**FINAL REPORT**

# NIAGARA TUNNEL PROJECT

## QUANTITATIVE RISK ASSESSMENT REPORT

*Prepared for*

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## E.1 INTRODUCTION

URS Corporation (URS) was retained by Ontario Power Generation Inc. (OPG) on November 16, 2004, to provide hazard identification and both qualitative and quantitative risk analysis services for the Niagara Tunnel Project (the Project). This report covers only the quantitative analysis portion of the work.

The Niagara Tunnel Project will see the construction of a new tunnel approximately 12.5 m in diameter and approximately 10.5 km long. The tunnel will carry water from the Niagara River above the Falls, under the City of Niagara Falls, to the Sir Adam Beck 1 and 2 Generating Stations in Queenston Heights, Ontario. The tunnel will increase the amount of water available to the generating stations, thus allowing them to increase their energy production.

The Project is to be awarded to a design-build consortium based on a Proposal Invitation that includes a preliminary design prepared by OPG and its representative, Hatch Mott Macdonald (HMM). The Proposal Invitation was issued to shortlisted design-build consortia on December 22, 2004, with a closing date in spring of 2005. Construction activities are expected to start in the summer of 2005, with completion of the tunnel expected in 2009.

This Risk Assessment began prior to the issue of the Proposal Invitation to shortlisted consortia, and was completed during the Proposal Preparation stage of the design-build assignment. The analysis is a snapshot in time: risks are considered as they appear just prior to contract award. As the project progresses, some risks will be retired as their danger is passed, with or without the event actually occurring. Additional risks will also present themselves as the project progresses: OPG staff will add these to the risk spreadsheet as they become known.

The detailed results of this risk assessment will also provide OPG with a tool for monitoring and mitigating risks throughout the design-build assignment.

## E.2 RISK ASSESSMENT METHODOLOGY

The project used a "Chance Method" methodology in a Monte Carlo analysis. The methodology consists of:

- identifying all conceivable hazards that could occur during the project, and
- assessing for each one a probability of occurrence, a cost impact and a schedule (delay) impact
- combining the probabilities and consequences to identify the outcomes in 5,000 separate possible scenarios of the project, to obtain a distribution of possible outcomes.

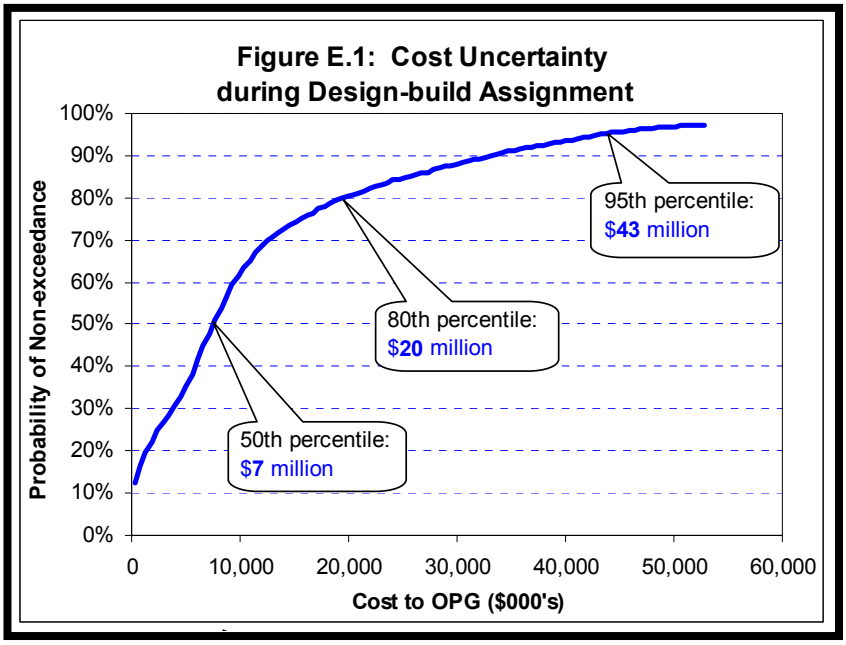
The probability, cost and schedule values were established by members of an Expert Panel consisting of Niagara Tunnel project team members from OPG and HMM, facilitated by the URS team. The analysis considers only those costs which affect the construction project, through to the time of commissioning. Risks during operation were not considered in the analysis.

## E.3 RISK ASSESSMENT RESULTS

The Risk Assessment focused on understanding the overall potential for project impacts in three main areas:

- Project cost overruns
- Project schedule overruns
- Economic losses due to uncompensated delays in project completion

The estimated probability distribution of project cost overruns is shown in Figure E.1.



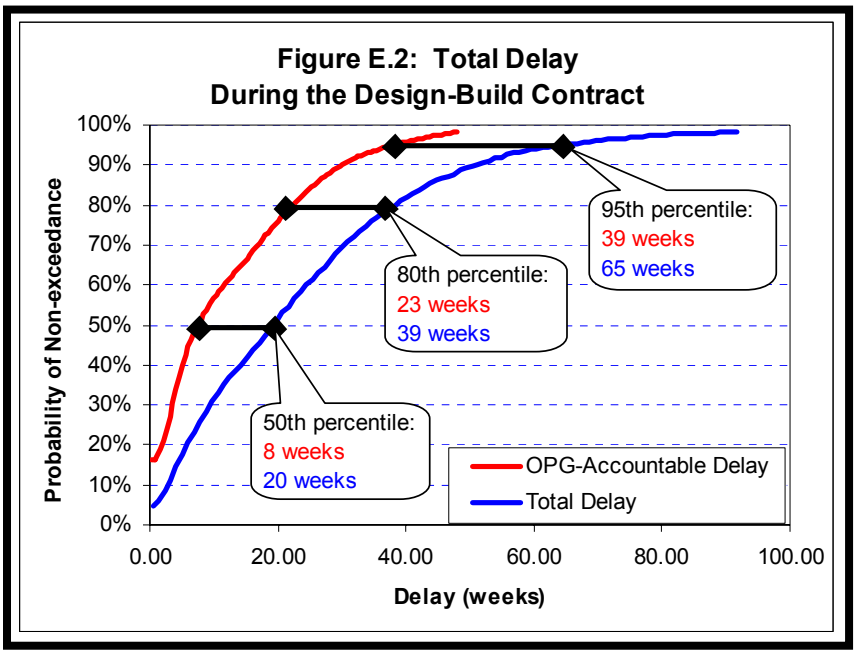

Costs relating to various types of Differing Site Condition claims are the most significant contributors to the cost uncertainty.

Important costs not considered in this analysis are the bid price, which will already be fixed once the design/build contract begins, and operating risks such as swelling of the surrounding rock (causing stress and potential damage to the tunnel lining) during tunnel operation.

It is common practice to establish a cost contingency based on the 80$^{th}$ percentile of the cost distribution for a project, which would be $20 million in this case, or less than 5% of the expected bid price. This is much lower than experience would suggest for a project contingency amount, for the following reasons:

- Many of the risks that would normally be borne by the owner have, in the case of this project, been placed with the contractor in the contract terms and conditions
- There are "normal" contingency items that should be included in the project contingency amount, but which are not included in this risk analysis as they are expected and therefore part of the basic project budget
- Some of the estimates of probability provided by the Expert Panel may require revision once a design-build contract has been awarded and details of construction methods and management approach are known.

