study (p. 56) states that the Eagles Plains are approximately 300 km from the planned pipeline route and would be uneconomical to tie-in on a stand-alone basis. As a result, the GLJ Study only considers the Mackenzie Delta/Beaufort Sea and the Colville Hills petroleum areas as economic gas supplies for the MGP. As shown in Map #1, the study area was defined to encompass only the Mackenzie Delta/Beaufort Sea and the Colville Hills. The study area is approximately 625 km x 680 km or 425,000 km^2.

[7] http://www.esri.com/software/arcview/
[8] http://www.gtcocalcomp.com/

Map #1 here

Existing Human Activities

As shown in Map # 2, Existing Human Activities were identified using the NWT Digital Atlas.[9]

The study area contains a total of seven settlements, of which three (Fort McPherson, Tsiigehtchic, and Inuvik) are connected to the Dempster Highway, an all-weather gravel road to the Yukon Territory. The remaining four settlements (Aklavik, Tuktoyaktuk, Fort Good Hope, and Colville Lake) are accessible by winter road only.

The *Ikhil Pipeline* currently supplies natural gas for local consumption in Inuvik.

Updated *Wells* data were received from the National Energy Board in the summer of 2004.

Historical Seismic Lines are incomplete and current only to 1992. National Energy Board staff provided the following cautions about their seismic line database: [10]

> Our digital data is supplied by the companies based on what they had in their databases in 1988 and the work that was done subsequently. We digitized additional lines for which we had seismic sections. Generally, the lines in our database are from 1974 (when seismic sections were first required) through the present. Almost all of the pre-1974 seismic is NOT in our database. There are some (few) earlier lines if the data was in the company databases at the time we gathered the data.

Updates were requested from the National Energy Board[11] on November 3, 2004, but no response was received.

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[9] NWT Digital Atlas. 2002. Compiled by the World Wildlife Fund on 3 CD-ROMs.
[10] Rudi Klaubert. Regulatory Information Administrator, National Energy Board, Calgary, rklaubert@neb-one.gc.ca. Personal communication, February 28, 2002.
[11] Rudi Klaubert, rklaubert@neb-one.gc.ca

Map #2 goes here

Gas Supply Scenarios, Data Summary, and Methods

The GLJ Study identifies five gas supply scenarios:

1. Contingent Onshore Resources at 1.2 billion cubic feet per day or 34 million m^3 per day (Figure 31, p. 55)
2. Contingent and Prospective Onshore Resources at 1.2 billion cubic feet per day or 34 million m^3 per day (Figure 32, p. 63)
3. Contingent and Prospective Onshore and Offshore Resources at 1.2 billion cubic feet per day or 34 million m^3 per day (Figure 33, p. 63)
4. Contingent and Prospective Onshore and Offshore Resources with Increased Pipeline Capacity at 1.8 billion cubic feet per day or 51 million m^3 per day (Figure 34, p. 65)
5. Contingent and Prospective Onshore and Offshore Resources with NEB P_{50} Resource Estimates at 1.2 billion cubic feet per day or 34 million m^3 per day (Figure 35, p. 65)

This study mapped out Scenario # 4, which is the maximum production scenario. Scenarios # 3, # 4, and # 5 all result in the same number of new production and exploration wells, but the phasing of the new wells is timed differently. It would be possible to create maps showing the sequencing of development under all five scenarios, but the level of effort required is beyond the scope of this project.

On the following page, Table # 1 summarizes the estimated cumulative number of wells, linear kilometres of seismic, and length of pipelines using the "Contingent and Prospective Onshore and Offshore Resources at 1.8 billion cubic feet per day or 51 million m^3 per day" scenario as presented in the GLJ Study. The GLJ Study does not describe the associated infrastructure (e.g. compressor stations, roads, borrow sites etc.) and it is beyond the scope of this project to develop an estimate.

It is likely that the exploratory drilling and seismic activities would be phased over the course of several years. To simplify the modelling, each year in Table # 1 and each of the subsequent maps represents a "snapshot" of the cumulative hydrocarbon activities that would have been carried out up to that particular year.

