ONTARIO POWER GENERATION

OPG Confidential

Quantitative Risk Assessment

Niagara Tunnel Project

July 27, 2005

File: R-NAW130-001900-P

Introduction

This report summarizes the methodology and results of the quantitative risk assessment for the Niagara Tunnel Project (NTP), which was used to determine cost and schedule contingencies for the project. This report is an update of an earlier report[1] prepared by consultants URS Canada Inc. URS reported on the findings of a risk assessment that was conducted in December 2004 to March 2005, before responses to the Proposal Invitation were received from the design-build proponents. Thus, the URS report considered generic risks to the NTP without taking into account differences in design, construction methods, commercial terms and other aspects that vary among the design-build proponents. Upon completion of its consulting assignment in early May, URS transferred to OPG the quantitative model used in the assessment. After the design-build proposals were received and analyzed in May-June 2005, the assessment was updated to:

- Confirm the overall analytical assumptions;
- Confirm estimated numerical inputs;
- Identify additional hazards and remove hazards that are no longer relevant; and
- Adapt the assessment to reflect differences among the proposals.

The quantitative risk model is based on a list of potential hazards that could cause cost and schedule overruns. For each hazard, the model includes estimates of probability and consequence to project cost and schedule if the hazard occurs. The model aggregates the hazards into probability distributions of potential cost and schedule overruns, using a Monte Carlo simulation (a commonly used method for quantitative risk analysis in engineering and other fields). Contingencies for cost and schedule are determined from these distributions, at a confidence level consistent with OPG's risk tolerance for the NTP.

Expert Panel Workshops

Expert panel workshops were conducted on June 29 and July 12, 2005 to identify necessary updates to the assessment. The expert panel for these workshops consisted of mostly the same individuals who contributed to the earlier assessment facilitated by URS. The panel included NTP team members from OPG, Hatch Mott MacDonald / Acres International (HMM/Acres) and Torys, representing engineering, legal, commercial and other areas of expertise.

During the workshops, the expert panel agreed to the following overall assumptions and estimates for the assessment:

- For all hazards in the model, estimates of cost consequence include only direct cost impacts (e.g., incremental materials and labour to correct a problem) and exclude costs from the Contractor's and OPG's "burn rate" during delays.
- Schedule delays are estimated in terms of critical path impact (i.e., delays are estimated net of "float" in the project schedule).
- The cost consequences of schedule delays were calculated by multiplying delays by a "burn rate" of $275,000 per day, based on:

Contractor's labour	$225,000
Stand-by cost of equipment	$25,000
HMM/Acres cost	$20,000
OPG cost	$5,000
	$275,000

[1] Niagara Tunnel Project, Quantitative Risk Assessment Report – Final Report. Prepared for Ontario Power Generation. URS Canada Inc., May 2005.

- Interest during construction (IDC) was not included in the cost estimates (IDC was accounted for separately in the project cost estimate and cash flow projection).

The initial quantitative risk register described in the URS report was used as a starting point. All hazards were reviewed and their probabilities of occurrence, as well as cost and schedule consequences, were re-evaluated. Some of the hazards were determined to be no longer relevant and were removed from the register. Five new hazards were added to the register based on information in the design-build proposals (e.g., more detail on geotechnical risks). Differences among the three proposals were also discussed, which led to different numerical estimates for certain hazards as applied to each proposal. For example, the risk of water inflows into the tunnel depends on the tunnel alignment, type of tunnel boring machine and the liner design, which vary among the proposals. The final register for the selected contractor is attached as Appendix A.

Analysis

The Monte Carlo simulation methodology used in the model is described in detail in the URS report. OPG conducted the simulations with Palisade @RISK, a software package linked to Microsoft Excel. The analysis combined probabilities and consequences by aggregating 10,000 separate, randomly generated trials to generate probability distributions of possible outcomes. For each trial, a hazard either occurred or did not occur, depending on its probability. If the hazard occurred in a given trial, its cost and schedule delay were determined randomly from probability distributions based on the expert panel's estimates. (The expert panel workshops estimated the mean values of cost and schedule impacts. These mean values were converted to lognormal probability distributions using assumptions described in the URS report.) For each trial, the total cost and schedule delays were calculated. Schedule delays were separated into: 1) OPG-accountable delays, i.e., delays for which no Liquidated Damages (LDs) are payable, such as delays triggered by Differing Subsurface Conditions (DSC) claims; 2) Contractor-accountable delays, for which LDs are payable, which is most other types of delay; and 3) the sum of these two. The results from all 10,000 trials were combined into probability distributions of cost and schedule delays.