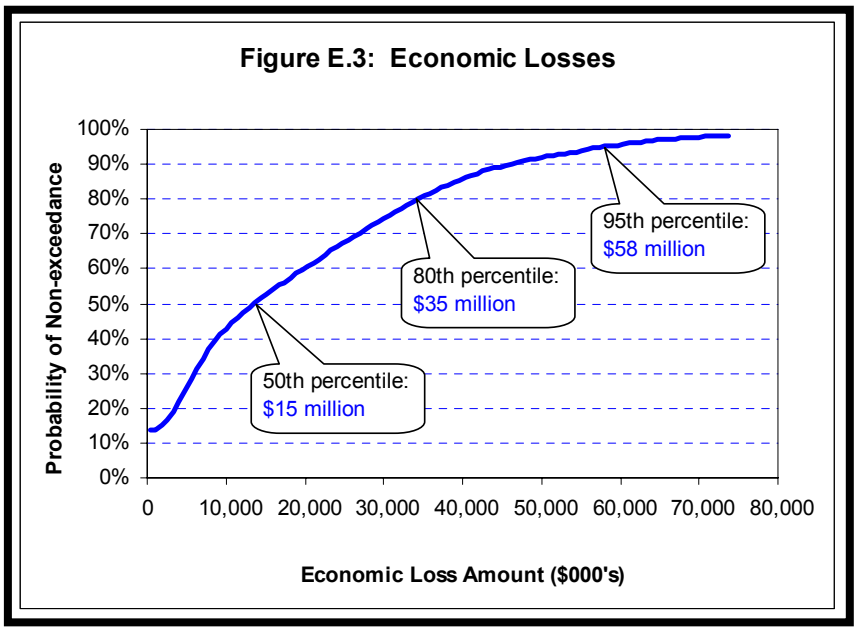
Figure E.2 shows the estimated distribution of project delay. The red line shows the delay for which OPG would be accountable, for which no liquidated damages would be payable, and the blue line shows the total estimated delay.




The delay impacts of Figure E.2 are independent of the costs shown in Figure E.1. Where a particular hazard was forecast to have both a cost impact and a delay impact, they were independent. For example, the lack of a particular permit could have been assigned a cost impact of $2 million and a delay impact of 6 weeks. Where this occurred, the cost impact would have been for additional staff or consulting costs, permit fees, public relations expenditures, etc., but would not have included the economic losses due to the 6-week delay of the project.

Figure E.3 shows the estimated distribution of economic losses to OPG. Economic losses represent the impact on OPG's earnings due to delays in opening of the tunnel into revenue service, plus applicable interest and other costs. The economic losses were determined from:

- Delays for which OPG is accountable
- Delays in excess of 52 weeks for which the contractor is accountable
- Failure to collect liquidated damages from the contractor that should be due to OPG for non-performance (due either to delay or insufficient water flow in the tunnel)



## E.4 RECOMMENDATIONS

We recommend that the OPG project team incorporate the contingencies for cost, schedule delay, and economic losses into its planning processes, considering also any contingencies that should be included for the project but which were not included in this analysis (i.e. outcomes that are likely to occur, but which are not specifically included in the main project budget).

We further recommend that OPG continue to maintain and update the risk register included as Appendix A, retiring and updating individual hazards as necessary.

## 1.1 BACKGROUND

URS Corporation (URS) was retained by Ontario Power Generation Inc. (OPG) on November 16, 2004, to provide hazard identification and both qualitative and quantitative risk analysis services for the Niagara Tunnel Project (the Project).

The Niagara Tunnel Project will see the construction of a new tunnel approximately 12.5 m in diameter and approximately 10.5 km long. The tunnel will carry water from the Niagara River above the Falls, under the City of Niagara Falls, to the Sir Adam Beck 1 and 2 Generating Stations in Queenston Heights, Ontario. The tunnel will increase the amount of water available to the generating stations, thus allowing them to increase their energy production.

This Project has been under consideration by OPG and its predecessor, Ontario Hydro, for more than a decade. The Environmental Assessment (EA) for the Project was approved by the Minister of the Environment in 1998, naming a number of conditions to be met and permits required in order for construction to proceed.

The tunnel will generally follow the same horizontal alignment as the existing canal and two existing tunnels, however the new tunnel is expected to have a much deeper vertical alignment at approximately 200m below the surface at its lowest point. This deeper alignment will allow the new tunnel to avoid going through an area of glacial fill called St. David's gorge, which was considered less favourable for tunneling than the surrounding rock at the time the conceptual design was initiated and the EA approved.

The Project is to be awarded to a design-build consortium based on a Proposal Invitation that includes a preliminary design prepared by OPG and its representative, Hatch Mott Macdonald (HMM). Proponents are to submit their proposals on the basis of the supplied concept drawings and the owner's mandatory requirements, but may offer alternatives where substantial cost savings can be realized.

The Proposal Invitation was issued to shortlisted design-build consortia on December 22, 2004, with a closing date in spring of 2005. Construction activities are expected to start in the summer of 2005, with completion of the tunnel expected in 2009.

OPG asked URS to carry out this Risk Assessment in late November 2004, at the time the Proposal Invitation was in its final stages of preparation.

The URS scope of work includes both a qualitative and a quantitative risk assessment for this project. This report covers only the quantitative portion of the work. A report on the qualitative risk assessment was provided under separate cover[1].

[1] URS, *Niagara tunnel project – Qualitative Risk Assessment Report*, prepared for OPG, February 2005.

## 1.2 OUTLINE AND STRUCTURE OF THIS DOCUMENT

This report forms the quantitative assessment deliverable required under our contract. It outlines our method of analysis and its results. It is intended to be read in conjunction with the qualitative report portion of the risk analysis.

## 1.3 DEFINITION OF TERMS

The following definition of terms were used by URS and OPG to conduct the assessment and develop the risk registers.

***Hazard*** – A situation that, if it occurs, brings about a negative impact on achieving Project objectives.

***Cause*** – The circumstances that allow a hazard to manifest itself.

***Likelihood*** – an event's probability of occurrence over the lifetime of the hazard, expressed in this report in qualitative terms such as likely or unlikely.

***Consequence*** – impact of hazard occurrence measured for several aspects of the Project, such as financial, schedule or environmental impacts.

***Risk*** - expressed as the combination of the likelihood of an event occurring over a specified time frame, and the consequence if the event occurs.

***Inherent Risk*** – Risk, assessed at the commencement of the Project with no specific mitigation or control measures in place.

***Residual Risk*** – The risk assessed at a particular point during the Project and considering all mitigation and control measures in force at the particular point in time that the assessment is taking place.

***Risk Register*** – A formalized record of risks identified from the risk assessment process including full descriptive details of mitigation and control measures, risk owners and with appropriate cross-references. The risk register is the primary means of recording and monitoring the risk management process.

***High Level Risk Register*** – A risk register that considers only aggregate or high-level risks, of interest at the "program" or "project" level, for the purpose of overall project risk evaluation and management.

***Risk Assessment*** – the formalized process of identifying hazards and associated risks, of evaluating their consequence and probability of occurrence, and of preparing strategies as appropriate for preventative and contingent actions.

***Risk Management*** – the overall systematic process of Risk Assessment, risk mitigation and control

***Risk Factor*** – a unique combination of hazard, cause and outcome. In this analysis, each risk factor is assigned a unique number for analysis purposes.

***Simulation*** – any analytical method that is meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce.[2]

***Monte Carlo simulation*** – a simulation technique for forecasting the range of results most likely to occur, by generating random numbers for the input variables and recording the distribution of the results over a large number of trials.

***Trial*** – one iteration of a Monte Carlo simulation, for which each input variable is assigned a single value according to its distribution, and each dependent variable will have a unique value based on its relationship with the input variables.

## 1.4 WARRANTY, LIMITATIONS AND RELIANCE ON URS REPORTS

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[2] Decisioneering, Inc., *Crystal Ball Version 7 User Manual*, 2004

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The purpose of this risk assessment is to quantify the uncertainty associated with the cost and schedule for the Niagara Tunnel Project as defined in the Scope of Work. This section provides an overview of the risk analysis methodology, describes the assessment of the input, and presents the results of the risk analysis.