Table # 1 Summary of Estimated Cumulative Hydrocarbon Activities (Contingent and Prospective Onshore and Offshore Resources with Increased Pipeline Capacity at 1.8 billion cubic feet per day or 51 million m^3 per day)

Year	Original Data Contained in GLJ Study			Derived Data	
	Contingent Resources (Existing Fields with Proven Gas)	Prospective Resources			
		New Production Wells	Total New Exploration Wells (Production Wells + Dry Wells)	New Seismic Lines (Linear Kilometres)	Cumulative Length of Trunk and Feeder Pipelines
2009	Parsons Lake, Taglu, Niglintgak (Anchor Fields) ***3 (Cumulative Total)***	none	none	none	1,397 km
2011	Parsons Lake, Taglu, Niglintgak (Anchor Fields); Adgo, Yaya, Garry North, Garry South, Hansen, Kumak, Maillik, Pelly, Reindeer, Titalik, Tuk, Unak, Unipkat, Ya Ya North, and Ya Ya South (Mackenzie Delta); Bele, Tedji, Tweed (Colville Hills) ***21 (Cumulative Total)***	none	none	none	2,012 km
2013	Parsons Lake, Taglu, Niglintgak (Anchor Fields); Adgo, Yaya, Garry North, Garry South, Hansen, Kumak, Maillik, Pelly, Reindeer, Titalik, Tuk, Unak, Unipkat, Ya Ya North, and Ya Ya South (Mackenzie Delta); Bele, Tedji, Tweed (Colville Hills) ***21 (Cumulative Total)***	53 (Colville Hills) 13 (Basin Margin) 17 (Listric Fault – Onshore) ***83 (Cumulative Total)***	384 (Colville Hills) 108 (Basin Margin) 62 (Listric Fault – Onshore) ***554 (Cumulative Total)***	21,888 km (Colvile Hills) 19,656 km (Basin Margin) 19,110 km (Listric Fault – Onshore) ***60,654 km (Cumulative Total)***	3,260 km
2016	Parsons Lake, Taglu, Niglintgak (Anchor Fields); Adgo, Yaya, Garry North, Garry South, Hansen, Kumak, Maillik, Pelly, Reindeer, Titalik, Tuk, Unak, Unipkat, Ya Ya North, and Ya Ya South (Mackenzie Delta); Bele, Tedji, Tweed (Colville Hills); Amauligak, Issungnak, Itiyok, South Isserk, Ukalerk, Kadluk, Kiggavik, Minuk, Netserk, South Nipterk (Beaufort Sea Offshore) ***31 (Cumulative Total)***	53 (Colville Hills) 13 (Basin Margin) 17 (Listric Fault – Onshore) ***83 (Cumulative Total)***	384 (Colville Hills) 108 (Basin Margin) 62 (Listric Fault – Onshore) ***554 (Cumulative Total)***	21,888 km (Colvile Hills) 19,656 km (Basin Margin) 19,110 km (Listric Fault – Onshore) ***60,654 km (Cumulative Total)***	3,510 km
2027	Parsons Lake, Taglu, Niglintgak (Anchor Fields); Adgo, Yaya, Garry North, Garry South, Hansen, Kumak, Maillik, Pelly, Reindeer, Titalik, Tuk, Unak, Unipkat, Ya Ya North, and Ya Ya South (Mackenzie Delta); Bele, Tedji, Tweed (Colville Hills); Amauligak, Issungnak, Itiyok, South Isserk, Ukalerk, Kadluk, Kiggavik, Minuk, Netserk, South Nipterk (Beaufort Sea Offshore) ***31 (Cumulative Total)***	29 (Colville Hills) 35 (Basin Margin) 30 (Listric Fault – Onshore) 31 (Listric Fault – Offshore) ***125 (Cumulative Total)***	384 (Colville Hills) 108 (Basin Margin) 62 (Listric Fault – Onshore) 130 (Listric Fault – Offshore) ***684 (Cumulative Total)***	21,888 km (Colvile Hills) 19,656 km (Basin Margin) 19,110 km (Listric Fault – Onshore) 26,930 km (Listric Fault – Offshore) ***87,584 km (Cumulative Total)***	3,813 km

Original Data Contained in GLJ Study

The sources for the *Contingent Resources* data are contained in the following pages of the GLJ Study:

Anchor Fields (p. 53);
Mackenzie Delta (p. 53);
Colville Hills (p. 55); and
Beaufort Sea Offshore (p. 57).

The locations of the *Contingent Resources* were identified using the GIS database containing *Existing Wells* obtained from the National Energy Board.