OPG's cost contingency is taken from the cost distribution. OPG's schedule contingency is taken from the OPG-accountable schedule distribution, because the design-build Agreement compensates OPG for contractor-accountable delays through payment of LDs (i.e., the project could be completed late, but OPG is adequately compensated and so no schedule contingency is required). It is also assumed that the project schedule, which is set by the contractor, includes some contingency as determined by the contractor.

It is possible that delays caused by the contractor could exceed a certain threshold, based on the maximum LD amount of 20% of the contract price. OPG would be effectively accountable for schedule over runs exceeding the threshold. Using a daily LD amount of $200,000, a seven day work week and an assumed contract value of $600 million, the threshold for schedule LDs is calculated to be 85 weeks. Contractor-accountable delays never exceeded this amount in the simulation, thus, the LD threshold did not influence the OPG-accountable delay distribution.

Results

For the selected proposal, at a 90% confidence level, OPG's cost contingency for the tunnel contract is $96 million (Figure 1). The schedule contingency, based on the estimated OPG-accountable delay at 90% confidence, is 36 weeks (Figure 2).

The hazards that contribute most to these contingency amounts are shown in "tornado diagrams" (Figures 3 and 4) based on expected values for these hazards (probability X mean consequence).

Figure 1. Potential cost overrun ($ million)

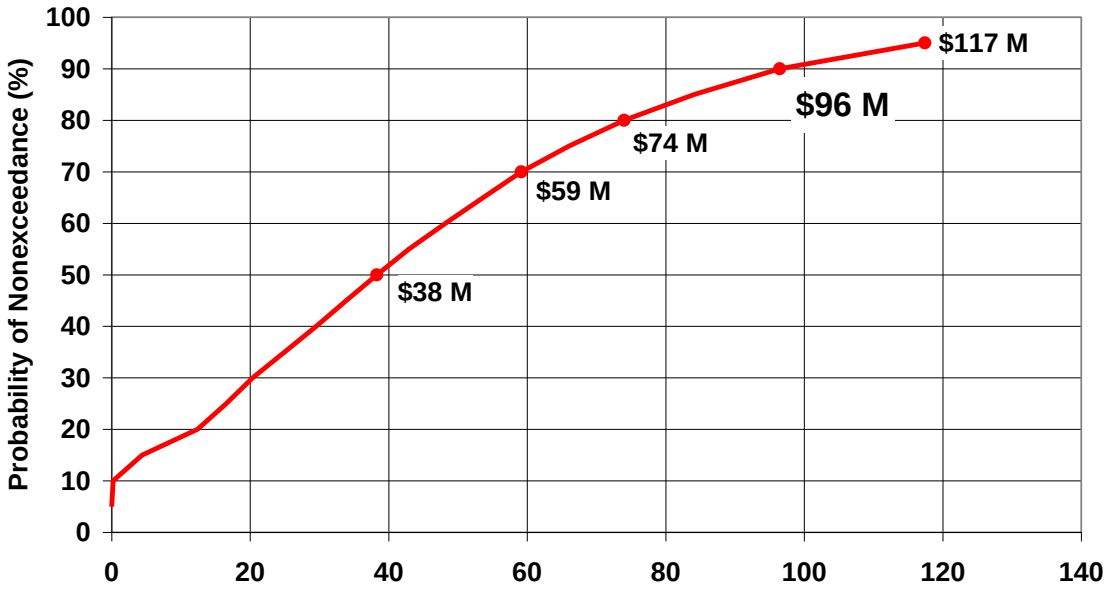


Figure 2. Potential delays (weeks)