## 2.1 PROBABILITY AND CONSEQUENCE ESTIMATES

The probability, cost and schedule values shown in the quantitative risk register were developed by members of the Expert Panel. The Expert Panel, consisting of approximately 25 project team members from OPG and HMM, included representation from technical, legal, environmental, financial, insurance, public relations and other experts familiar with the project. For details concerning Expert Panel, please refer to the Qualitative Risk Assessment Report.

The quantitative analysis followed the qualitative analysis. At two of the project's Expert Panel workshops, panel members were asked to quantify risk consequences in terms of cost and schedule delay impacts. Only costs to OPG were considered. (I.e. Where the costs would fall on the contractor, they were not included in the analysis. In some cases this could cause contractor bankruptcy, which is covered as a separate hazard.)

This analysis is a snapshot in time: risks are considered as they appear at the point in time just prior to contract award. As the project progresses, some risks will be retired as their danger is passed, with or without the event actually occurring. Additional risks will also present themselves as the project progresses: these should be added to the risk spreadsheet as they become known.

The Expert Panel was asked to consider which risks from the qualitative analysis should be considered in the quantitative analysis. Four criteria were applied in identifying appropriate risk factors to include in the quantitative analysis, with all four conditions needing to be met for inclusion in the analysis:

- The risk factor should identify an unexpected and hence unplanned adverse condition or event. If an adverse condition is known or anticipated with a high probability (greater than 80%), its cost impact would be reflected in the base cost.
- The risk factor should not be associated with a condition or event whose chance of occurrence is remote (defined as less than 1 in 1000 for this analysis). Thus, for example, a major earthquake that could cause extensive damage in the project area was not included as a risk factor, because its chance of occurrence was judged to be less than 1 in 1000. Note that some hazards included in this analysis had lower probabilities. Although these will not be strongly influential on the risk cost estimates, these hazards have been included for future use by OPG in the event that the probabilities become more likely due to some future event.
- The cost or schedule impact of the risk factor should be significant (defined to be at least one million dollars or two weeks' delay for this project). Risk factors whose impact is less than these thresholds would be included as a part of the normal cost/schedule variation.

- The nature of the risk is such that the project would not proceed into the construction phase if the risk occurred. For example, if the US-Canada treaty on water usage were dissolved, the Niagara Tunnel would not proceed at all, so it would not be appropriate to include a cost or delay amount for such a hazard in the analysis.

For each hazard considered in the quantitative analysis, the Expert Panel established its probability and its cost and delay impacts. The process for quantifying these inputs is described in the following paragraphs.

Initial "seed" probability values were entered into the quantitative risk register based on the likelihood estimates established in the qualitative analysis[3], using the lookup values in Table 2.1. Expert Panel members reviewed these "seed" probability numbers in connection with the various risks, and adjusted up or down, in accordance with their professional judgment.

**Table 2.1: Initial "Seed" Probability Estimates**

| Likelihood Rating | Probability |
|---|---|
| 0 | 0 |
| 1 | 0.001 |
| 2 | 0.01 |
| 3 | 0.1 |
| 4 | 0.2 |
| 5 | 0.75 |

Cost and delay consequences were entered into the model as two-parameter log normal distributions, defined by their mean and 5th and 95th percentiles[4] as established at the Expert Panel workshops.

The log normal distribution is generally used to model price and schedule uncertainty because of the following properties:

- The uncertain variable can increase without limit, but cannot fall below zero
- The uncertain variable is positively skewed with most of the values near the lower limit, while a small number of values can reach levels significantly above the mean

Initial "seed" cost consequence numbers were automatically entered into the risk registers during the initial qualitative portion of the workshop, through a process of looking up the qualitative cost consequence rating in Table 2.2. Expert Panel members reviewed the resulting cost consequence values for each individual risk, and adjusted up or down from these "seed" values, in accordance with their professional judgment.

**Table 2.2: Initial "Seed" Cost Consequence Estimates ($000's)**

| Qualitative Rating | 5th percentile | mean | 95th percentile |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 1 | 50 | 200 | 500 |
| 2 | 500 | 1,400 | 3,000 |
| 3 | 3,000 | 5,800 | 10,000 |
| 4 | 10,000 | 25,000 | 50,000 |
| 5 | 50,000 | 200,000 | 500,000 |

[3] In the qualitative analysis, likelihoods and consequences of the various hazards were given a rating from 1 through 5, based on the Expert Panel's judgment.

[4] The log normal distribution is uniquely defined using only two parameters. For the purpose of this analysis, we defined the distribution using the mean and 95th percentile, and determined the 5th percentile from the resulting distribution. All three parameters were presented to the Expert Panel for review.

In a similar fashion, initial schedule consequence numbers were entered into the risk register using the lookup values in Table 2.3. Expert Panel members reviewed the schedule consequence values in connection with the various risks, and adjusted up or down from these "seed" values in accordance with their professional judgment.

**Table 2.3: Initial "Seed" Schedule Delay Estimates (weeks)**

| Qualitative Rating | 5th percentile | mean | 95th percentile |
|---|---|---|---|
| 0 | 0.0 | 0.0 | 0.0 |
| 1 | 0.5 | 1.0 | 2.0 |
| 2 | 1.0 | 2.0 | 4.0 |
| 3 | 2.3 | 4.0 | 7.0 |
| 4 | 7.4 | 15.0 | 30.0 |
| 5 | 27.0 | 52.0 | 100.0 |

The quantitative analysis did not consider corporate Reputation, Regulatory/ Legal, Health and Safety, or Environmental consequences, except to include out-of-pocket costs to OPG for dealing with these risks (e.g. marketing costs relating to mitigation of an adverse "Reputation Impact" are included, but there is no assessed monetary value of the reputation impact itself).

## 2.2 CHANCE METHOD ANALYSIS METHODOLOGY

The quantitative risk assessment matrix is shown in Appendix A. The following paragraphs describe the methodology for setting up the matrix. The hazard ID number used in the quantitative analysis is based on the hazard ID numbers assigned in the qualitative analysis. A complete hazard listing is shown in Appendix E for reference purposes.

The quantitative analysis used a "Chance Method" Monte Carlo methodology with 5000 trials[5]. The analysis used the Crystal Ball software package, which operates within the Microsoft Excel platform. Crystal Ball is commonly used in engineering, financial and other disciplines for risk analysis. A similar software package called "@Risk" is in regular use by OPG for this purpose[6].

Cost and schedule were run simultaneously:

- for each trial an event occurred or did not occur, in proportion to its probability
- if the event occurred during the trial, both its cost and its schedule delays were determined randomly from the log normal distribution describing them. The cost amount was added to the total cost, and the delay amount was added to the total delay.

[5] Several of model runs were made using 20,000 trials. This resulted in smoother curves, but did not significantly affect the magnitude of the output.

[6] The Risk Assessment deliverables to OPG include copies of all project files suitable for operation using @Risk.

### 2.2.1 Model Treatment of Project Risk Factors

For most of the hazards, impact of the various risk factors was estimated using the probability of the hazard occurring, and its cost or schedule distribution, with the resulting amount being added to the total cost/delay in each trial where it occurred. For example, risk factor 50202 (late availability of TBM due to manufacturing problems) was modelled as follows:

- Its probability of 0.2 was modelled in Crystal Ball using the "yes/no" distribution, which returns a value of "1" 20% of the time, or in 1000 of the 5000 trials, as shown in Figure 2.1. For the remaining 4000 trials (80% of the time), the probability distribution will return a value of zero.
- It has no cost impact to OPG. Its schedule impact is a log normal distribution with a mean of 15 weeks, as shown in Figure 2.2.

