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Analysis of uncertainty consideration in environmental assessment: an empirical study of Canadian EA practice

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Identifying and communicating uncertainty is core to effective environmental assessment (EA). This study evaluates the extent to which uncertainties are considered and addressed in Canadian EA practice. We reviewed the environmental protection plans, follow-up programs, and panel reports (where applicable) of 12 EAs between 1995 and 2012. The types of uncertainties and levels of disclosure varied greatly. When uncertainties were acknowledged, practitioners adopted five different approaches to address them. However, uncertainties were never discussed or addressed in depth. We found a lack of suitable terminology and consistency in how uncertainties are disclosed, reflecting the need for explicit guidance, and we present recommendations for improvement. Canadian Environmental Impact Statements are not as transparent with respect to uncertainties as they should be, and uncertainties in EA need to be better considered and communicated.

Keywords: uncertainty; communication; disclosure; environmental assessment (EA); prediction; environmental protection plans (EPPs); follow-up; transparency

1. Introduction

The rationale for environmental assessment (EA) is to provide decision makers and stakeholders with a complete understanding of a proposed project, including its potential impacts and strategies to effectively manage those impacts. However, because EA is designed as a process to identify and manage future outcomes, uncertainties are unavoidable (Duncan 2008). Uncertainty in EA is due, in part, to complexities in the design and operation of large development projects (Noble and Storey 2005), and to the inherent complexity of environmental systems (Berg and Scheringer 1994) – such as the large number of potentially important components and interrelationships to be considered when assessing impacts, or time lags in their response (Jaeger 1998; Findlay and Bourdages 2000). Since there will *always* be knowledge gaps and uncertainty in EA (Arts, Caldwell, and Morrison-Saunders 2001), the problem is whether and how uncertainty information is communicated and how uncertainties are addressed in EA (Tennøy, Kværner, and Gjerstad 2006; Duncan 2008; Leung *et al.* 2015).

Previous research has shown that uncertainties in EA often are not given sufficient attention (Wood 2008; Tennøy, Kværner, and Gjerstad 2006). Several scholars have thus urged for better consideration of uncertainties in EA since, arguably, the cost of restoring

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unintended impacts is much greater than the cost of preventative measures (Wardekker *et al.* 2008). Uncertainty disclosure in EA promotes greater consideration and communication of the potential risks associated with a proposed development project, helps ensure the accountability of the proponent and decision makers, and promotes transparency and openness throughout the project evaluation process (Tennøy, Kværner, and Gjerstad 2006; Wardekker *et al.* 2008). However, notwithstanding consistent messages about the need for better consideration and disclosure of uncertainties in EA (e.g., De Jongh 1988; Wood, Dipper, and Jones 2000; Tennøy, Kværner, and Gjerstad 2006; Wood 2008; Leung *et al.* 2015), *how* uncertainties are considered and disclosed in EA practice has received little to no attention. There is a need to understand the practice of how uncertainties are considered in EA, and the procedures in place to deal with them, before current uncertainty communication practices may be improved. This need may become more urgent in the future as a result of increasing pressures for resource development and demands for more rapid assessment and project approvals (Gibson 2012; Bond *et al.* 2014), potentially based on limited environmental baseline data and correspondingly greater uncertainties.

This study examines the extent to which uncertainty is considered and addressed in Canadian EA practice. The purpose is to identify potential trends and good practices in order to help future EA practitioners and decision makers to better consider and disclose uncertainty. We focus our attention on Environmental Protection Plans (EPPs) and follow-up programs, as reported in project Environmental Impact Statements (EISs), and the reports of project review panels (where applicable). Our objectives are to identify what kinds of uncertainties are expressed in EPPs, follow-up programs, and panel reports and to examine whether and how the uncertainties identified are being addressed. In the sections that follow, we first present our study design, including the sample of EAs and our approach to identifying and classifying uncertainties. Results are then presented showing how uncertainty was disclosed in the EAs and, when disclosed, how uncertainty was addressed. This is followed by a discussion of the results and implications and recommendations for uncertainty disclosure in EA practice.

2. Methods

Our methods consisted of sampling comprehensive study and review panel EAs; identification of uncertainties in EA documentation; and categorization of uncertainty disclosure practices. Comprehensive study EAs are in-depth assessments, usually reserved for large-scale projects having the potential for significant adverse environmental effects. Projects that are particularly complex, with the potential for greater uncertainties or public concerns, may be referred to a review panel. Under both types of assessment, a project proponent is responsible for preparing an EIS. The EISs are presented to decision makers and the public as part of the regulatory-based EA process to communicate about a project's potential impacts and proposed mitigation. Under a review panel assessment, there is further inquiry by an independent panel that may commission additional studies and hold public hearing processes. Our analysis focused on the EISs prepared by project proponents, particularly the follow-up programs and EPPs developed as part of those EISs, and, in the case of review panel EAs, also the final reports of the review panels.

2.1. Selection of environmental assessments

Twelve Canadian federal (or joint federal-provincial) EAs were selected for analysis. Only EAs completed since proclamation of the 1995 *Canadian Environmental*

Assessment Act and before the proclamation of the 2012 *Canadian Environmental Assessment Act* were included. Attention focused on EAs for large infrastructure or resource extraction projects. Completed comprehensive study and review panel EAs were initially identified on the Canadian Environmental Assessment Agency's (CEAA) website, and full documentation was accessed either through a particular government agency's website, or by contacting a specific government agency or project proponent.

The EA selection was stratified according to: the type of EA (comprehensive study or review panel), location (provinces or territories), and development sector. The intent was to sample as diversely as possible. The EAs covered 14 development sectors, including mining, road construction, gas facilities, flood control, storage facilities, treatment centers, pipelines, power lines, nuclear facilities, decommissioning, decontamination and remediation projects, groundwater collector wells, hydroelectricity, offshore oil and gas development, port and marine development, and ski development. The number of completed comprehensive study EAs was higher than the number of review panels, and EAs were unevenly distributed across the provinces and territories. This was because, for example, no review panel or comprehensive study EA reports were available for either the Yukon or Nunavut. Also, no information on review panel EAs was available for Manitoba. For Saskatchewan and Prince Edward Island, EAs were identified but documentation could not be obtained. Where the geographic distribution of attainable EAs was more condensed, more were selected for inclusion in the study (Table 1).

The process of obtaining EA documentation was difficult, even though EISs and review panel reports are, in principle, public documents. Similar challenges to obtaining EA reports were experienced by Ball, Noble, and Dubé (2013), who reported missing or incomplete assessments in their study of EA in Alberta and Saskatchewan. Accessing comprehensive study EA reports was particularly problematic, and we were often directed to reviews or summaries versus being provided with the comprehensive study report itself. The availability of EA documentation is an important issue because learning from past experience, and using that knowledge to better manage uncertainties in future assessments, is only possible if information about past projects is accessible. Otherwise, past mistakes may be repeated, knowledge gaps will persist, and many uncertainties may remain unaddressed.

2.2. *Identification of uncertainties*

Extracting uncertainty information from the EISs and panel reports was based on content analysis – a systematic approach to the gathering of unstructured information into specific and predetermined categories (Krippendorff 2004). Qualitative content analysis addresses the form of the information collected, while quantitative analysis records the incidences of the form of the information collected (Smith 1975). For our reviews of EISs, attention focused on the proponent's EPPs (i.e., mitigation measures and contingency plans to deal with potential impacts) and follow-up programs (i.e., monitoring, adaptive management, and auditing plans) since, arguably, these are the components of a project assessment that should be designed to account for uncertainties in impact prediction, in project design, in environment and socioeconomic system response, and in the effectiveness of any proposed mitigation measures (Noble 2015).

Uncertainty information was extracted from the EPPs and follow-up programs for each EIS, and from the review panel reports where applicable, by applying a series of review questions (Table 2) that were developed based on previous approaches to EIS reviews by Burris and Canter (1997) and Söderman (2005). Not all questions were answered for each EIS – as when uncertainty was not disclosed in the documents some

Table 1. Sample of projects and environmental assessment documentation included in our analysis.