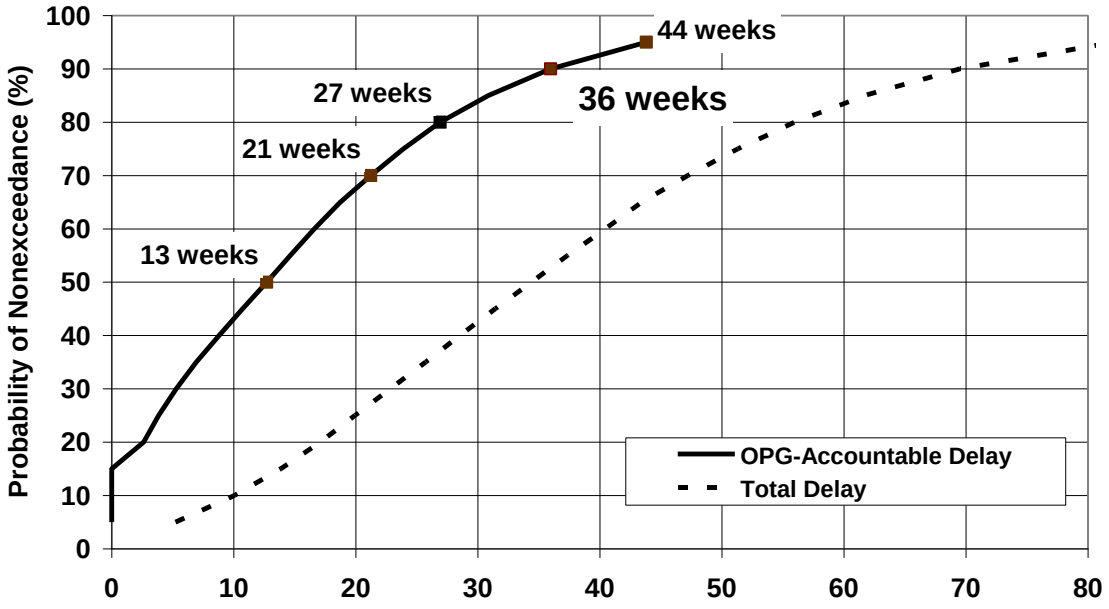


Figure 3. Top contributors to cost risk

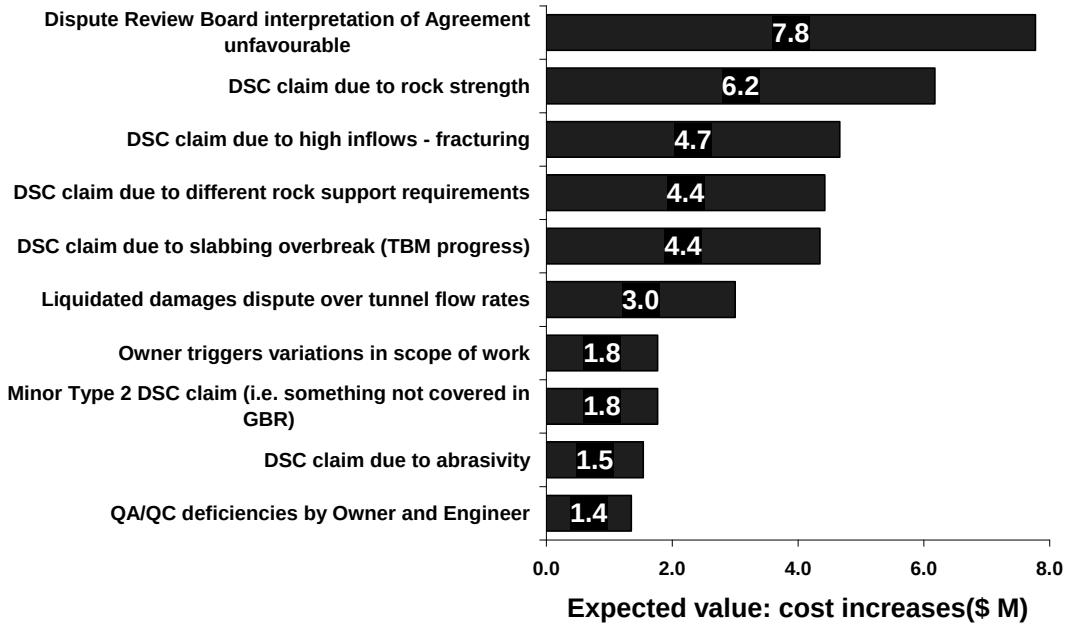
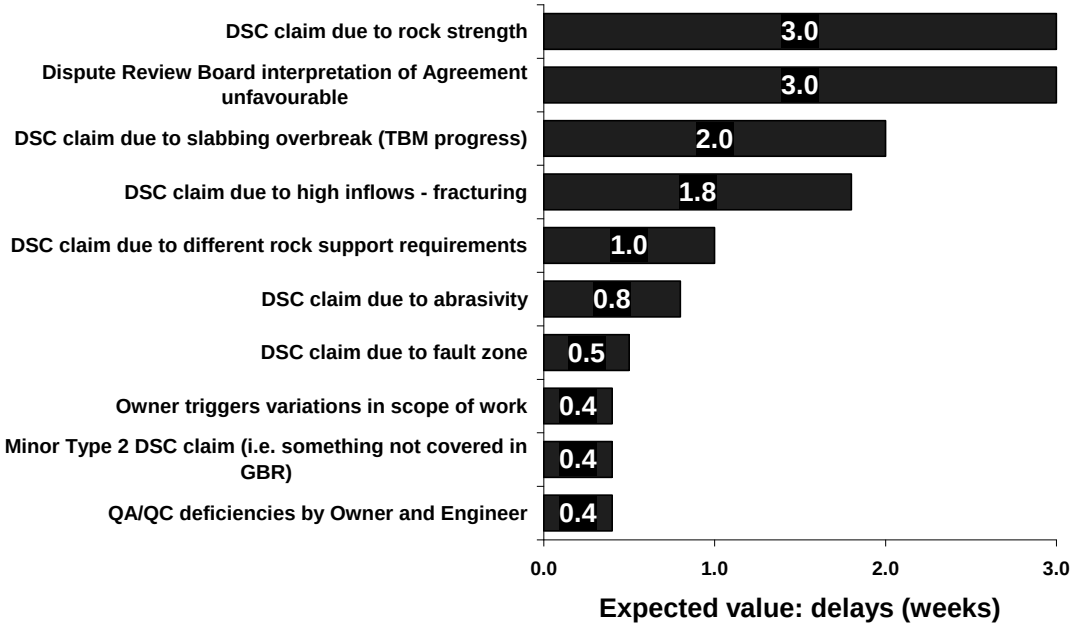