**Figure 2.1: Probability of "Late Availability of TBM due to Manufacturing problems"**

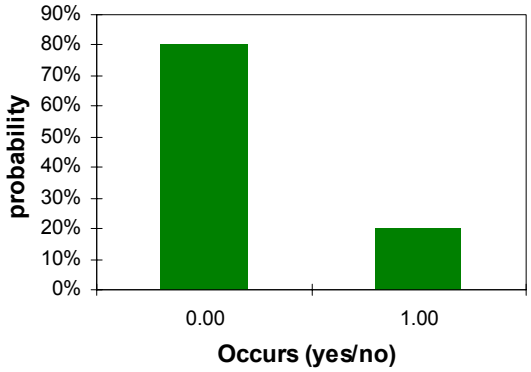
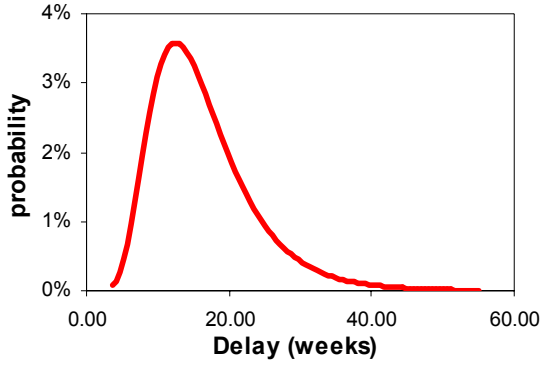



**Figure 2.2: Delay Distribution for "Late Availability of TBM due to Manufacturing Problems"**




- The resulting "bottom line" schedule impact of this risk factor to the project is shown in Figure 2.3. As expected, the schedule impact of this risk factor by itself is equal to zero approximately 80% of the time, and the remaining 20% is distributed approximately log normal with a mean of 15 weeks.

**Figure 2.3: Impact of "Late Availability of TBM due to Manufacturing" on overall Project Schedule**

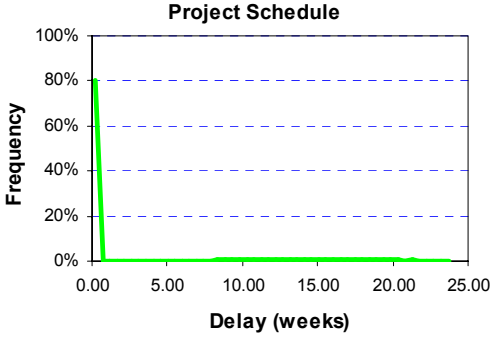
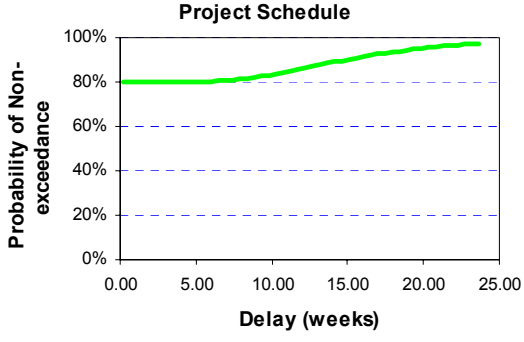



**Figure 2.4: Impact of "Late Availability of TBM due to Manufacturing" on overall Project Schedule**



Because of the difficulty of reading the combined impact of the probability and cost distribution, as shown in Figure 2.3, the cumulative version of the chart, shown in Figure 2.4, is often preferred to express the combined distribution. Expressing the results in this way, as a "probability of non-exceedance", it is possible to see that the expected impact of this variable on the project schedule is zero 80% of the time, and that the 95$^{th}$ percentile occurs at approximately 20 weeks. In other words, there is a 95% probability that the delay due to this risk factor will be 20 weeks or less. Where appropriate, probability distribution results in this report are shown in both formats.

### 2.2.2 Model Treatment of Risk Factors Affecting Project Cost

Most of the cost risk factors in this analysis were assessed in the manner described in Section 2.2.1, above. Contributions to project cost that were calculated in a different manner included:

- The actual bid price will be known within weeks of the completion of this risk analysis. A risk-based estimate of bid price was therefore not included. Base bid price was given as a minimum of $450 million. This value was entered into the matrix as a log normal distribution with mean of $520 million and 95$^{th}$ percentile of $600 million, which has a 5$^{th}$ percentile value of $450 million. A probability of 1 was associated with this cost.
- Estimated liquidated damages due to contractor delay was estimated by multiplying the calculated contractor-caused delay (see Section 2.2.2) by the daily liquidated damages amount from the Proposal Invitation ($200,000). No probability was associated with this amount, as it was determined from the probabilities and costs of the various items contributing to it.
- Risk factor 40802 (liquidated damages dispute over delay in project completion). This amount was calculated from the liquidated damages amount described above. The amount of the dispute was taken as a proportion of the total liquidated damages amount, the proportion being taken as a triangular distribution with a mean of 30%, a maximum of 90% and a minimum of 0%. This risk was given the same probability (10%) as risk factor 40801 (liquidated damages dispute over rates).
- Risk factor 41701 (Economic losses due to Delay in Project Startup (Uninsurable Delay)) reflects the economic losses due to various potential delays in construction, i.e. the economic losses for each day the new tunnel will not be in operation. The risk factor is discussed in detail in Section 3.1.3.
- Risk factor 41702 (additional costs due to project delay). This amount refers to the costs to OPG associated with extending the project in the absence of liquidated damages. It was estimated as 10% of the economic losses amount, above.

### 2.2.3 Model Treatment of Risk Factors Affecting Project Schedule

The overall project schedule is shown in Table 2.4. Each risk factor in Appendix A was assigned to one or more project work items, and its undelayed start and end dates were found from Table 2.4. The matrix in Appendix A was then sorted by start date to allow for a

generally chronological order to the risk factors in the matrix. The delay associated with each risk factor was determined from its probability and its delay distribution (in weeks), following the methodology described in Section 2.2.1.

In order to combine the delays, a "float"[7] column was added to the matrix in Appendix A. Where a risk factor has zero float, the risk factor would be on the critical path and its delay would add directly to the total project delay. For projects not on the critical path, the delay was assumed to occur at some random time during the float period. For any given trial, if the remaining float was less than the delay associated with the risk factor, then any excess delay time would be added to the total project delay. This treatment of float was mostly used for risk factors associated with obtaining permits: in many cases the permits would not be required until a particular portion of the construction (such as tunnelling) was to begin, but OPG would be in a position to apply for and receive them well in advance of that time.