The GLJ Study provides a "High Estimate" (P_{10} OGIP[12]), "Low Estimate" (P_{90} OGIP), and "Best Estimate" (P_{50} OGIP) for the *Prospective Resources* using Monte Carlo risk analysis (p. 23). The detailed methods for estimating the total number of wells for the *Prospective Resources* data are contained in the following pages of the GLJ Study:

Basin Margin (p. 28);
Listric Fault (p. 34); and
Colville Hills (p. 38).

The GLJ Study also provides summary tables for all the *Prospective Resources* (pp. 50-51).

The *Prospective Resources* then had to be transformed into a geo-spatial format using GIS software. The DNR Sample Generator Extension,[13] developed by the Minnesota Department of Natural Resources, generates a given number of points or lines that are randomly distributed throughout a specific area. This extension also allows for the random selection of a given percentage of these features. This extension was used to randomly generate the estimated number of exploration wells in each petroleum exploration play area and then randomly select those wells that would become production wells.

[12] OGIP is "Original Gas-in-Place"
[13] http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions/sampling/dnrsample.html

Derived Data

The following methods were used to generate derived data and transform it into a geo-spatial format using GIS software.

Seismic Lines

The GLJ Study (Table 22, p. 61) states that the following seismic costs, as shown in Table # 2, would be required for each well, based on historical figures:

Table # 2 Estimated Seismic Cost Per Well

Area/Play	**Estimated Seismic Cost Per Well (Millions of Dollars)**
Mackenzie Delta/Basin Margin	12.0
Mackenzie Delta/Listric Fault	12.0
Beaufort Sea/Listric Fault	15.0
Colville Hills	2.8

Requests were submitted to the Pembina Institute[14], the Canadian Association of Geophysical Contractors[15], and Northern Oil and Gas Directorate, Indian and Northern Affairs Canada[16], to estimate the linear kilometres of seismic that could be shot for these costs.

Only the Pembina Institute responded to these requests, but was unable to provide an estimate of linear kilometres per well based on the costs of seismic per well identified in the above table. The Pembina Institute did state that between 1995 and 2002 there was an average of 3 to 20 linear kilometres of seismic conducted per well per year in Alberta, Saskatchewan, and British Columbia. The upper figure of 20 linear kilometres of seismic per well was applied to the suggested number of exploration targets required in each petroleum exploration area and test GIS data were generated. The resulting pattern appeared very sparse compared to relatively more mature petroleum exploration areas in the NWT such as Fort Liard and Cameron Hills.

[14] http://www.pembina.org/
[15] http://www.cagc.ca/
[16] http://www.ainc-inac.gc.ca/oil/index_e.html

For comparison, data from the Fort Liard Cumulative Effects Mapping Project[17] were re-calculated. Based on NEB data, land use permit data, and cut-lines on National Topographic Series map sheets, there may be as much as 218 linear kilometres of seismic per well in the Fort Liard study area. Based on visible cut-lines from Indian Resource Satellite (IRS) 5 metre resolution satellite imagery (1999-2003) acquired by the Deh Cho Land Use Planning Committee,[18] there may be as much as 120 linear kilometres of seismic per well in the Fort Liard study area.

Thus, the only remaining approach was to use the *Wells* data from the National Energy Board and *Historical Seismic Lines* data from the NWT Digital Atlas to calculate the ratios of linear kilometres of seismic per well for each petroleum exploration area. Since the *Historical Seismic Lines* are current only to 1992, wells drilled after 1992 in the *Wells* dataset were excluded. This ratio was then multiplied by the suggested number of exploration targets required, as estimated by the GLJ Study for each petroleum exploration area (Table 7, p. 50). Table # 3 summarizes the results of these calculations.