Figure 4. Top contributors to OPG-accountable delays



Reference Number	Risk Label	Hazard	Cause of Hazard	Potential Consequence	Probability	5th percentile cost ($1,000)	mean cost ($1,000)	95th percentile cost ($1,000)	5th percentile delay (weeks)	mean delay (weeks)	95th percentile delay (weeks)
1	Ministry of Environment (MOE) not in agreement with proposed work	Not meeting terms and conditions of Environmental Assessment (EA) Approval	MOE not in agreement with proposed work	Schedule Delay	0.01				7	15	30
2	Ministry of Natural Resources (MNR) not in agreement with proposed work	Not meeting terms and conditions of EA Approval	MNR not in agreement with proposed work	Schedule Delay	0.05				2	4	8
3	Niagara Peninsula Conservation Authority (NPCA) not in agreement with Welland River impact	Not meeting terms and conditions of EA Approval	NPCA not in agreement with the impact on the Welland River	Unexpected additional costs to avoid project delay	0.01				15	26	52
4	Other interested parties/regulators not in agreement with project	Not meeting terms and conditions of EA Approval	Other regulators having jurisdiction not in agreement with proposed work	Schedule Delay	0.01	500	1,400	3,000	7	15	30
5	Unexpected results from groundwater monitoring	Not meeting terms and conditions of EA Approval	Unexpected results from groundwater study (cross-connections, increased salinity)	Unexpected additional costs to avoid project delay	0.1	4,000	10,000	25,000			
6	Unexpected results from excavated materials plan	Not meeting terms and conditions of EA Approval	Unexpected results from excavated materials plan	Unexpected additional costs to avoid project delay	0.1	4,000	10,000	25,000			
7	Unforeseen new requirement added by MOE	Not meeting terms and conditions of EA Approval	Unforeseen new requirement added by MOE	Schedule Delay	0.001	3,000	5,800	10,000	2	4	8
8	Permits not obtained due to contractor delay	Required Permits not obtained	Contractor did not submit in time	Schedule Delay	0.1				7	15	30
9	Permits not obtained due to OPG delay	Required Permits and Approvals not obtained	OPG did not submit in time	Schedule Delay	0.01				5	8	16
10	Late response from third party to regulator	Required Permits not obtained	Late response from third party to regulator	Schedule Delay	0.1				4	10	20
11	Additional study required by regulatory authority	Required Permits not obtained	Additional study required by regulatory authority	Schedule Delay	0.1				4	10	20
12	Required permit not identified	Required Permits not obtained	Required permit not identified	Schedule Delay	0.1				7	15	30