Project	EIS documentation
Joslyn North Mine Project, Alberta[1]	Deer Creek Energy Limited 2006. *Section B Project Description and Section D Environmental Assessment*; Total E&P Joslyn Limited 2011. *Joslyn North Mine Project – Report of the Joint Review Panel*
Prosperity Gold-Copper Mine, British Columbia[1]	Taseko Mines Limited 2009. *Prosperity Gold-Copper Project Environmental Impact Statement/Application*; Taseko Mines Limited 2010. *Prosperity Gold-Copper Mine Project – Report of the Federal Review Panel*
Lower Churchill Hydroelectric Generation and Transmission Project, Newfoundland and Labrador[1]	Nalcor Energy 2011. *Lower Churchill Hydroelectric Generation Project–Report of the Joint Review Panel*; Nalcor Energy 2013. *Lower Churchill Project – Project Wide Environmental Protection Plan Component 1 and 4b*
Mackenzie Gas Pipeline, Northwest Territories[1]	Imperial Oil Resources Ventures Limited, ConocoPhillips, Shell, ExxonMobil and Aboriginal Pipeline Group 2004. *Environmental Impact Statement for the Mackenzie Gas Project;* Joint Review Panel appointed to review the environmental impacts of the proposed Mackenzie Gas Project 2009. *Report of the Joint Review Panel for The Mackenzie Gas Project*
Marmot Basin Ski Development, Alberta[2]	Iris Environmental Systems 1999. *A Proposal to Develop a Chairlift and Ski Runs on Eagle Ridge Marmot Basin Ski Area, Jasper National Park*
Prince George Hart Water Supply, British Columbia[2]	Golder Associates 2003. *Application for Environmental Assessment Certificate and Draft Comprehensive Study Report for the City of Prince George Island Collector Well*
Swan Valley Gasification Project, Manitoba[2]	Golder Associates 2000. *Environmental Impact Assessment for the Swan Valley Gasification Project*
Liquefied Natural Gas Terminal and Multi-Purpose Pier, New Brunswick[2]	Jacques Whitford Environment Limited 2004. Environmental Impact Statement *Liquefied Natural Gas Marine Terminal and Multi-Purpose Pier*
Deep Panuke Offshore Oil Development, Nova Scotia[2]	EnCana Energy Corporation 2006. *Deep Panuke Offshore Gas Development Plan-EIS;* EnCana Energy Corporation. 2002. *Deep Panuke Offshore Gas Development – Comprehensive Study Report*
Highway 407 East Transportation Corridor, Ontario[2]	Ministry of Transportation 2009. *407 East Individual Environmental Assessment and Preliminary Design Study;* CEAA 2011. *407 East Transportation Corridor – Comprehensive Study Report*
Aquarius Gold Mine, Ontario[2]	AGRA Earth and Environmental Limited 1999. *Comprehensive Study Report Environmental Assessment, Aquarius Project*
Waskaganish Permanent Road Development, Quebec[2]	INRS (Institut national de la recherche scientifique) 1998. The Crees of The Waskaganish First Nation. Waskaganish Permanent Road Environmental and Social Impact Study, Volume I - Impact Analysis

[1]*Review panel assessment.*
[2]*Comprehensive study assessment.*

Table 2. Review questions used to gather uncertainty information from environmental protection plans, follow-up programs, and review panel reports.

1. Do mitigation/follow-up/contingency plans directly disclose/address uncertainty?
   - What is the uncertainty about? (e.g., predictions, mitigation, project design, etc.)
   - What types of uncertainty are identified? (e.g., model uncertainties, data uncertainties, etc.)
2. Is uncertainty used as a criterion when addressing the significance of residual impacts?
3. When identified, how is uncertainty addressed?
   - Is uncertainty justified or ignored?
   - Is uncertainty addressed by more research?
   - Is uncertainty explored through risk-based scenarios, worst-case scenarios, or probabilities?
   - Is uncertainty mitigated?
   - Is uncertainty addressed through adaptive management measures?
4. When follow-up or adaptive management measures are proposed to address uncertainties, are the program details disclosed? (e.g., schedule, budget, authority, management thresholds, monitoring design)
5. Are uncertainties identified in the proponent's EPP or follow-up program further discussed or addressed in review panel reports?
6. Are new uncertainties identified or discussed in review panel reports that were not identified or disclosed in the proponent's EPP or follow-up program?
7. When uncertainty is identified in review panel reports, how is it addressed?
   - Is uncertainty justified or ignored?
   - Is uncertainty addressed by more research?
   - Is uncertainty explored through risk-based scenarios, worst-case scenarios, or probabilities?
   - Is uncertainty mitigated?
   - Is uncertainty addressed through adaptive management measures?

questions could not be addressed. For example, in the Prosperity Gold-Copper Project EIS the follow-up program raised the issue of uncertainty about human impacts on Grizzly Bear mortality. Review question number four (see Table 2) was therefore applicable in this case, to assess how uncertainty was addressed by the proposed follow-up program measures. However, the 'Grizzly Bear Mortality Investigation Program' is not described in detail: only a summary is provided.

2.3. *Categorization of uncertainty disclosure practices*

Different types of uncertainty can be distinguished, some of which may be possible to quantify (e.g., Benetto, Dujet, and Rousseaux 2006, Peche and Rodriguez 2011, Ross, Booker, and Montoya 2013), while other types are not due to lack of knowledge about the components and structure of the environmental or socioeconomic systems affected (Duncan 2013; Bond *et al.* 2015). For each environmental component (e.g., air, water, soils, wildlife) identified in each EIS, specific uncertainties in mitigation, contingency plans, and follow-up programs were then categorized based on: (1) what the uncertainty was generally about; (2) the nature and level of uncertainty disclosure; and (3) how the uncertainty was addressed. The same categorization was applied to uncertainties identified in review panel reports, where applicable, for panel review EAs.

The first category of uncertainty, *what the uncertainty was about*, identifies the specific focus of uncertainty. In mitigation or follow-up, for example, this may include uncertainty about cumulative impacts, residual impacts, or the effectiveness of mitigation

Table 3. Classification system used to describe the extent to which uncertainty is expressed in environmental protection plans, follow-up programs, and review panel reports.

Level of disclosure	Content	Description
None	n/a	Uncertainty is not disclosed (neither suggested nor mentioned), neither directly nor indirectly.
Low	Implicit	Uncertainty is suggested implicitly and not specifically referred to as uncertainty. It is not explained or discussed, and the type of uncertainty is not identifiable.
	Explicit	Uncertainty is suggested explicitly and referred to as uncertainty but not explained or discussed. The type of uncertainty is not identifiable.
Medium	Implicit	Uncertainty is explained and/or discussed to some degree, but not referred to as uncertainty.
	Explicit	Uncertainty is explained and/or discussed explicitly to some degree, and referred to as uncertainty.
High	Implicit	Uncertainty is explained and discussed in depth, but not referred to as uncertainty.
	Explicit	Uncertainty is explained and discussed in depth, and referred to as uncertainty.

Source: Adapted, based on Tennøy, Kværner, and Gjerstad (2006).

measures. In contingency plans, uncertainty may be about the risk of a failure, or about the effectiveness of the contingency plans. The second category, *the nature and level of uncertainty disclosure*, refers to how uncertainty is communicated or discussed in the EIS or panel report. Our classification of the nature and level of uncertainty disclosure was based largely on Tennøy, Kværner, and Gjerstad's (2006) analysis of uncertainty in EA impact predictions in Denmark, and drawing also on uncertainty classifications found elsewhere in the literature (e.g., De Jongh 1988; Walker *et al.* 2003). We categorized uncertainty disclosure from no disclosure to low to high disclosure, and whether the disclosure was explicit or implicit in nature (Table 3).