Table # 3 Linear Kilometres of Seismic Per Well

	Linear Kilometres of Historic Seismic Lines (Extracted from NEB Database 1967 - 1992)	**Number of Wells (Extracted from NEB Database 1966 - 1992)**	**Ratio of Linear Kilometres of Seismic per Well (Until 1992)**	**Suggested Number of Exploration Targets Required (2009 – 2027)**	**Estimated New Linear Kilometres of Seismic Required (2009 – 2027)**
Basin Margin	10,955	60	182	108	19,656
Listric Fault	47,216	172	274	192	52,608
Colville Hills	3,424	17	57	384	21,888

The ratios of linear kilometres of seismic per well in Table # 3 are substantially higher than the estimates provided for Alberta, Saskatchewan, and British Columbia to the Pembina Institute by provincial regulatory authorities. On the other hand, the ratios in the Table # 3 are within the same order of magnitude as those from the Fort Liard study area, where seismic lines were documented using cartographic, GIS, and remote sensing approaches. However, it is recognized that the ratio of linear kilometres of seismic per well may be reduced as a petroleum exploration area matures. Nevertheless, due to the current absence of any other data, the best possible option is to use the *Estimated New Linear Kilometres of Seismic Required* from Table # 3 as the best available estimate.

[17] http://www.carc.org/2002/Final_Fort_Liard_Technical_Report_May_17_2002.pdf
[18] http://www.dehcholands.org

The DNR Sample Generator Extension,[19] was used to randomly generate the estimated linear kilometres of seismic in each petroleum exploration play area. The length of each seismic line was set to 10 kilometres as this is the longest segment permitted by the software.

Pipelines

The "Roads2Wells" [20] ArcView script, developed by the Community and Environment Spatial Analysis Centre[21], was used to generate feeder pipelines connecting new production wells to the main pipeline trunk. This script automatically connects a set of points (i.e. wells) to the nearest line segment (i.e. pipeline). It should be noted that this script connects the wells in the order that they appear in the database, which may not necessarily be the order in which they would be drilled. Furthermore, the script simply generates straight lines without account for topographic constraints. Where the script generated lines crossing major lakes, these lines were manually edited to avoid water crossings.

[19] http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions/sampling/dnrsample.html
[20] http://arcscripts.esri.com/details.asp?dbid=13795
[21] http://www.commenspace.org/

Proposed Project – 2009

Operation of the MGP is expected to begin in 2009.

On December 2, 2004 original GIS data for the whole MGP corridor was received from Esso, including the following features:

1. *MGP Engineered Route*
2. *Compressor Stations*
3. *Camps, Stockpile, and Staging Site*
4. *Borrow Sites.*

The *Proposed All Weather Road* and the *Proposed Winter Road* were digitized from the *Environmental Impact Statement for the Mackenzie Gas Project Volume 5: Biophysical Impact Assessment Part F: Climate Change, Cumulative Effects, Biodiversity and Environmental Effects on the Project, Appendix A, Baseline Disturbance Maps.*[22]

Map # 3 shows the pipeline corridor connecting into the Parsons Lake, Taglu, and Niglintgak anchor fields.

[22] http://www.ngps.nt.ca/applicationsubmission/Images/MGP_EIS_Vol5_FigureA.1.jpg; http://www.ngps.nt.ca/applicationsubmission/Images/MGP_EIS_Vol5_FigureA.2.jpg; http://www.ngps.nt.ca/applicationsubmission/Images/MGP_EIS_Vol5_FigureA.3.jpg; http://www.ngps.nt.ca/applicationsubmission/Images/MGP_EIS_Vol5_FigureA.4.jpg;

Map #3 goes here

Petroleum Exploration Areas

As shown in Map #4, the GLJ Study (Table 7, p. 50) identifies three specific petroleum exploration play areas that could supply gas to the MGP:

1. Basin Margin (Mackenzie Delta)
2. Listric Fault (Mackenzie Delta and Beaufort Sea)
3. Cambrian Sandstone (Colville Hills)

The Basin Margin and Listric Fault were digitized from Map 2 "Regional Geology – Beaufort Sea and Mackenzie Delta"[23] (p. 13) and Map 3 "Listric Fault Zone and Basin Margin Play Area – Beaufort Sea and Mackenzie Delta"[24] (p. 47) in the GLJ Study.