Reference Number	Risk Label	Hazard	Cause of Hazard	Potential Consequence	Probability	5th percentile cost ($1,000)	mean cost ($1,000)	95th percentile cost ($1,000)	5th percentile delay (weeks)	mean delay (weeks)	95th percentile delay (weeks)
13	Permit conditions not acceptable to OPG	Required Permits not obtained	Permit conditions not acceptable to OPG	Schedule Delay	0.01				4	6	12
14	Fisheries Act terms not met	Project does not meet terms and conditions of the Fisheries Act authorizations	Failure to account for terms and conditions of Fisheries Act	Schedule Delay	0.01				2	4	8
15	Quality Assurance/Control (QA/QC) deficiencies by Owner and Engineer	Contract documents insufficiently detailed and imprecise	Deficiencies in QA/QC by Owner and Engineer	Inadequate communication of design requirements to Contractor	0.1	3,000	5,800	10,000	2	4	8
16	Major Type 2 Differing Subsurface Conditions (DSC) claim (i.e., something not covered in Geotechnical Baseline Report - GBR)	Contract documents insufficiently detailed and imprecise	Deficiencies in GBR (i.e. something not covered in GBR)	Major Type 2 DSC claims	0.01	24,000	50,000	90,000	7	15	30
17	Minor Type 2 DSC claim (i.e., something not covered in GBR)	Contract documents insufficiently detailed and imprecise	Deficiencies in GBR (i.e. something not covered in GBR)	Minor Type 2 DSC claims	0.1	5,000	10,000	20,000	2	4	8
18	Inadequate project processes and procedures	Inadequate project processes and procedures	Various	Cost, schedule and quality	0.1				7	12	24
19	High Insurance Premiums due to market conditions	Insurance Premiums prohibitively high	Insurance market conditions / capacity	Cost impact to project budget	0.01	3,000	5,800	10,000			
20	Inability to make insurance claim: loss not covered	Inability to make insurance claim	Insurance does not cover claim	Cost impact to project budget	0.02	6,000	15,000	32,000			
21	Inability to make insurance claim: failure to apply properly	Inability to make insurance claim	Failure to apply properly	Cost impact to project budget	0.01	10,000	25,000	50,000			
22	Owner triggers variations in scope of work	Inability to control project cost to within approved budget	Owner triggers variations in scope of work	Project overruns, schedule delays	0.1	5,000	10,000	20,000	2	4	8
23	Contractor successfully claims that OPG failed to disclose key pre-tender information	Inability to control project cost to within approved budget	Contractor successfully claims that OPG failed to disclose key pre-tender information	Additional compensation to contractor	0.01	5,000	10,000	20,000			
24	Inability to enforce warranty	Inability to enforce warranty	Insufficient funds withheld for holdback	Financial impact	0.001	24,000	50,000	90,000			