For example, the Prosperity Gold-Copper Project EIS states, regarding direct mortality for grizzly bear: "actual baseline poaching incidence is unknown" (Taseko Mines Limited 2009, Vol. 5, Sect. 6, 128); there is "no local information on incidence of grizzly bear road kills" (Taseko Mines Limited 2009, Vol. 5, Sect. 6, 128); and "there is no baseline (mortality) data" (Taseko Mines Limited 2009, Vol. 5, Sect. 6, 261). In this case, the uncertainty disclosure could be categorized as *implicit* based on use of the terms 'unknown', 'no local information', and 'no baseline (mortality) data'. Further, the uncertainty was explained to some degree; enough that it could be determined as both *stochastic* (due to the variability in environmental, societal, and technological processes) and *epistemic* (due to the imperfection of our understanding of processes). As such, it was classified as a *medium* level of disclosure.

The third component, *how the uncertainty was addressed*, refers to the actions taken by the proponent or review panel, or recommended actions, to deal with uncertainty in those cases where uncertainty was disclosed. Again, taking the Prosperity Gold-Copper case as an example, in the review panel report, uncertainty about the project's effects on grizzly bears was justified by the localized nature of the project's predicted impacts. The panel noted that: "there was some uncertainty about the Project's effects on grizzly bears" (Taseko Mines Ltd. 2010, 225), but that "at a broader regional scale, the total affected area would be relatively small" (Taseko Mines Ltd. 2010, 225), and "while that … grizzly population is nearing the endangered level, the population of grizzly bears at the provincial level is more stable" (Taseko Mines Ltd. 2010, 225); and "consequently, the Panel finds that the overall effects on biodiversity due to a possible further reduction in the … grizzly bear population would not be considered significant" (Taseko Mines Ltd. 2010, 225). Thus, while uncertainty was raised, the panel justified not dealing with the uncertainty and no specific action was recommended to address it. Similar kinds of actions were grouped until several common responses to addressing uncertainty emerged from the content analysis.

3. Results

3.1. How uncertainty was disclosed

Table 4 summarizes the total number of times uncertainties were expressed in the EPPs and follow-up sections of the EISs and in the panel reports; the number of uncertainties with a *low* or *medium* level of disclosure; and the number of uncertainties disclosed according to what they were generally about (i.e., impact predictions, cumulative impacts, residual impacts, mitigation measures, and follow-up programs). There was no *high* disclosure found in any report.

Uncertainties disclosed about initial impact predictions (prior to mitigation) were the most common disclosures, followed by uncertainties about the effectiveness of the prescribed mitigation measures, uncertainties about the probability and significance of residual impacts, and uncertainties about potential cumulative impacts (Table 4). Overall, we found that uncertainties about follow-up programs were rarely mentioned in the EIS, aside from the Lower Churchill Hydroelectric Generation Project. Three reports (Prince George Hart Water Supply Project, Liquefied Natural Gas Terminal and Multi-Purpose Pier, and Waskaganish Permanent Road) did not disclose any uncertainties. Not surprisingly, more uncertainties were disclosed in review panel assessments than comprehensive studies – by their nature, review panel EAs are triggered due to the complex and often uncertain nature of a proposed project and involve further scrutiny of impact predictions and, potentially, related uncertainties. Review panel EAs also provide for additional rounds of public input and review, and the opportunity for further discussion and debate of uncertainties. We observed that review panels often acknowledged the general complexity and unpredictability of environmental processes more so than project proponents did in their EISs; however, we also found that specific uncertainties were never discussed in depth nor explained by review panels.

We also found inconsistencies with respect to *how* uncertainty was disclosed (Table 4). Uncertainty disclosure was either not done or was classified as *low* or *medium* in all EAs, including both EIS documentation and panel review reports. Uncertainties were sometimes identifiable, but it was often not clear what the uncertainty was about. When uncertainties were identifiable, they were mainly about data, context, and model uncertainties – including stochastic and epistemic uncertainties. In some cases uncertainty was taken into account, to some extent, through contingency scenarios, but these were never discussed and addressed in depth in the EIS documentation. When uncertainties were mentioned (either explicitly or suggested implicitly), they were never explored using worst-case outcomes, or using risk or probability assessments.

Terminology used for reporting uncertainty varied considerably. In all reports, expressions such as 'may', 'could', 'probably', 'maybe', or 'as soon as possible' were commonly used where uncertainty was not disclosed, but may have indeed been present (Table 5). For example, the Joslyn North Mine EIS (Deer Creek Energy Limited 2006, 10–30) identifies "follow-up monitoring that *could* be done to ensure the long-term

Table 4. Number of times uncertainties were expressed, by level of disclosure (low or medium), and what the uncertainties were about.

Project	Total number of uncertainties	Level of disclosure: Low [I = implicit; E = explicit]	Level of disclosure: Medium [I = implicit; E = explicit]	Uncertainties about: Impact predictions	Cumulative impacts	Mitigation measures	Residual impacts	Potential failure of follow-up programs
Joslyn North Mine[1]	35	18 [18 I]	17 [4I, 13E]	14	11	3	7	0
Prosperity Gold-Copper Mine[1]	47	6 [5I, 1E]	41 [16I, 25E]	31	3	6	5	0
Lower Churchill Hydroelectric Generation[1]	18	9 [1I, 8E]	9 [2I, 7E]	10	1	7	0	2
Mackenzie Gas[1]	24	7 [1I, 6E]	17 [12I, 5E]	22	0	2	0	0
Marmot Basin[2]	4	0	4 [4I]	4	0	0	0	0
Prince George Hart Water Supply[2]	0	0	0	0	0	0	0	0
Swan Valley Gasification[2]	1	1 [1I]	0	1	0	0	0	0
Liquefied Natural Gas Terminal and Multi-Purpose Pier[2]	0	0	0	0	0	0	0	0
Deep Panuke Offshore Gas Development[2]	6	6 [6I]	0	0	0	0	6	0
407 East Transportation Corridor[2]	6	3 [2I, 1E]	3 [3E]	2	0	4	0	0
Aquarius Gold Mine[2]	10	10 [5I, 5E]	0	5	0	5	0	0
Waskaganish Permanent Road[2]	0	0	0	0	0	0	0	0
Altogether	151	60 [39I, 21E]	91 [38I, 53E]	89	15	27	18	2

[1] *Review panel assessment.*
[2] *Comprehensive study assessment.*

Table 5. Common terminology identified from the sample of 12 EAs where uncertainty was not disclosed or suggested, but where vague or imprecise wording suggest a gap in knowledge or non-commitment about a particular impact prediction or prescribed mitigation action.

• Might/may	• Could/can	• Likely/unlikely	• Potential/potentially
• Probably	• Improbable	• Relatively	• Approximately
• Assumed	• As needed	• To the extent possible	• Where/when possible
• As much as possible	• As soon as possible	• When operationally feasible	• Where technically feasible
• Where appropriate	• Where economically feasible		

sustainability of the soils resource", and in the Marmot Ski Area EIS, with regard to past baseline conditions and forest age, reports that "low elevation forests were *probably* not old aged" (Iris Environmental Systems 1999, D.10, 30). No uncertainty was actually disclosed in these two examples, and no particular type of uncertainty was identified such that it could be appropriately managed. These kinds of expressions (Table 5) were extensively used in all EA documentation, but without qualification, and they suggest vagueness and imprecision about impacts, mitigation, contingencies, and follow-up programs. When these expressions were used, it was not possible to determine whether the EA was intending to disclose or hide a gap in knowledge. The use of such vague and imprecise terminology has been reported elsewhere as a persistent problem in Canadian EA practice (Noble and Storey 2005).