**Table 2.4: Project Schedule**

| Work Item | Decription | Duration (weeks) | Starts | Ends | Comes before | with float (weeks) | Comes before | with float (weeks) | Comes before | with float (weeks) | Comes before | with float (weeks) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | RFP for Contractor | 19 | 1-Nov-2004 | 14-Mar-2005 | A2 | 0 | | | | | | |
| A2 | negotiation and Board Approval | 11 | 18-Mar-2005 | 3-Jun-2005 | C2 | 0 | A5 | 0 | D1 | 0 | A3 | 35 |
| A3 | initial inlet works | 104 | 26-Feb-2006 | 24-Feb-2008 | A4 | 43 | A7 | 40 | | | | |
| A4 | completion of inlet works | 27 | 27-Dec-2008 | 4-Jul-2009 | E | 5 | | | | | | |
| A5 | outlet excavation | 47 | 22-Jun-2005 | 17-May-2006 | D2 | 0 | | | | | | |
| A6 | tunnel boring | 120 | 25-Jul-2006 | 11-Nov-2008 | A7 | 0 | A4 | 0 | | | | |
| A7 | remove TBM and cleanup | 22 | 21-Nov-2008 | 24-Apr-2009 | A8 | 0 | | | | | | |
| A8 | final outlet works | 15 | 22-Apr-2009 | 5-Aug-2009 | E | 0 | | | | | | |
| B | enabling work | 28 | 5-Jan-2005 | 20-Jul-2005 | A3 | 35 | A6 | 60 | | | | |
| C1 | permits & approvals - OPG | 15 | 15-Oct-2004 | 28-Jan-2005 | A5 | 25 | A3 | 60 | | | | |
| C2 | permits & approvals - contractor | 18 | 12-Jun-2005 | 16-Oct-2005 | A6 | 40 | | | | | | |
| D1 | deliver TBM | 55 | 12-Jun-2005 | 30-Jun-2006 | D2 | 0 | | | | | | |
| D2 | mobilize TBM | 3 | 1-Jul-2006 | 21-Jul-2006 | A6 | 0 | | | | | | |
| E | commissioning & cleanup | 7 | 12-Aug-2009 | 30-Sep-2009 | | | | | | | | |
| F | project closeout | 26 | 30-Sep-2009 | 31-Mar-2010 | | | | | | | | |
| G | operation | 5148 | 30-Sep-2009 | 8-Sep-2099 | | | | | | | | |

[7] In critical path analysis, float refers to the time between activities not on the critical path. For example, say three tasks are required in order to complete a project. Task A is estimated to take 1 week to perform and Task B is estimated to take 2 weeks. Tasks A and B are independent of each other, but both tasks must be fully completed prior to beginning Task C. In this case, Tasks B and C would be on the critical path, because a delay in the completion of either of them will add directly to the overall time it takes to do the project. Task A could be up to 1 week late without making a difference to the project completion, so there is 1 week of "float" associated with Task A.

This section of the report presents the "base case" Risk Analysis model results from the Monte Carlo analysis using the data and methodologies described in Section 2. The results are presented separately for cost uncertainty, schedule uncertainty and economic loss uncertainty.

All uncertainties in this analysis are measured against OPG's expectations as of the signing of the design-build contract. Uncertainties in the bid price or schedule have not been included, as the bid information will be known in full in the near future.

## 3.1 COST UNCERTAINTY MODEL RESULTS

Table 3.1 shows the distribution of cost as determined in this analysis. The rows containing the 50th, 80th and 95th percentiles have been highlighted for easier reference.

| Percentile (Probability of Non-exceedance) | Risks during Design-build assignment | Economic Losses due to delay in project startup (Uninsurable) | Total Economic Losses | Liquidated Damages payment |
|---|---|---|---|---|
| 0% | - | - | - | (72,800) |
| 5% | - | - | - | (53,429) |
| 10% | 298 | - | - | (41,496) |
| 15% | 843 | - | 2,163 | (32,959) |
| 20% | 1,668 | 3,168 | 3,981 | (27,712) |
| 25% | 2,720 | 4,429 | 5,187 | (23,181) |
| 30% | 4,089 | 5,423 | 6,330 | (18,687) |
| 35% | 5,203 | 6,450 | 7,572 | (13,621) |
| 40% | 6,094 | 7,561 | 9,186 | (9,817) |
| 45% | 6,908 | 9,107 | 11,302 | (7,633) |
| 50% | 7,818 | 11,195 | 13,861 | (6,041) |
| 55% | 8,676 | 13,785 | 16,845 | (4,789) |
| 60% | 9,713 | 17,064 | 20,261 | (3,598) |
| 65% | 11,132 | 21,133 | 23,491 | (2,303) |
| 70% | 12,817 | 24,509 | 27,143 | (956) |
| 75% | 15,875 | 28,044 | 30,759 | - |
| 80% | **19,937** | 32,294 | 34,637 | - |
| 85% | 25,708 | 36,868 | 39,538 | - |
| 90% | 33,249 | 43,020 | 46,452 | - |
| 95% | 43,542 | 55,149 | 58,423 | - |
| 100% | 113,569 | 148,449 | 148,449 | - |

**Table 3.1: Summary of Niagara Tunnel Project Risk Costs ($thousands)**

In reading Table 3.1, the number in the leftmost column is the percentile, or probability of non-exceedance, for the numbers shown in the body of the table. For example, the 80th percentile of "Risks during the design-build assignment" is $19,937,000, meaning that there is an 80% probability that the unplanned costs associated with the design build assignment will be less than

or equal to $19,937,000. This column represents all the unforeseen costs arising from the design-build contract, including additional payments to the contractor as well as to other parties, and is discussed further in subsection 3.1.1.

Note that the numbers in the various columns of Table 3.1 cannot be added directly together for statistical reasons. (i.e. the 95$^{th}$ percentile of Bid Price would not be expected to occur at the same position in the distribution as the 95$^{th}$ percentile of "risk costs during tunnel operation". It is because of this non-additive property that the Monte Carlo method is required to combine independent variables with their probabilities.) For detailed model results, please refer to Appendix B.

Note that the centre column, "Economic losses due to Uninsurable Delay", has a zero value for the percentiles up to and including the 15th. This indicates that the probability that this value will be zero is between 15 and 20%. The adjacent column, "Total economic losses", includes the centre column, plus any economic losses due to failure to collect liquidated damages due to either contractor delay or insufficient flow through the tunnel upon completion.

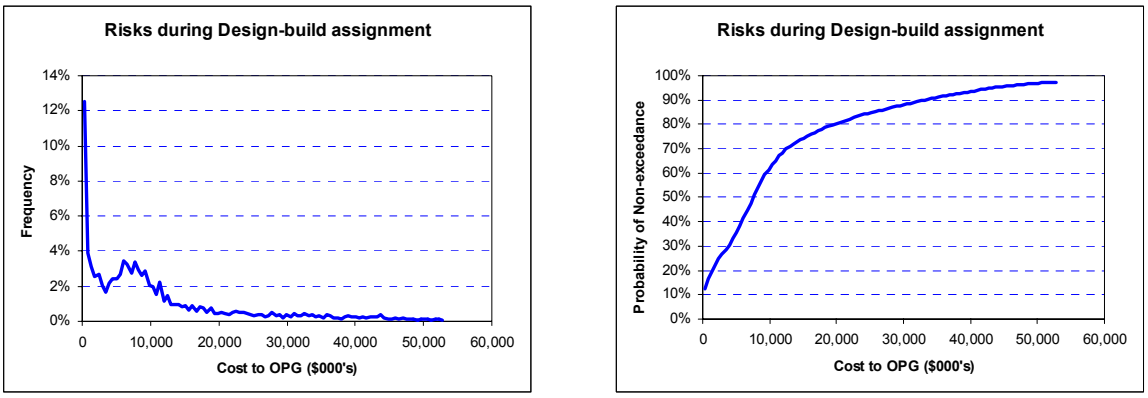
The liquidated damages column contains negative numbers, as these amounts represent payments to OPG rather than costs. The percentiles from 75% and above are zero for this item, indicating that the probability that there will be a liquidated damages payment for contractor schedule delay is between 70 and 75 %.