Map 1 "Regional Geology – Northern Canada" in the GLJ Study that shows the Colville Hills petroleum exploration play area at a very small scale and is missing from the on-line version of the report.[25] Furthermore, the area delineated for the Colville Hills in the GLJ Study extends further west (all the way to the Mackenzie River) compared to the area shown in the DIAND Northern Oil and Gas Directorate's study "Petroleum Exploration in Northern Canada: A Guide to Oil and Gas Exploration and Potential."[26] As a result, the Colville Hills petroleum exploration play area was obtained in GIS format from the CS Lord Geoscience Centre in Yellowknife based on data originally delineated by Peter Davenport of the Geological Survey of Canada.[27]

The *Regional Study Area* was digitized from the *Environmental Impact Statement for the Mackenzie Gas Project Volume 5: Biophysical Impact Assessment Part F: Climate Change, Cumulative Effects, Biodiversity and Environmental Effects on the Project, Appendix A, Baseline Disturbance Maps.*[28]

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23 http://www.ngps.nt.ca/applicationsubmission/Documents/MGP_GLJ_Final_Gas_Resources_and_Supply_Study_Contents_Set_2_S.pdf
24 http://www.ngps.nt.ca/applicationsubmission/Documents/MGP_GLJ_Final_Gas_Resources_and_Supply_Study_Contents_Set_3_S.pdf
25 http://www.ngps.nt.ca/applicationsubmission/Documents/MGP_GLJ_Final_Gas_Resources_and_Supply_Study_Contents_Set_1_S.pdf
26 http://www.ainc-inac.gc.ca/oil/Pdf/chapter1.pdf; http://www.ainc-inac.gc.ca/oil/Pdf/c2_northern.pdf
27 pdavenpo@nrcan.gc.ca
28 http://www.ngps.nt.ca/applicationsubmission/Images/MGP_EIS_Vol5_FigureA.1.jpg;
http://www.ngps.nt.ca/applicationsubmission/Images/MGP_EIS_Vol5_FigureA.2.jpg;
http://www.ngps.nt.ca/applicationsubmission/Images/MGP_EIS_Vol5_FigureA.3.jpg;
http://www.ngps.nt.ca/applicationsubmission/Images/MGP_EIS_Vol5_FigureA.4.jpg;

Map #4 goes here

Induced Development – 2011

According to the 1.8 billion cubic feet per day (51 million m^3 per day) scenario the GLJ Study (p. 53 and p. 55), the remaining fields with discovered resources in the Mackenzie Delta and the Colville Hills would first be connected to the MGP. In the Mackenzie Delta (p. 53), these include Adgo, Yaya, Garry North, Garry South, Hansen, Kumak, Maillik, Pelly, Reindeer, Titalik, Tuk, Unak, Unipkat, Ya Ya North, and Ya Ya South. In the Colville Hills (p. 55), these include Bele, Tedji, and Tweed. These fields were identified and selected from the *Wells* database received from the National Energy Board in the summer of 2004.

Using "Roads2Wells" script,[29] the selected wells were then automatically connected with feeder pipelines to the MGP.

Map # 5 shows induced development in 2011 according to the 1.8 billion cubic feet per day (51 million m^3 per day) scenario, as described in the GLJ Study (Table 37, page 83).

[29] http://arcscripts.esri.com/details.asp?dbid=13795

Map #5 goes here

Induced Development - 2013

According to the 1.8 billion cubic feet per day (51 million m^3 per day) scenario in the GLJ Study (Table 37. p. 83), the onshore prospective resources in the Basin Margin, Listric Fault, and Colville Hills petroleum areas would be connected to the MGP in 2013.

According to the "Best Estimate", the GLJ Study (Table 7, p. 50) states that the following wells would have to be drilled in each petroleum area to locate these prospective resources as shown below in Table # 4.

Table # 4 Estimate of New Wells Required

	Basin Margin	Listric Fault	Colville Hills	TOTAL
New Production Wells	13	48	53	114
Suggested # of Exploration Targets Required	108	192	384	684

Using the DNR Sample Generator Extension,[30] the suggested number of exploration target wells was randomly generated throughout each petroleum exploration area. Using this same extension, the number of production wells was then randomly selected from the new exploration target wells in each petroleum exploration area. In the case of the Listric Fault, only wells falling within the onshore of the Listric Fault were used. These included 17 new production wells out of 62 exploration targets required.

Using the "Roads2Wells" script,[31] the new production wells were then connected with feeder pipelines to the MGP. Where the script generated lines crossing major lakes, these lines were manually edited to avoid water crossings.