In those instances where uncertainty was *implicitly disclosed*, disclosure was either *low* or *medium*. Low and implicit disclosure implies that uncertainty was suggested, but not explicitly identified, explained, or discussed. The type of uncertainty was not identifiable. Medium and implicit disclosure implies that uncertainty was explained to some degree but not referred to as uncertainty. The type of uncertainty, such as data uncertainty for example, was identifiable. In the contingency planning sections of the EISs reviewed, uncertainty was always implicitly taken into account simply by way of definition, and purpose, of contingency planning. Table 6 provides examples of the terminology often used for the implicit disclosure of uncertainties in the EIS's mitigation measures and follow-up programs. In most instances, disclosure was considered low and the source or type of uncertainty was not identifiable. In the Swan Valley Gasification Project EIS, for example, reference is simply made to "unexpected conditions" (Golder Associates 2000, 154), but with no further explanation, when referring to the possibility of control or mitigation failures during pipeline construction. In contrast, the Prosperity Gold-Copper Project EIS implicitly disclosed uncertainties associated with impacts to groundwater, referring to "confidence in the project's effects assessment" (Taseko Mines Limited 2009, Vol. 4, Sect. 4, 138), and then qualifying the level of confidence based on reasoned argumentation. The source of uncertainty was easily identifiable and could be associated with a particular cause – in this case impact prediction and context and stochastic uncertainty.

Table 6. Common terminology identified from the sample of 12 EAs where uncertainty was implicit – uncertainty was suggested but not explored or specifically referred to as uncertainty.

• Unplanned	• Unknown	• Data gaps	• Confidence in prediction
• Unexpected	• Knowledge deficiencies	• Moderate reliability	• Unreliable
• Unpredictability		• Accuracy	

There were also examples of *explicit disclosure* of uncertainties – where uncertainty was explicitly identified but not explained or discussed, or where uncertainty was explained or discussed and referred to as uncertainty. There were more examples of explicit than implicit disclosure. The review panel report for the Joslyn North Mine, for example, notes regulator concerns about the "uncertainty of the predictive models" and that, based on the limited data and assumptions, it is not possible to "predict with certainty the success of fish habitat compensation" (Total E&P Joslyn Ltd. 2011, 65). In this case, uncertainty was about impact prediction and mitigation effectiveness, and the source of the uncertainty was identifiable – data, modeling, and recognized stochastic uncertainty. Similar examples of explicit disclosure were found in the Prosperity Gold-Copper Project EIS, Mackenzie Gas Project panel report, and the 407 East Transportation Corridor project.

3.2. When disclosed, how uncertainty was addressed

Uncertainty was often discussed only in a general way by project proponents in their EPPs and follow-up programs, and by review panels in their panel reports. Review panel reports in particular often acknowledged uncertainty, but then stated that uncertainty *should* be addressed with follow-up programs and/or precautionary measures, yet provided few recommendations or limited direction for addressing specific uncertainties. In the Mackenzie Gas Project, for example, the review panel's report focused on uncertainty, emphasizing "…the implications of uncertainties for decision making are explicitly considered; and greater emphasis on monitoring and adaptive management is required" (Joint Review Panel appointed to review the environmental impacts of the proposed Mackenzie Gas Project 2009, 95). The panel recommended adaptive management strategies due, in part, to the proponent's "heavy reliance on their proposed monitoring programs … when the monitoring programs themselves were ill-defined…" (Joint Review Panel appointed to review the environmental impacts of the proposed Mackenzie Gas Project 2009, 96), but no specific uncertainties were identified by the review panel and no specific direction provided for adaptive management to address the uncertainty.

In all 12 EISs, commitments were made in follow-up programs that further information would be gathered through monitoring, post-project approval; however, in almost all cases it was not possible to determine the specific uncertainties identified in the EIS, if any, that follow-up was intended to address. The details of follow-up programs were not discussed – specifically the schedule or timing of implementation, the authority to implement or manage, and management thresholds. Commenting on the Joslyn North Mine fish and fish habitat assessment, the review panel expressed concerns about the uncertainty of predictive models, predictive accuracy, and the success of habitat compensation measures, noting that conditions would be required as part of the project authorization, including the use of adaptive management to address uncertainty (Total E&P Joslyn Ltd. 2011, 65), but no details were provided on the means to validate predictions and outcomes to resolve uncertainties.

Aside from general discussions of uncertainties and broad-brush recommendations about the need for follow-up programs or adaptive management, when uncertainty was disclosed, either implicitly or explicitly, several approaches could be identified to address that uncertainty (Table 7). In any single EA, multiple approaches were often identified and sometimes used in combination and, as such, the number of uncertainties presented in Table 7 does not reflect the total number of incidences where uncertainties were disclosed. When uncertainty was discussed only in a general way, no uncertainties were clearly identifiable, and thus not reported in the table. Uncertainties addressed only by

Table 7. Number of uncertainties addressed using one, or a combination, of the different approaches identified in 9 of the 12 EAs.

Project	Number of uncertainties that are…				
	…not addressed, or else estimated but then ignored	…not addressed, but this was either justified or hidden	…addressed with precautionary approaches	…addressed with sensitivity analysis, or the use of conservative estimates	…addressed by proposing additional research
Joslyn North Mine Project[1]	23	0	1	4	1
Prosperity Gold-Copper Mine Project[1]	18	3	0	6	0
Lower Churchill Hydroelectric Generation Project[1]	5	0	1	0	1
Mackenzie Gas Project [1]	8	0	5	8	0
Marmot Basin Project[2]	4	1	0	0	0
Swan Valley Gasification Project[2]	0	0	1	0	0
Deep Panuke Offshore Gas Development Project[2]	6	0	0	0	0
407 East Transportation Corridor project[2]	1	0	0	0	3
Aquarius Gold Mine project[2]	8	7	0	1	0

[1]*Review panel assessment.*
[2]*Comprehensive study assessment.*

broad recommendations for follow-up or adaptive management were also not considered in the table. No uncertainties were disclosed in the Prince George Hart Water Supply Project, the Liquefied Natural Gas Terminal and Multi-Purpose Pier, and the Waskaganish Permanent Road project.

3.2.1. Uncertainty not addressed, or uncertainty levels estimated but then ignored

Most uncertainties disclosed remained unaddressed – including those cases where qualitative estimates of the levels of uncertainty were provided. For example, in the Joslyn North Mine EIS the *levels of confidence* in impact predictions were noted, sometimes assigning a 'level of confidence' (e.g., low, moderate, high) or 'level of scientific uncertainty', but often no information was provided on how these levels were defined. For those impacts where the level of confidence was defined, there was no discussion of what was to be done to reduce the uncertainty or whether it played a significant role in any subsequent management actions. Further, in many cases, after identifying specific knowledge gaps in a table in the EIS, uncertainty due to such knowledge gaps was subsequently ignored in any further impact analysis or discussion about mitigation. Similar practices were found in the Prosperity Gold-Copper Mine (for vegetation and wetland ecosystems), the Liquefied Natural Gas Terminal Project, and the Deep Panuke Offshore Gas Project.

3.2.2. Uncertainty not addressed, but this was either justified or hidden

A second approach was to justify the neglect of uncertainty treatment based on the abundance or resilience of the affected component, or the small size or footprint of the project. In the Aquarius Gold Mine EIS, for example, the wetland resilience was expected to compensate for any uncertainties associated with the possible failure of mitigation measures, reporting that "no environmental effects are anticipated in the event of restoration failure … as natural succession would continue, with the result that wetland habitats will develop on their own, but simply over a greater time period" (AGRA Earth and Environmental Limited 1999, 487).

In the Marmot Basin EIS, uncertainty reported in baseline conditions was deemed unimportant in terms of understanding the significance of the project's impacts because of the small size of the project relative to the 'regional environment'. Concern about the loss of old-growth forest was explicitly recognized, and the EIS reports that tree age measurements were not undertaken in the study area (Iris Environmental Systems 1999, 266) and that nearby tree age and stand structure may not reflect conditions in the project area (Iris Environmental Systems 1999, 268). However, the EIS argued that the tree species of concern is "abundant and widely distributed" elsewhere and "the removal of a small number of these tree species … within a confined area is not anticipated to have anything more than a localized impact" (Iris Environmental Systems 1999, 268). The compounding effects of any uncertainties in data and baseline conditions, when considering potential future disturbances to forests in the region due to other projects, were not considered.