### 3.1.1 Unforeseen Costs During the Design/Build Assignment

Figure 3.1 represents all the cost risks associated with the design/build contract, over and above the bid price, including:

- Extra costs paid to the design/build contractor
- Additional insurance premiums
- Extra costs to obtain permits
- Additional costs to third parties as a result of unplanned project events (e.g. out-of-pocket costs of dealing with damage to OPG's reputation)

**Figure 3.1: Costs During Design/Build Assignment**

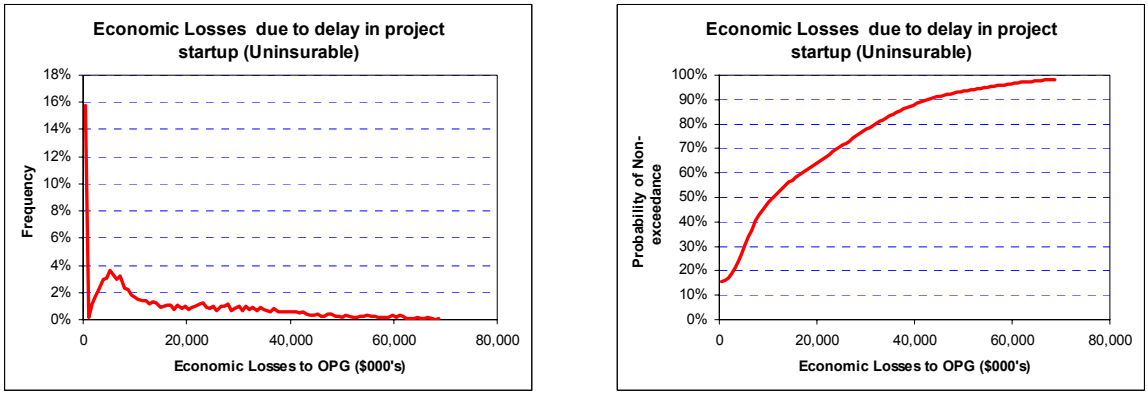


### 3.1.2 Economic losses due to Uninsurable Delay

Delays in the project are, for the most part, not a concern to OPG due to the project's liquidated damages clause, which calls for the contractor to pay OPG $200,000 per day if the project goes past the target contract end date. However, if (a) the delay exceeds 52 weeks such that liquidated damages are capped, or (b) the delay (no matter how short) is caused by OPG, then OPG will not be reimbursed for its loss in energy production capability.

This risk was modelled by explicitly capturing the instances of project delay attributable to the contractor, beyond 52 weeks in any of the Monte Carlo trials, plus all instances of project delay attributable to OPG, and multiplying by $200,000 per day. The resulting distribution is shown in Figure 3.5. Note that the economic losses amount is zero just over 15% of the time, and that the tail of the distribution is long and flat. The 80$^{th}$ and 95$^{th}$ percentiles of this distribution are $32 million and $55 million, respectively.

**Figure 3.2: Economic losses due to Project Delay (Uninsurable loss of Revenue)**




In Appendix A, delays for which the contractor is accountable are identified with a "1" in the right-most column, labelled "Contractor accountable for Delay".

In addition to delay of tunnel operation, there are other possible sources of economic losses to OPG considered in this analysis:

- 40801: liquidated damages dispute over tunnel flow rates
- 40802: liquidated damages dispute over delay in project completion

These risk factors were added to the "Economic losses due to Project Delay", to obtain the "Total Economic losses" distribution shown in Table 3.1. Their contribution was minor compared to the economic losses associated with the delay of tunnel operation.

## 3.2 DELAY UNCERTAINTY MODEL RESULTS

Table 3.2 summarizes the modelled project delay uncertainty.

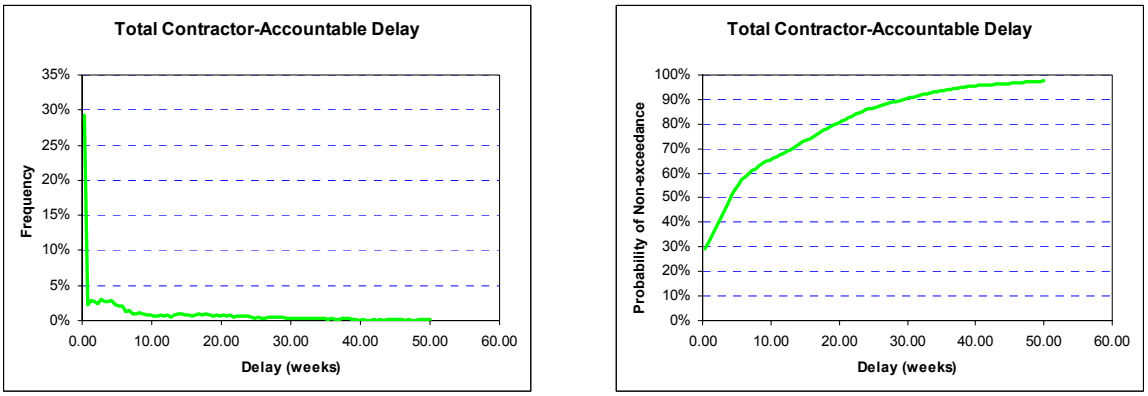
**Table 3.2: Summary of Niagara Tunnel Project Delay Uncertainties (weeks)**

| Percentile (Probability of Non-exceedance) | Total Contractor-Accountable Delay | Total OPG-Accountable Delay during Design-Build contract | Design-Building Project Startup Delay | Total Delay |
|---|---|---|---|---|
| 0% | - | - | - | - |
| 5% | - | - | - | 1.2 |
| 10% | - | - | - | 3.3 |
| 15% | - | - | - | 4.8 |
| 20% | - | 2.1 | - | 6.3 |
| 25% | - | 3.1 | - | 8.0 |
| 30% | 0.7 | 3.8 | - | 9.8 |
| 35% | 1.6 | 4.5 | - | 11.9 |
| 40% | 2.6 | 5.3 | - | 14.7 |
| 45% | 3.4 | 6.3 | - | 17.2 |
| 50% | 4 | 8 | - | 20 |
| 55% | 5.4 | 9.6 | - | 22.3 |
| 60% | 7.0 | 11.9 | - | 25.0 |
| 65% | 9.7 | 14.5 | - | 28.1 |
| 70% | 13.3 | 17.1 | - | 30.8 |
| 75% | 16.5 | 19.7 | - | 34.5 |
| 80% | 20 | 23 | - | 39 |
| 85% | 23.5 | 25.9 | - | 43.9 |
| 90% | 29.6 | 30.2 | - | 51.1 |
| 95% | 38 | 39 | 4 | 65 |
| 100% | 117.3 | 82.2 | 302.6 | 307.4 |

The first delay column in Table 3.1 is for delays caused by the contractor, for which OPG would expect to receive liquidated damages under the design-build contract terms. Risk factors included in this column are identified in Appendix A by a "1" in the column headed "Contractor Accountable for Delay".

The distribution of this delay item is shown in Figure 3.3. Note that the 95$^{th}$ percentile of this distribution is 38.1 weeks, well below the limit for liquidated damages. One would conclude from this distribution that it is unlikely that the cap on liquidated damages will come into play, based on the data provided by the Expert Panel.

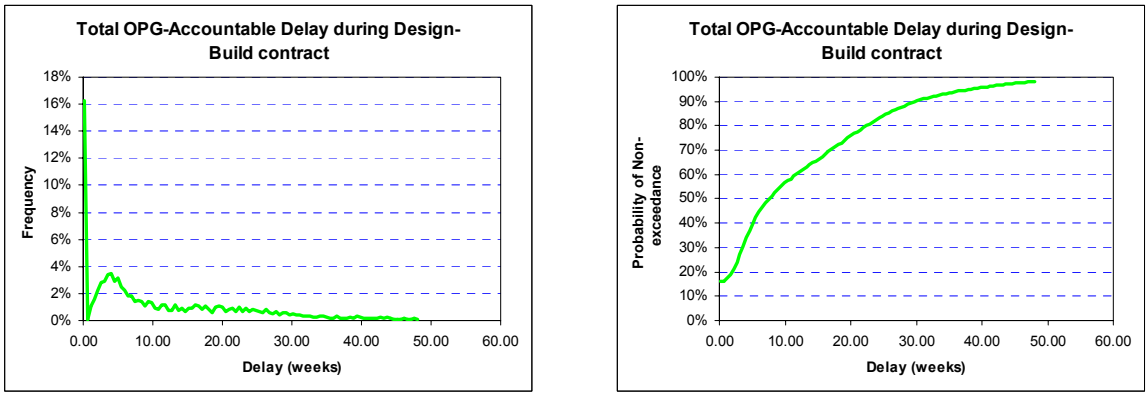
**Figure 3.3: Contractor-Accountable Project Delay**




The liquidated damages distribution, shown in the last column of Table 3.1, was obtained from the distribution shown in Figure 3.3 by multiplying by $200,000 per day and 7 days per week.