Using the DNR Sample Generator Extension,[32] the estimated new linear kilometres of seismic were randomly generated in each petroleum area. In the case of the Listric Fault, only seismic lines falling within the onshore of the Listric Fault were used. This included approximately 19,110 linear kilometres of seismic. Seismic exploration may occur several years prior to the drilling of exploration wells. However, in the absence of more detailed information, the seismic activity is sequenced at the same time as the drilling of exploration wells to show a "snapshot" of the cumulative total linear kilometres of seismic per well after the wells have been brought into production. No further seismic is shown for these wells after they are brought into production.

Map # 6 shows induced development in 2013.

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[30] http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions/sampling/dnrsample.html
[31] http://arcscripts.esri.com/details.asp?dbid=13795
[32] http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions/sampling/dnrsample.html

Map #6 goes here

Induced Development – 2016

According to the 1.8 billion cubic feet per day scenario in the GLJ Study (Table 37. p. 83), the discovered offshore resources in the Beaufort Sea would be connected to the MGP in 2016.

The GLJ Study (p. 57) identifies discovered offshore fields in the Beaufort Sea, including Amauligak, Issungnak, Itiyok, South Isserk, Ukalerk, Kadluk, Kiggavik, Minuk, Netserk, and South Nipterk. These fields were identified and selected from the *Wells* database provided by the National Energy Board.

Using the "Roads2Wells" script,[33] these wells were then connected with feeder pipelines to the MGP.

Map # 7 shows induced development in 2016.

[33] http://arcscripts.esri.com/details.asp?dbid=13795

Map #7 goes here

Terminal Development – 2027

According to the 1.8 billion cubic feet per day (51 million m^3 per day) scenario in the GLJ Study (Table 37, p. 83), the final and terminal development would connect the undiscovered offshore resources in the Listric Fault petroleum area to the MGP in 2027.

As generated in the previous section, the remaining exploration target wells and new production wells were selected for the offshore Listric Fault only. These included 31 production wells out of a total of 130 exploration targets required. It is possible that these fields could be accessed through directional drilling from multi-well artificial offshore islands. However, the modelling of directional drilling is beyond the scope of this study and each well is shown individually.

As generated in the previous section, the seismic lines were selected for the offshore Listric Fault only. These included approximately 26,930 linear kilometres of seismic lines. Seismic exploration may occur several years prior to the drilling of exploration wells. However, in the absence of more detailed information, the seismic activity is sequenced at the same time as the drilling of exploration wells to show a "snapshot" of the cumulative total linear kilometres of seismic per well after the wells have been brought into production. No further seismic is shown for these wells after they are brought into production.

Using the "Roads2Wells" script,[34] these wells were then connected with feeder pipelines to the MGP.

Map # 8 shows terminal development of the MGP in 2027.

[34] http://arcscripts.esri.com/details.asp?dbid=13795

Map #8 goes here

GLOBIO Terrestrial Impact Scenario – 2027

Using the United Nations Environment Program's GLOBIO (Global Methodology for Mapping Human Impacts on the Biosphere)[35] and the results of other relevant field studies[36], "zones of influence" were applied to various proposed and induced infrastructure components of the MGP to present the potential for cumulative effects for the 2027 terminal development scenario. The predicted ecological effects from human activities was applied only in onshore areas and only in the terrestrial environment. The following zones of influence were used:

Boreal Forest (south of the tree-line)

Infrastructure Type	High Impact (Reduced Abundance of Birds)	Medium-high impact (Reduced Abundance of Large Mammals)	Low-medium impact (Cumulative Effects on Flora and Fauna)
Roads, communities	300 m	900 m	3,000 m
Winter roads	225 m	675 m	2,250 m
Pipelines	150 m	450 m	1,500 m
Seismic Lines	unknown	250 m (Woodland Caribou)	unknown
Exploration Wells	unknown	500 m (Woodland Caribou)	unknown
Producing Wells	unknown	1,000 m (Woodland Caribou)	unknown

Arctic Tundra (north of the tree-line, terrestrial)

Infrastructure Type	High Impact (Reduced Abundance of Birds)	Medium-high impact (Reduced Abundance of Large Mammals)	Low-medium impact (Cumulative Effects on Flora and Fauna)
Roads, communities	1,000 m	3,000 m	10,000 m
Winter roads	750 m	2,250 m	7,500 m
Pipelines	500 m	1,500 m	5,000 m

The size of the areas for the predicted impacts are as follows:

High Impact (Reduced Abundance of Birds) = 2,678 km^2
Medium-high impact (Reduced Abundance of Large Mammals) = 26,712 km^2
Low-medium impact (Cumulative Effects on Flora and Fauna) = 20,265 km^2

The total area of impact based on the GLOBIO buffers applied is 37,895 km^2.