3.2.3. Uncertainty was to be addressed with precautionary approaches

The precautionary principle or a precautionary approach was sometimes recommended to address uncertainty. The most elaborated example we found was the assessment of the effects of subsidence due to natural gas reservoir depletion in the Mackenzie Gas Project.

The EIS reported "there is a relatively high degree of confidence that effects will be less than predicted because where data is uncertain, the precautionary principle has been applied in developing the effects assessment" (Imperial Oil Resources Ventures ConocoPhillips, Shell, ExxonMobil and Aboriginal Pipeline Group 2004, Vol. 5, Sect. 7, 186). However, aside from indicating that a precautionary principle was applied "to ensure that the EIS does not under-report potential effects" (Imperial Oil Resources Ventures, ConocoPhillips, Shell, ExxonMobil and Aboriginal Pipeline Group 2004, Vol. 5, Sect. 7, 186), no details were provided. The definition of a precautionary approach was briefly explained, based on Government of Canada (2001), and two short examples of how this approach can be applied were then provided. The EIS then gives assurance that "In response to uncertainties in the prediction of project effects, programs will be established … to monitor effects and to provide a basis for adjusting environmental management actions" (Imperial Oil Resources Ventures, ConocoPhillips, Shell, ExxonMobil and Aboriginal Pipeline Group 2004, Vol. 5, Sect. 7, 187), but these programs were not discussed in the EIS. Three other EAs also recommended some form of precautionary approach to address uncertainties, but provided even less detail or explanation: Joslyn North Mine, for the establishment of wildlife corridors; Lower Churchill Hydroelectric Generation Project, for potential ecological and mercury effects downstream; Swan Valley Gasification, for potentially unstable soils.

3.2.4. Uncertainties were addressed with the use of conservative estimates or sensitivity analysis

Conservative estimates or sensitivity analysis were more often used to address uncertainties than precautionary approaches. The use of conservative estimates allowed the assessor not to consider uncertainty any further, as there was a high degree of confidence that an effect was overestimated. This was the case in the Prosperity Gold-Copper Project EIS where the emission rates for particulate matter used in modeling "were estimated based on a combination of emission factors" and "there is a high degree of confidence that emissions are being over-estimated" (Taseko Mines Limited 2009, Vol. 4, Sect. 2, 48). The EIS goes on to report: "As such, the rating of prediction confidence is high for the Project based on quality of baseline data, emissions data, and confidence in the conservative nature of analytical techniques applied in this assessment" (Taseko Mines Limited 2009, Vol. 4, Sect. 2, 48). For effects to groundwater, the difficulty in accurately predicting changes in flows was addressed by using sensitivity analyses to evaluate variability in model responses. It was subsequently concluded that, "based on the results of the sensitivity analyses, confidence is medium to high that a conservative assessment … has been considered in the environmental assessment" (Taseko Mines Limited 2009, Vol. 4, Sect. 2, 139).

Conservative estimates were also used in the Mackenzie Gas Project to address uncertainties about air quality impact predictions. Confidence that impacts will be less than predicted was rated high because conservative estimates were used to address data and model uncertainties. For greenhouse gas emissions, for example, the EIS reports that the "…prediction confidence in the effects related to greenhouse gas emissions is high because the likely emissions will be less than predicted. The potential contribution of the project to greenhouse gas emissions was calculated based on peak operations, with all equipment operating at full capacity" (Imperial Oil Resources Ventures, ConocoPhillips, Shell, ExxonMbil and Aboriginal Pipeline Group 2004, Vol. 5, Part A, Sect. 2, 107). Similar approaches, using sensitivity analyses and conservative approaches, were found in the Joslyn North Mine Project and the Aquarius Gold Mine Project.

3.2.5. Uncertainties were addressed by proposing additional research

In four EAs, the approach to addressing reported uncertainties was a proposal for additional research. This approach was specifically used in review panel EAs, where the panel acknowledged uncertainty and recommended more research to compensate for the proponent's absence of data about a particular impact or about the effectiveness of a particular mitigation measure. However, the specific nature of the recommended, additional research was not disclosed in the review panel reports. For example, in the Joslyn North Mine Project, the panel identified uncertainty regarding mitigation and monitoring with respect to wildlife corridor establishment (Total E&P Joslyn Ltd. 2011, 45), and then concluded: "…more studies of the local study area and the regional study area are needed before a final conclusion can be drawn" (Total E&P Joslyn Ltd. 2011, 45). There were no clear commitments or directions to the project proponent on what research was needed to address the uncertainty before the start of the proposed project. Similar approaches to addressing uncertainty, and challenges, were identified in the Lower Churchill Hydroelectric Generation Project, and the 407 East Transportation Corridor Project.

4. Discussion

4.1. Uncertainty disclosure

There has been much written on the need to better communicate uncertainties in EA practice and the implications of non-disclosure (Duncan 2013; Wardekker *et al.* 2008). Yet, given the hundreds of impact predictions and mitigation measures identified across the 12 EAs in our sample, our results reflect the findings of Tennøy, Kværner, and Gjerstad (2006) and Wiklund (2011) in that uncertainties are not fully disclosed in EA practice and EA documents often portray a degree of confidence that may not exist. Context, input and model uncertainties were the types of uncertainty most often disclosed; however, these uncertainties were never discussed in depth in any of the EAs. We found only limited consideration of bias uncertainties, uncertainties due to changes in project design, or statistical uncertainties. Uncertainties about impact predictions were the most frequently identified across the sample of EAs (89 identified cases). Uncertainties about impact mitigation measures were disclosed in only half of the EAs examined, with a total of 27 identified disclosures. Uncertainties associated with cumulative impacts and residual impacts were less often disclosed. Cumulative impacts uncertainties were discussed in only three of the reports (15 noted uncertainties), while uncertainties associated with residual impacts were discussed in only four of the reports (18 noted uncertainties). The precautionary principle was sometimes referred to, but applied only in exceptional cases and, when applied, without detailed information about how it was applied. For example, none of the EAs mentioned a shift in the burden of proof (i.e., that those responsible for an activity must vouch for its harmlessness and be held responsible if damage occurs), as required by the Wingspread Statement on the Precautionary Principle (Ashford *et al.* 1998).

Our results also indicate that the EA reports lacked consistency regarding uncertainty disclosure, with no standard practice, procedure, or terminology. No clear patterns could be identified. Low or medium levels of disclosure were identified throughout any single EA, and among the various EAs – sometimes uncertainties were clearly identified and addressed and in other cases uncertainties were noted but it was not clear what the uncertainty was about. This was also the case regarding explicit and implicit disclosures – sometimes uncertainty was only suggested or implicit, and in other instances uncertainty was expressed explicitly. The term 'confidence' was used often to describe uncertainty in half of the EAs, but in any single EA confidence levels were not clearly defined and there was variation in how uncertainty was expressed.

This inconsistency in uncertainty disclosure may be a reflection of the lack of standard, good-practice guidance for reporting, and subsequently addressing uncertainties in EA practice (Leung *et al.* 2015). This was evident by the widespread, and inconsistent, use of vague and unqualified terminology such as ‘may’, ‘could’, ‘probably’, ‘maybe’, or ‘as soon as possible’. Implicit disclosure and the use of such vague terminology not only makes uncertainty classifications presented in the academic literature (e.g., Tennøy, Kværner, and Gjerstad 2006; Walker *et al.* 2003; De Jongh 1988) difficult to apply, if not impractical, it also poses challenges to regulatory decision makers in trying to identify whether and where uncertainty exists and how significant these uncertainties are with respect to a project’s approval or approval conditions. Consistent with Larsen, Kørnøv, and Driscoll (2013) and Petersen *et al.* (2011), we suggest there is a need for improved understanding of, consistency among, and transparency of uncertainty reporting practices by those involved in the EA process. The Committee on Decision Making Under Uncertainty (2013), for example, suggests that to successfully communicate uncertainty there is a need to develop communication plans and strategies that are sensitive to the needs of stakeholders and decision makers – in this case affected communities and regulatory agencies.