The third column of Table 3.2 is for delays during the design-build contract that would not be included in the liquidated damages calculation, so OPG would be accountable for their impacts (whether or not they are within OPG's control.) These are shown in Figure 3.4.

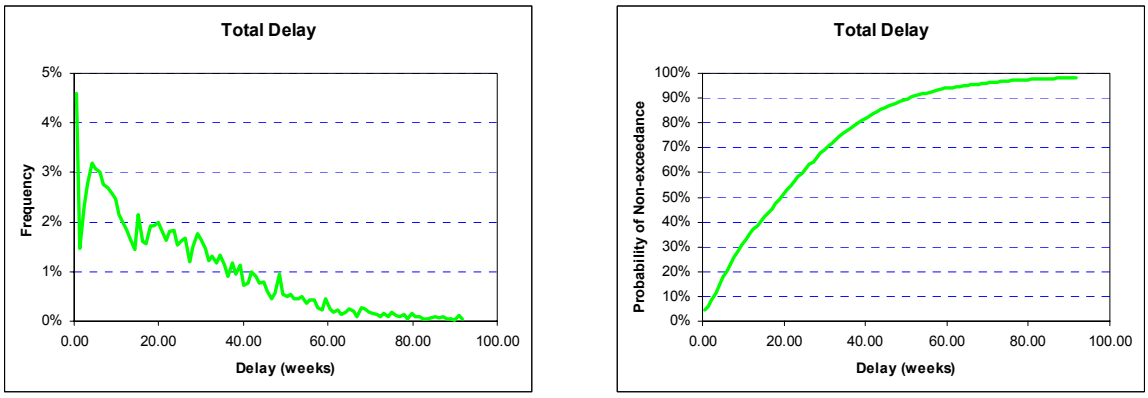
**Figure 3.4: OPG-Accountable Project Delay**



The fourth column of Table 3.2 also contains delays which would not be within the contractor's control, but are not part of the design-build contract period. In effect, these are delays which would have the effect of delaying the award or the start of the project. These delays are not included in Figure 3.4.

The last column of Table 3.2 is the total delay, as shown in Figure 3.5. This amount is the sum of all the other delays of Table 3.2.

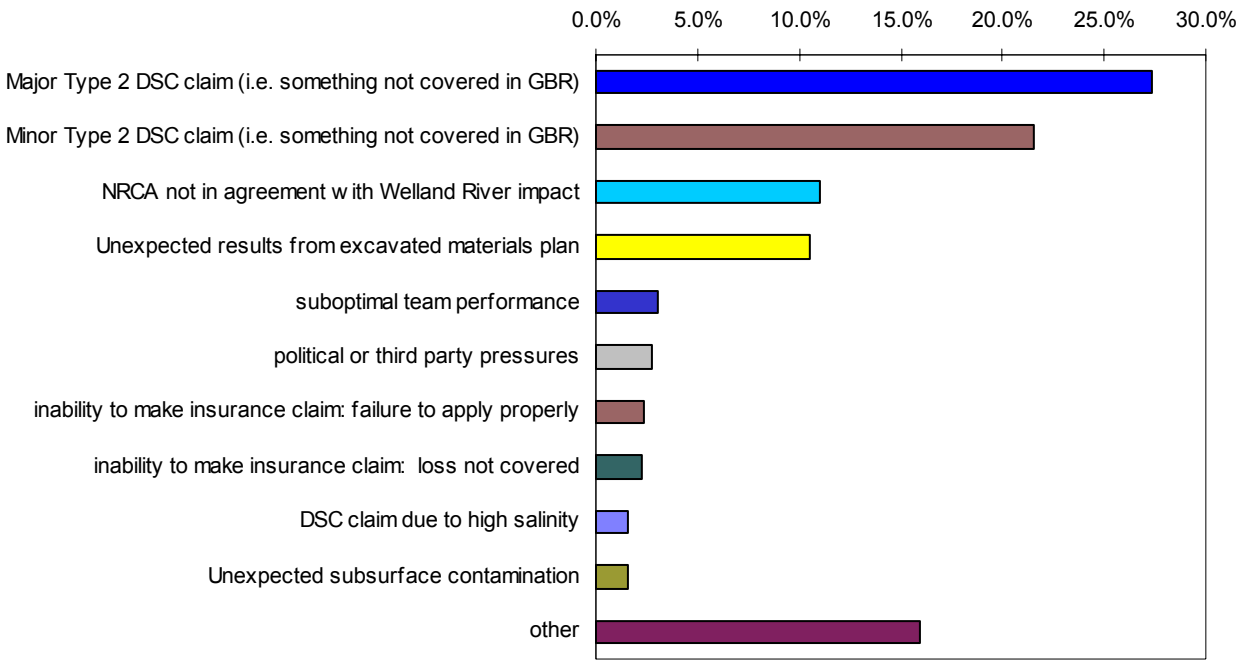
**Figure 3.5: Total Project Delay**



## 3.3 KEY RISK DRIVERS

Figure 3.6 shows the key cost risk drivers identified for the Project, shown as a "tornado diagram" plotting the relative contribution of each variable to the total cost uncertainty. This chart was created using the Sensitivity feature in Crystal Ball. Please refer to Appendix C for more detailed versions of these diagrams.

**Figure 3.6: Top Contributors to Cost Uncertainty during Design-build assignment**



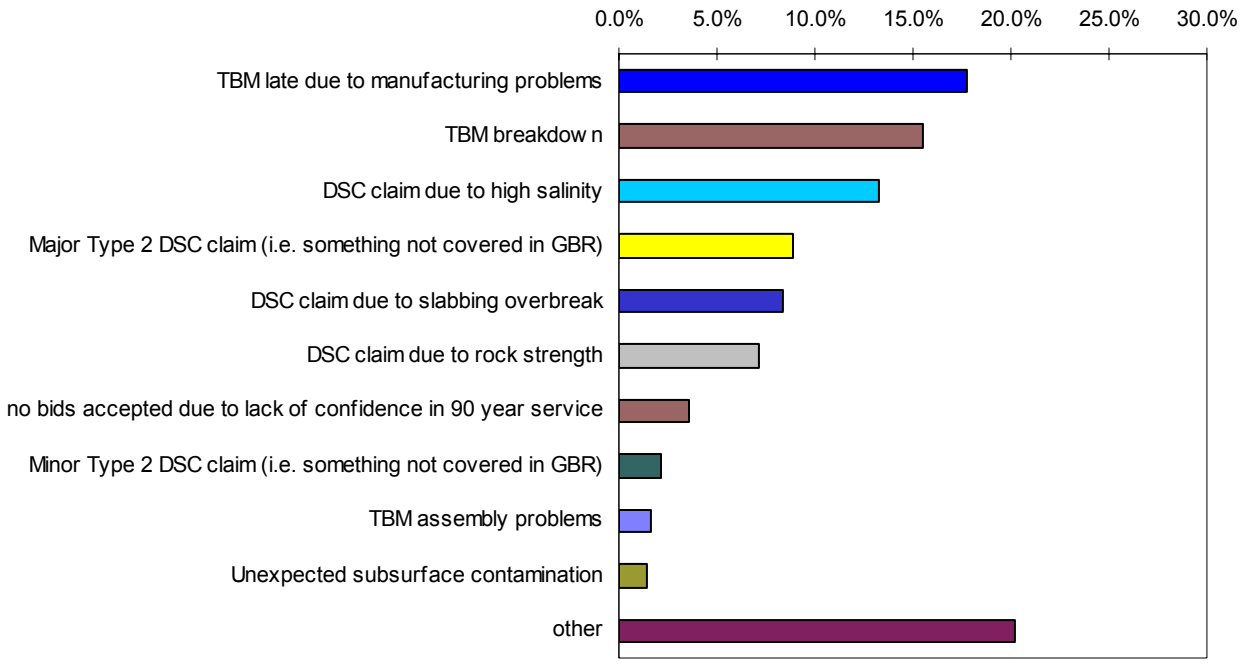

As shown in Figure 3.6, four variables combine to account for approximately 70% of the variability in cost, with none of the remaining risk factors accounting for more than 3%. In particular, costs relating to various types of Differing Site Condition (DSC) claims account for approximately 50% of the variability.