Map #9 shows the GLOBIO terrestrial impact scenario for 2027.

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[35] http://www.globio.info/
[36] C. Nellemann, I. Vistnesb, P. Jordhøyc, O. Strandc, A. Newtond. 2003. Progressive impact of piecemeal infrastructure development on wild reindeer. Biological Conservation. 113 (2003) 307–317; S. Dyer et al. 2001. Avoidance of industrial development by woodland caribou. Journal of Wildlife Management 65(3):531-542.

Map #9 (GLOBIO) goes here

Conclusions and Recommendations

The GLJ Study provides a straightforward basis for mapping the induced development and cumulative effects of the MGP without the need for probabilistic dynamic modelling. Mapping the results of the GLJ Study vividly illustrates the actual implications of the MGP until 2027 with regard to future wells, feeder pipelines, and seismic activity. However, an estimate of the infrastructure associated with induced development such as access roads, compressor stations, and borrow sites is beyond the scope of this study.

The main limitations of this approach are:

1. It assumes that the forecasts and assumptions in the GLJ Study are correct.
2. The random point and line generator software distributes wells and seismic lines randomly throughout each petroleum area without regard for more detailed geology or petroleum potential.
3. The automated script connects the new wells through feeder pipes based on the order in which the wells appear in the database, which may not necessarily be the order in which they would be drilled.
4. The feeder pipes generated by the automated script are straight and do not account for topographic constraints unless manually edited.
5. The best available estimate for future seismic activity involved calculating ratios of existing wells to historical seismic lines. These ratios may become reduced as petroleum exploration areas mature.
6. According to standard cartographic convention, the symbols for the hydrocarbon activities are sufficiently large to be easily legible on the small-scale maps. This exaggerates their actual physical footprint.

It is noteworthy that the EIS for the MGP does not apply any "zones of influence" to its cumulative effects assessment. The GLOBIO methodology of predicting ecological effects from human activities was applied to the terminal development at 2027 (only in onshore areas and only in the terrestrial environment) to present the potential for cumulative effects from the Project. Further study is suggested to include all possible infrastructure in the maps and modelling (e.g., access roads, borrow pits, gathering systems, compressor stations), better mapping of potential development within the producing areas, and more precise zones of influence on the Mackenzie Delta/Beaufort Sea terrestrial/aquatic/marine ecosystems.

Care will have to be taken to identify an appropriate Regional Study Area to address the "Modifiable Area Unit Problem"[37] in order to meaningfully calculate how much of a given study area is impacted. It should be noted that the "Regional Study Area" defined in the EIS does not encompass all of the petroleum exploration areas where the GLJ Study states that induced development will take place.

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[37] The Modifiable Areal Unit Problem (MAUP) states that changing the shape or size of the units on which the data are mapped can change the resulting models generated from the data.

Finally, it will be necessary to calculate different zones of influence for the Beaufort Sea marine environment. Further research is required to locate additional field studies that have identified zones of influence in the marine environment.[38]

Although it is beyond the scope of this work, there are methods to avoid or reduce cumulative effects including the following:

- Land use planning can set aside significant areas that should be protected or to set general terms and conditions on resource development and other human activities. Plans can help avoid resource use conflicts and set thresholds.
- There are different methods to explore for non-renewable resources that reduce the final footprints of these activities on land and water. For example, using helicopters to bring in drilling equipment rather than building roads, or low-impact seismic.
- Terms and conditions can be placed on individual land and water permits or licences to reduce footprints. Monitoring, inspections and enforcement can also be used to help avoid and reduce cumulative effects.
- Timing and phasing of development to allow for no net loss of habitat or upper disturbance thresholds.
- Improved reclamation and recovery requirements at the conclusion of land use operations may enhance natural recovery processes and timing.
- State of the environment monitoring and reporting can improve environmental management and linkages amongst planning, assessment, permitting, inspection and audit functions.

[38] Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope, National Research Council. 2003. Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. Washington DC, National Academy Press. p. 100. http://books.nap.edu/books/0309087376/html/100.html. This report summarizes the research by stating that Bowhead Whales avoid seismic and drilling by 15-20 km.