4.2. Good and poor practices

The highest level of disclosure found in the proponent’s EPPs and follow-up programs was *medium* (see Table 3) – uncertainty was identified and explained, and discussed to some degree, but never fully addressed. Some relatively good practices were identified from our analysis: in some cases, for example, predicted impacts were assigned a ‘level of confidence’ or a ‘level of certainty’; in other cases uncertainties were acknowledged and discussed in separate sections for each environmental receptor. Tables were used in four of the EAs for assigning a level of confidence or certainty (Joslyn North Mine, Prosperity Gold-Copper Mine, Liquefied Natural Gas Terminal, Deep Panuke Offshore Oil Development); however, it often received no further attention in the EA. In only 3 of the 12 EAs more detailed attention was given to uncertainty, addressing it in a separate section of EIS documentation (Aquarius Gold Mine, Mackenzie Gas Project, Prosperity Gold-Copper Mine). However, aside from the categorization and discussion of uncertainties surrounding impacts to vegetation and wetland ecosystems for the Prosperity Gold-Copper Mine Project, these two approaches (categorization and specific discussion) were never used in the same report. Further, although uncertainty was discussed in a separate section of the Aquarius Gold Mine EIS, the nature of the uncertainty was never fully explained. Arguably, these two approaches (categorization and specific discussion) are complimentary and together would provide more useful and comprehensive information to stakeholders and decision makers. Expressing or quantifying levels of confidence is an effective means to communicate that uncertainty exists; however, where it does exist it requires further explanation or description in terms of the nature of the uncertainty, the implications for the project or decision making, and the means to address it (Duncan 2008; Geneletti *et al.* 2003; Tennøy, Kværner, and Gjerstad 2006; Walker *et al.* 2003; Wardekker *et al.* 2008).

Uncertainties were often reported in the proponent’s EIS to be addressed using follow-up programs or adaptive management; however, it was unclear in most cases whether and how these programs directly addressed the uncertainties that were disclosed. The programs were never discussed in depth and, as such, we were unable to assess whether the uncertainties disclosed in the EISs were indeed addressed through proposed follow-up or adaptive management programs. Overall, the number of cases where uncertainties identified in the EIS were *not* addressed by follow-up, or by any other means, was higher than the number of cases where uncertainties *were* addressed. The proponent's EIS typically relied on the anticipated success of mitigation measures, on contingency plans, and on follow-up programs that were never discussed in depth with regard to uncertainties − an approach characterized by Tinker *et al.* (2005) as 'paper promises'.

Impacts that were uncertain were rarely rated as significant; when they were rated as significant the uncertainty was not addressed. It is unclear whether uncertainty was intentionally hidden in the proponent's EIS (see Wood 2008), or whether proponents or practitioners thought it was too difficult or not necessary to disclose uncertainties. It may be, according to Duncan (2008), that proponents simply have a vested interest in making their EISs appear defensible and politically palatable, resulting in practices that systematically seek to minimize uncertainty disclosure. Until there are specific requirements for uncertainty disclosure, and established standards for how to do so and for the nature and level of information required in an EIS, practice will continue to be mixed.

Our findings are consistent with findings of researchers from other nations (e.g., De Jongh 1988; Tennøy, Kværner, and Gjerstad 2006; Duncan 2008), indicating that the information communicated in EA regarding uncertainty is often simplified and incomplete. This study also confirms previous evidence from Sweden in that the effectiveness of mitigation measures, contingency plans, and follow-up programs are presented more confidently than they should be (Wiklund 2011). Moreover, the lack of in-depth consideration of uncertainty can be likened to Tennøy, Kværner, and Gjerstad (2006)'s *black box,* illustrating the lack of transparency and accountability toward the public and regulatory decision makers. In the EAs we examined, even though uncertainties were never discussed in depth, they were somehow acknowledged in the reports, albeit implicitly, which confirmed the unavoidable presence of uncertainties in EA as described in studies conducted in the Netherlands (Arts, Caldwell, and Morrison-Saunders 2001; Walker *et al.* 2003), Northern Italy (Geneletti *et al.* 2003), and the USA (Canter 1996). However, given that uncertainties were not disclosed consistently and not addressed thoroughly, our research confirms that how and where to address uncertainty information remains a challenging task in EA.

4.3. Implications for regulatory decision makers

Our results suggest that although in some cases uncertainties are disclosed, there is insufficient information made available for those responsible for project approvals to adequately assess and understand the implications of uncertainty, and whether and how it should affect project approvals or licensing conditions. Decision makers, as informed readers of EAs, are sometimes made aware that uncertainty exists, but they are rarely presented with detailed information as to the nature and potential implications of the uncertainty. In review panel reports, for example, attention often focuses on uncertainty as a general concept and with broad-brush recommendations to address uncertainty, but with limited guidance or information for decision makers as to what specific conditions or actions are necessary to manage uncertainty, and the implications for the viability or acceptability of the project.

Our results confirm previous reviews of EA uncertainty, concluding that decision makers are not made fully aware of uncertainties in EA (Tennøy, Kværner, and Gjerstad

2006). That said, Duncan (2008) suggests that even when decision makers are made aware of uncertainties they may choose not to disclose them further or address them. In our study, aside from information requests submitted during the EA process, we found no indication that decision makers requested additional information about the uncertainties found in the EIS, specifically their sources and implications, especially when information communicated was vague and incomplete. Such information would allow decision makers to make more informed decisions (Geneletti *et al.* 2003) and promote prudent strategies (Reckhow 1994) and ensure better EA overall (Duncan 2008; Tennøy, Kværner, and Gjerstad 2006; Ragas *et al.* 2009).

5. Conclusions

Very few studies have investigated *how* uncertainties are actually considered and disclosed in EA practice, despite EA having a more than 40-year history, and our study addresses this urgent need. This paper examined the ways in which EAs address uncertainties, particularly in the proponent's EPPs and follow-up programs, and in the reports of review panels, to identify current trends and good and poor practices. Our results indicate that EAs need to better reflect the complexity of environmental processes, the incompleteness of knowledge and the uncertainty of making predictions about the future impacts of a project than what is currently practiced. Consistent with Budescu, Por, and Broomell (2012) and Leung *et al.* (2015), there is a need for uncertainty information to be documented in a way that can be easily and effectively transmitted to decision makers, the public, and other stakeholders – but also in a way that facilitates depth in understanding of the implications of uncertainty and how it will be addressed through EPPs, follow-up programs, and panel reports. In our study, when uncertainty was disclosed there was limited, and often superficial, discussion of the implications of the uncertainties. Based on our sample of EAs, there appears to be overconfidence in EPPs and follow-up programs in Canadian EA – an observation consistent with EA evaluations in Norway (Tennøy, Kværner, and Gjerstad 2006), Australia (Duncan 2008), and Sweden (Wiklund 2011).

It was challenging to gather and assess uncertainty disclosure based on EA documentation, largely because uncertainty information was typically qualitative, implicit, and variably reported using diverse terminology. There was no consistent terminology used in the same EA to communicate uncertainty – a problem that also persists in the scientific community (Walker *et al.* 2003). Some useful approaches were identified in the EAs, including the use of conservative estimates, sensitivity analysis, and precautionary approaches. However, there is a need for improved guidance and reporting standards to assess and address uncertainties in EA practice (Wood 2008), so as to "enhance transparency and improve handling of uncertainties" in EA (Karlson, Mörtberg, and Balfors 2014, 17). For example, the use of separate sections or tables to disclose uncertainties is helpful and appropriate, but uncertainties also need to be discussed in depth and more explicitly addressed, for each step of the EA. Table 8 provides some preliminary guidance in this regard, based on the observations emerging from our results.