Reference Number	Risk Label	Hazard	Cause of Hazard	Potential Consequence	Probability	5th percentile cost ($1,000)	mean cost ($1,000)	95th percentile cost ($1,000)	5th percentile delay (weeks)	mean delay (weeks)	95th percentile delay (weeks)
25	Unsuccessful bidder sues for damages	OPG sued for damages by unsuccessful bidder	Claims for unfair process due to conflicts of interest, application, undisclosed criteria, etc.	Financial, corporate reputation	0.1	800	2,000	4,500			
26	Dispute Review Board interpretation of Agreement unfavourable	Dispute Review Board interpretation of Agreement unfavourable	Dispute Review Board error	Financial, schedule delays	0.2	4,000	10,000	25,000	7	15	30
27	Property acquisition delay due to affected 3rd parties	Delay in obtaining necessary property rights from third parties not subject to Expropriation Act	Re-evaluation of project by affected third parties	Unexpected additional costs to avoid project delay	0.002	1,800	3,000	5,000			
28	Tunnel Boring Machine (TBM) late due to late order by Contractor	Late availability of TBM	Late Submittal/ ordering	Schedule Delay	0.01				7	15	30
29	TBM late due to manufacturing problems	Late availability of TBM	Manufacturing problems	Schedule Delay	0.2				5	8	16
30	TBM late due to shipping delays	Late availability of TBM	Shipping delays (due to weather)	Schedule Delay	0.01				2	4	8
31	Inadequate TBM	Inadequate design of the TBM for the Niagara project	Contractor design error	Schedule Delay	0.2				4	10	20
32	TBM assembly problems	Late availability of TBM	Assembly and commissioning problems	Schedule delay	0.2				2	4	8
33	Regional power outage	Interrupted power supply for site works	Regional power outage	Lack of electrical power for TBM	0.15	500	1,400	3,000	1	2	4
34	Segment plant breakdown	Segments not available in timely manner	Plant breakdown (e.g. due to fire, etc.)	Schedule delay, possibly leading to stopping forward progress of TBM	0.01				15	26	40
35	Adverse weather	Work impeded by adverse weather conditions	Storms, extreme temperature, winter weather	Schedule delay, primarily at inlet and outlet works	0.1				1	2	4
36	Productivity and skilled labour shortage	Problems with availability of required trade and skill people	General conditions on the construction labour market in Southern Ontario	Schedule delay	0.05				15	26	52

Reference Number	Risk Label	Hazard	Cause of Hazard	Potential Consequence	Probability	5th percentile cost ($1,000)	mean cost ($1,000)	95th percentile cost ($1,000)	5th percentile delay (weeks)	mean delay (weeks)	95th percentile delay (weeks)
37	Inundation of tunnel inlet work area, shaft and reception area for TBM	Flooding of the works during construction	Breach of temporary structure at inlet works	Inundation of tunnel inlet work area and shaft and reception area for TBM	0.01	50	200	500	9	16	32
38	Inundation of tunnel inlet work area, shaft and entire tunnel after TBM breakthrough	Flooding of the works during construction	Breach of temporary structure at inlet works	Inundation of tunnel inlet work area and shaft and entire tunnel after TBM breakthrough	0.001	50	200	500	20	52	104
39	Inundation of tunnel outlet work, including inundation of tunnel excavation and TBM	Flooding of the works during construction (flooding due to extreme rainfall)	Breach at outlet works	Inundation of tunnel outlet work, including mucking operation and active mining tunnel portal, including inundation of tunnel excavation and TBM	0.001	50	200	500	4	10	20
40	Tunnel collapse due to inadequate or inappropriate design	Tunnel collapse	Engineering error or omission (inadequate or inappropriate design)	Lining overstressing and failure; legal proceedings against designer	0.01				15	30	60
41	Tunnel collapse due to ground conditions	Tunnel collapse	Unforeseen ground conditions	Submittal of DSC claim - legal proceedings against owner; lining overstressing and failure	0.001	24,000	50,000	90,000	15	30	60
42	Tunnel collapse due to poor contractor workmanship	Tunnel collapse	Inadequate Contractor workmanship	Lining overstressing and failure	0.01				15	30	60
43	Gas in tunnel - higher concentrations than anticipated	Encountering gas in higher concentrations than anticipated.	Naturally occurring gas in rock formations - higher concentration than currently anticipated	Increased ventilation of all tunnel equipment to meet appropriate regulatory requirements - DSC claim	0.1	50	200	500	1	1	2
44	Loss of cross-sectional area in Pump Generating Station (PGS) canal due to blasting	Loss of cross-sectional area in PGS canal	Construction debris - primarily due to blasting	Loss of revenue and schedule delay for project completion carrying out remediation	0.05	500	1,000	2,000	1	2	4
45	Contractor non-compliance	Project design criteria not met	Contractor non-compliance	Schedule delay	0.01				2	4	8