We acknowledge the limitations to our study, in terms of the sample size and, in particular, the unavailability of complete EA documentation. Federal agencies are not legally obligated to keep the entire EIS available after disclosing them to the public at the time of the EA process, and documentation was difficult to obtain (see Ball, Noble, and Dubé 2013). The EA procedure is also a continuing process that involves an ongoing exchange of documents, suggestions, comments, and questions between the proponent,

Table 8. Preliminary guidelines on how uncertainty disclosure can be improved at each step of EA, based on the results from the document analysis of 12 comprehensive study and review panel EAs.

Steps of EIA	Recommendations for improved uncertainty disclosure
Screening	Uncertainty documentation and disclosure guidelines are communicated to the proponents and consultants of the project.
	Standard uncertainty typology and terminology is established for use in EIA reporting.
	There is an opportunity for the public to identify any perceived uncertainties related to the project early in the process, before EIS terms of reference are established.
Scoping	Uncertainty documentation and disclosure are required in EIS terms of reference.
	Uncertainties are identified and communicated early in the EIA process, when considering alternatives to proposed projects, developing baseline data, and gathering public opinions.
Impact prediction and evaluation; impact management	Uncertainties are identified and explained in a dedicated section of the EIS for each environmental component or predicted impact, for residual and cumulative impacts, mitigation measures, contingency plans, and follow-up programs.
	Consultants define and disclose the approaches taken to address uncertainties that cannot be reduced (e.g., data uncertainty). The parties responsible for addressing uncertainties in applied mitigation measures, contingency plans, and follow-up programs post project-implementation are identified.
	Uncertainty is a criterion used in significance determination.
	Consultants distinguish between the uncertainty in the prediction of effects and the uncertainty in the assessment of the importance of the associated impacts.
Review and decision	Transparency of uncertainty in the EIS and measures identified to address uncertainty are factors considered in the approval, or conditions for approval, of the EIS.
	Decision makers (or responsible authorities) communicate in their review and decision how information about uncertainties was considered in their review and/or decision.
Implementation and follow-up	Monitoring, auditing, and adaptive management plans for projects are publicly available so that consultants are able to use that information for future EISs.
	Monitoring, auditing, and follow-up reports document the experiences and lessons learned from the project regarding how to address uncertainties (e.g., inaccurate predictions, miscalculations, data gaps, misinterpretations) and are available for the improvement of future projects.

stakeholders, and regulators. We acknowledge that our review of EA documentation may not have been comprehensive of all information, as we could only access that which was made available via government websites for disseminating project information, via the proponent's website for public communications, or by requests made to government or proponent representatives. To better understand how uncertainty is considered in EA practice, and the influence on project approvals and licensing conditions, we recommend additional research that focuses also on exploratory interviews with practitioners, proponents, and decision makers.

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References

AGRA Earth and Environmental Limited. 1999. *Comprehensive Study Report: Environmental Assessment Aquarius Project*. AGRA Earth and Environmental Limited. Mississauga, Ontario, Canada; submitted to Echo Bay Mines Ltd., Timmins, Ontario.

Arts, J., P. Caldwell, and A. Morrison-Saunders. 2001. "Environmental Impact Assessment Follow-up: Good Practice and Future Directions – Findings from a Workshop at the IAIA 2000 Conference." *Impact Assessment and Project Appraisal* 19 (3): 175–185.

Ashford, N., K. Barrett, A. Bernstein, R. Costanza, P. Costner, C. Cranor, P. deFur *et al.* 1998. *Wingspread Conference on the Precautionary Principle*. Wingspread Statement. http://www.sehn.org/wing.html

Ball, M., B.F. Noble, and M. Dubé. 2013. "Valued Ecosystem Components for Watershed Cumulative Effects: An Analysis of Environmental Impact Assessments in the South Saskatchewan Watershed, Canada." *Integrated Environmental Assessment and Management* 9 (3): 469–479.

Benetto, E., C. Dujet, and P. Rousseaux. 2006. "Fuzzy-sets Approach to Noise Impact Assessment." *The International Journal of Life Cycle Assessment* 11 (4): 222–228.

Berg, M., and M. Scheringer. 1994. "Problems in Environmental Risk Assessment and the Need for Proxy Measures." *Fresenius Environmental Bulletin* 3 (8): 487–492.

Bond, A., J. Pope, A. Morrison-Saunders, F. Retief, and J.A.E. Gunn. 2014. "Impact Assessment: Eroding Benefits Through Streamlining?" *Environmental Impact Assessment Review* 45: 46–53.

Bond, A., A. Morrison-Saunders, J.A.E. Gunn, J. Pope, and F. Retief. 2015. "Managing Uncertainty, Ambiguity and Ignorance in Impact Assessment by Embedding Evolutionary Resilience, Participatory Modelling and Adaptive Management." *Journal of Environmental Management* 151: 97–104. doi:10.1016/j.jenvman.2014.12.030.

Budescu, D.V., H. Por, and S.B. Broomell. 2012. "Effective Communication of Uncertainty in the IPCC Reports." *Climate Change* 113 (2): 181–200.

Burris, R.K., and L.W. Canter. 1997. "Cumulative Impacts Are Not Properly Addressed in Environmental Assessment." *Environmental Impact Assessment Review* 17: 5–18.

Canter, L.W. 1996. "Scientific Uncertainty and the Environmental Impact Assessment Process in the United States." In *Scientific Uncertainty and Environmental Problem Solving*, edited by J. Lemons, 298–326. Cambridge: Blackwell Science.

CEAA (Canadian Environmental Assessment Agency). 2011. *407 East Transportation Corridor – Comprehensive Study Report*. Ottawa: Canadian Environmental Assessment Agency.

Committee on Decision Making Under Uncertainty. 2013. *Environmental Decisions in the Face of Uncertainty*. Washington, DC: National Academies Press.

Deer Creek Energy Limited. 2006. *The Joslyn North Mine Project-Section B Project Description and Section D Environmental Assessment*. https://exts2.aep.alberta.ca/DocArc/EIA/EIA/2005-03-DeerCreekEnergyLtdSAGDProjectPhaseIIIA.aspx

De Jongh, P. 1988. "Uncertainty in EIA." In *Environmental Impact Assessment: Theory and Practice*, edited by P. Wathern, 62–84. London: Routledge.

Duncan, R. 2008. “Problematic Practice in Integrated Impact Assessment: The Role of Consultants and Predictive Computer Models in Burying Uncertainty.” *Impact Assessment Project Appraisal* 26 (1): 53–66.

Duncan, R. 2013. “Opening New Institutional Spaces for Grappling with Uncertainty: A Constructivist Perspective.” *Environmental Impact Assessment Review* 38: 151–154.

EnCana Energy Corporation. 2002. *Deep Panuke Offshore Gas Development – Comprehensive Study Report*. http://www.ceaa-acee.gc.ca/68D50708-docs/report_e.pdf

EnCana Energy Corporation. 2006. *Deep Panuke Offshore Gas Development Plan-EIS. Volume 4 Environmental Assessment Report*. http://www.cnsopb.ns.ca/pdfs/1.pdf

Findlay, C.S., and J. Bourdages. 2000. “Response Time of Wetland Biodiversity to Road Construction on Adjacent Lands.” *Conservation Biology* 14 (1): 86–94.

Geneletti, D., E. Beinat, C.J.F. Chung, A.G. Fabbri, and H.J. Scholten. 2003. “Accounting for Uncertainty Factors in Biodiversity Impact Assessment: Lessons from a Case Study.” *Environmental Impact Assessment Review* 23 (4): 471–487.

Gibson, R. 2012. “In Full Retreat: The Canadian Government’s New Environmental Assessment Law Undoes Decades of Progress.” *Impact Assessment Project Appraisal* 30 (3): 179–188.

Golder Associates. 2000. *Environmental Impact Assessment for the Swan Valley Gasification Project*.

Golder Associates. 2003. *Application for Environmental Assessment Certificate and Draft Comprehensive Study Report for the City of Prince George Island Collector Well*. http://a100.gov.bc.ca/appsdata/epic/html/deploy/epic_document_209_15598.html

Government of Canada. 2001. A Canadian Perspective on the Precautionary Approach/Principle. http://www.cambridgeforums.com/ww.admin/materials/env/1389302564A_Canadian_Perspective_on_the_Precautionary_Principle_Approach_EC.pdf

Imperial Oil Resources Ventures Limited, ConocoPhillips Canada (North) Limited, Shell Canada Limited, ExxonMobil Canada Properties and Aboriginal Pipeline Group. 2004. Environmental Impact Statement for the Mackenzie Gas Project. http://www.mackenziegasproject.com/theProject/regulatoryProcess/applicationSubmission/Applicationscope/EIS.html

INRS (Institut national de la recherche scientifique). 1998. *The Crees of The Waskaganish First Nation. Waskaganish Permanent Road Environmental and Social Impact Study Volume I – Impact Analysis*. Québec: Université du Québec, Culture et Société.

Iris Environmental Systems. 1999. *A Proposal to Develop a Chairlift and Ski Runs on Eagle Ridge Marmot Basin Ski Area, Jasper National Park*. Prepared for the Ski Marmot Basin, Jasper National Park, Alberta, by IRIS Environmental Systems, Calgary, Alberta, Canada.

Jacques Whitford Environment Limited. 2004. Environmental Impact Statement Liquefied Natural Gas Marine Terminal and Multi-Purpose Pier. Prepared for Irving Oil Limited. http://www.ceaa-acee.gc.ca/6AC3B6B1-docs/report_e.pdf

Jaeger, J. 1998. “Exposition und Konfiguration als Bewertungsebenen für Umweltgefährdungen [On the Use of Exposition and Configuration as Stages for Assessing Environmental Threats].” *Zeitschrift für angewandte Umweltforschug (ZAU)* 11 (3/4): 444–466.

Joint Review Panel appointed to review the environmental impacts of the proposed Mackenzie Gas Project. 2009. *Foundation for a Sustainable Northern Future; Report of the Joint Review Panel for the Mackenzie Gas Project*. http://www.ceaa.gc.ca/default.asp?lang=En&n=155701CE-1

Karlson, M., U. Mörtberg, and B. Balfors. 2014. “Road Ecology in Environmental Impact Assessment.” *Environmental Impact Assessment Review* 48: 10–19.

Krippendorff, K. 2004. *Content Analysis: An Introduction to Its Methodology*. Pennsylvania: Sage.

Larsen, S.V., L. Kørnøv, and P. Driscoll. 2013. “Avoiding Climate Change Uncertainties in Strategic Environmental Assessment.” *Environmental Impact Assessment Review* 43: 144–150.

Leung, W., B. Noble, J.A.E. Gunn, and J.A.G. Jaeger. 2015. “A Review of Uncertainty Research in Impact Assessment.” *Environmental Impact Assessment Review* 50: 116–123.

Ministry of Transportation. 2009. *407 East Individual Environmental Assessment and Preliminary Design Study*. Ottawa: Ministry of Transportation of Ontario.

Nalcor Energy. 2011. *Lower Churchill Hydroelectric Generation Project – Report of the Joint Review Panel.* http://www.env.gov.nl.ca/env/env_assessment/projects/Y2010/1305/lower_churchill_panel_report.pdf

Nalcor Energy. 2013. *Lower Churchill Project-Project Wide Environmental Protection Plan Component 1 and 4b*. http://www.env.gov.nl.ca/env/env_assessment/projects/Y2010/1305/project_wide_epp_rev.pdf

Noble, B. 2015. *Introduction to Environmental Impact Assessment: A Guide to Principles and Practice*. New York: Oxford University Press.
Noble, B., and K. Storey. 2005. "Towards Increasing the Utility of Follow-Up in Canadian EIA." *Environmental Impact Assessment Review* 25 (2): 163−180.
Peche, R., and E. Rodriguez. 2011. "Environmental Impact Assessment by Means of a Procedure Based on Fuzzy Logic: A Practical Application." *Environmental Impact Assessment Review* 31 (2): 87−96.
Petersen, A.C., A. Cath, M. Hage, E. Kunseler, and J.P. Van der Sluijs. 2011. "Post-normal Science in Practice at the Netherlands Environmental Assessment Agency." *Science Technology and Human Values* 36 (3): 362−388.
Ragas, A.M.J., M.A.J. Huijbregts, I. Henning-De Jong, and R.S. Leuven. 2009. "Uncertainty in Environmental Risk Assessment: Implications for Risk-Based Management of River Basins." *Integrated Environmental Assessment and Management* 5 (1): 27−37.
Reckhow, K.H. 1994. "Importance of Scientific Uncertainty in Decision-making." *Environmental Management* 18 (2): 161−166.
Ross, T.J., J.M. Booker, and A.C. Montoya. 2013. "New Developments in Uncertainty Assessment and Uncertainty Management." *Expert Systems with Applications* 40 (3): 964−974.
Söderman, T. 2005. "Treatment of Biodiversity Issues in Finnish Environmental Impact Assessment." *Impact Assessment Project Appraisal* 23 (2): 87−99.
Smith, H. 1975. *Strategies of Social Research: The Methodological Imagination*. London: Prentice Hall International.
Taseko Mines Limited. 2009. *Prosperity Gold-Copper Project Environmental Impact Statement/ Application*. http://www.ceaa-acee.gc.ca/050/document-70eng.cfm?document=32276
Taseko Mines Limited. 2010. *Prosperity Gold-Copper Mine Project − Report of the Federal Review Panel*. http://www.ceaa-acee.gc.ca/050/documents/46911/46911E.pdf
Tennøy, A., J. Kværner, and K.I. Gjerstad. 2006. "Uncertainty in Environmental Impact Assessment Predictions: The Need for Better Communication and More Transparency." *Impact Assessment Project Appraisal* 24 (1): 45−56.
Tinker, L., D. Cobb, A. Bond, and M. Cashmore. 2005. "Impact Mitigation in Environmental Impact Assessment: Paper Promises or the Basis of Consent Conditions?" *Impact Assessment and Project Appraisal* 23 (4): 265−280.
Total E&P Joslyn Limited. 2011. *Joslyn North Mine Project − Report of the Joint Review Panel*. https://external.sp.environment.gov.ab.ca/DocArc/EIA/Pages/default.aspx
Walker, W.E., P. Harremoës, J. Rotmans, J.P. van der Sluijs, M.B.A. van Asselt, P. Janssen, and M.P. Krayer von Krauss. 2003. "Defining Uncertainty: A Conceptual Basis for Uncertainty Management in Model-Based Decision Support." *Integrated Assessment* 4 (1): 5−17.
Wardekker, J.A., J.P. van der Sluijs, P.H.M. Janssen, P. Kloprogge, and A.C. Petersen. 2008. "Uncertainty Communication in Environmental Assessments: Views from the Dutch Science-policy Interface." *Environmental Science and Policy* 11 (7): 627−641.
Wiklund, H. 2011. "Why High Participatory Ideals Fail in Practice: A Bottom-Up Approach to Public Nonparticipation in EIA." *Environmental Assessment Policy and Management* 13 (2): 159−178.
Wood, C., B. Dipper, and C. Jones. 2000. "Auditing the Assessment of the Environmental Impacts of Planning Projects." *Environmental Planning and Management* 43 (1): 23−47.
Wood, G. 2008. "Thresholds and Criteria for Evaluating and Communicating Impact Significance in Environmental Statements: 'See no Evil, Hear no Evil, Speak no Evil'?" *Environmental Impact Assessment Review* 28 (1): 22−38.