Reference Number	Risk Label	Hazard	Cause of Hazard	Potential Consequence	Probability	5th percentile cost ($1,000)	mean cost ($1,000)	95th percentile cost ($1,000)	5th percentile delay (weeks)	mean delay (weeks)	95th percentile delay (weeks)
46	Design not ready	Design of major component not complete before its construction commences	Poor scheduling by design/build team	Temporary works insufficient size to accommodate permanent works	0.01				5	8	16
47	DSC claim due to rock strength	Slower penetration by TBM and faster deterioration of cutters	Rock Strength higher than anticipated	Submittal of DSC claim - legal proceedings against owner	0.2	800	2,000	4500	7	15	30
48	DSC claim due to abrasivity	Encountering Ground Conditions more adverse than advertised in contract (TBM stuck)	Rock abrasivity higher than anticipated	Submittal of DSC claim - legal proceedings against owner	0.1				5	8	16
49	DSC claim due to high inflows - fracturing	Encountering Ground Conditions more adverse than advertised in Contract (additional drilling and grouting)	High inflows at tunnel heading above Queenston Shale (e.g. intense fracturing in bedrock)	Submittal of DSC claim - legal proceedings against owner	0.1	5,000	12,000	25,000	10	18	32
50	DSC claim due to fault zone	Encountering Ground Conditions more adverse than advertised in Contract (additional grouting)	Encountering an unexpected fault zone	Submittal of DSC claim - legal proceedings against owner;	0.05	2800	5,000	9,000	5	10	20
51	DSC claim due to BTEX (petroleum chemicals)	Encountering Ground Conditions more adverse than advertised in Contract	Encountering BTEX in tunnel in higher than advertised concentrations	Submittal of DSC claim - legal proceedings against owner;	0.01	2,600	4,000	8,000	1	2	4
52	DSC claim due to high salinity	Encountering Ground Conditions more adverse than advertised in Contract	Unexpectedly high salinity content of groundwater into tunnel heading	Corrosion of TBM or rolling stock - DSC Claim	0.01	3,000	5,800	10,000	7	15	30
53	DSC claim due to impact on INCW	Encountering Ground Conditions more adverse than advertised in Contract	Deformation to surface structures	Submittal of DSC claim - legal proceedings against owner;	0.05	2,800	5,000	9,000	2	4	8
54	Water control near St. David's Gorge	Difficulty in controlling water inflow	Contractor under-estimates inflow risk	Contractor-accountable cost and schedule delays	0.2				9	16	32

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55	Unexpected subsurface contamination	Excavated material is more contaminated than expected	Unexpected subsurface contamination (natural or anthropogenic)	Increased materials handling and disposal costs - DSC claim	0.001	10,000	20,000	40,000	4	6	12
56	Groundwater contamination due to dewatering	High levels or additional groundwater contamination encountered during excavation dewatering	Unexpected groundwater contamination	Increased cost to handle/treat/discharge water	0.01	500	1,400	3,000	4	6	12
57	Loss of seepage causes threat to dusky salamander	Threat to habitat and population of dusky salamander	Loss of seepage that creates habitat due to construction	Non-compliance with the Ontario Endangered Species Act	0.001	500	1,400	3,000			
58	Significant fire during construction	Significant fire during construction	Hot works and/or electrical work and/or naked flames in tunnel in a potentially gassy environment	Minor injury to loss of life or multiple lives	0.001				7	15	30
59	Major TBM breakdown	TBM forward progress impeded	TBM breakdown	Significant project delay to restore TBM progress	0.02				10	26	52
60	Minor TBM breakdown	TBM forward progress impeded	TBM breakdown	Project delay to restore TBM progress	0.2				5	8	16
61	DSC claim due to slabbing overbreak (TBM progress)	Encountering Ground Conditions more adverse than advertised in Contract	Slabbing overbreak is higher than expected	Submittal of DSC claim - legal proceedings against owner	0.2	1300	2,500	5,000	4	10	20
62	DSC claim due to different rock support requirements	Rock support requirements significantly different from baseline	Unexpected ground conditions	Submittal of DSC claim - legal proceedings against owner	0.25	4,000	10,000	25,000	2.5	4	8
63	Opportunity to recover cost/time due to different rock support requirements	Rock support requirements significantly different from baseline	Unexpected ground conditions	Shorter schedule and lower cost	0.05	-4,000	-10,000	-25,000	2	4	8