Important costs not considered in this analysis are:

- the bid price, which would already be fixed once the design/build contract begins, and
- operating risks such as swelling in the Queenston shale during tunnel operation. (Only four operating risks were identified during the Expert Panel workshops. These are described in Appendix D, and may be useful in analyzing the contractors' bids, in the event that proposed methodologies are expected to perform differently when construction is finished. However, a complete identification of operating risks is outside the scope of this assignment.)

Figure 3.7 shows the top 10 contributors to project delay.

**Figure 3.7: Top Contributors to Total Delay Uncertainty**




Items in Figure 3.7 include some which would be the contractor's concern, accounting for approximately 35% of the variability:

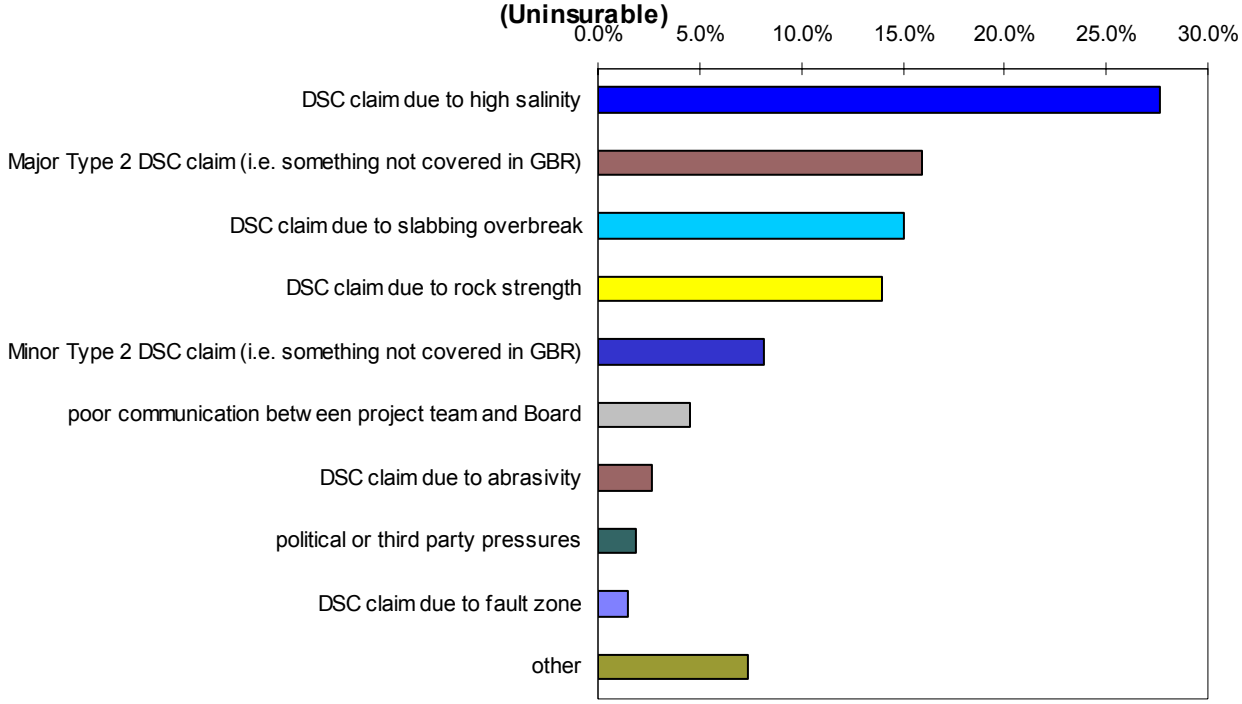
- TBM late due to manufacturing problems
- TBM breakdown
- TBM assembly problems

In addition, items which would therefore be OPG's responsibility add up to approximately 45% of the variability, mostly including items that would result in a DSC claim, including:

- DSC claim due to high salinity
- Major Type 2 DSC claim (i.e. something not covered in GBR)
- DSC claim due to slabbing overbreak
- DSC claim due to rock strength
- Minor Type 2 DSC claim (i.e. something not covered in GBR)
- Unexpected subsurface contamination

Figure 3.8 shows the contribution of the various risk factors to economic losses due to delay in tunnel operation. The significant factors contributing to economic losses are all OPG's responsibility, with seven of these items (accounting for 90% of the variability) relating to DSC claims. As discussed in Section 3.2, it is unlikely that the cap on liquidated damages will be reached for this project, based on the data assembled for this model.

**Figure 3.8: Top Contributors to Economic Losses due to Delay in Tunnel Operation (Uninsurable)**



The examination of "key risk drivers" described in Section 3.3 illustrated that the probabilities used in this analysis were, for the most part, the most significant contributors to overall cost and schedule risk. As a result, this sensitivity analysis was aimed at examining the effect of the uncertainty of probability on the overall model results.

For the sensitivity analysis, the fixed probability of occurrence used in the base analysis was allowed to vary over a range, based on the following guidelines:

- Probabilities less than or equal to 0.01 were allowed to vary randomly between their initial value and a value 10 times higher (e.g. if the probability used in Section 3 was 0.001, the range used in the sensitivity analysis was 0.001 to 0.01);
- Probabilities greater than 0.01 but less than 0.1 were allowed to vary randomly between their initial value and a value 2 times higher;
- Probabilities of 0.1 or higher were not varied for this sensitivity analysis.

The resulting costs area summarized in Table 4.1.

**Table 4.1: Sensitivity Analysis: Summary of Costs ($thousands)**

| Percentile (Probability of Non-exceedance) | Risks during design-build assignment | Lost revenue due to delay in project startup (Uninsurable) | Total Lost revenue | Liquidated Damages payment |
|---|---|---|---|---|
| 0% | - | - | - | (72,800) |
| 5% | - | - | 107 | (61,529) |
| 10% | 1,408 | - | 679 | (48,304) |
| 15% | 4,153 | - | 2,754 | (38,816) |
| 20% | 5,924 | 3,523 | 4,408 | (32,204) |
| 25% | 6,992 | 4,582 | 5,508 | (27,025) |
| 30% | 8,121 | 5,502 | 6,555 | (22,405) |
| 35% | 9,389 | 6,568 | 7,921 | (18,010) |
| 40% | 10,673 | 7,944 | 9,628 | (13,883) |
| 45% | 12,147 | 9,658 | 11,781 | (10,096) |
| 50% | 13,689 | 11,980 | 14,594 | (7,661) |
| 55% | 15,465 | 15,083 | 17,493 | (5,930) |
| 60% | 17,219 | 18,325 | 20,694 | (4,598) |
| 65% | 19,430 | 21,786 | 23,973 | (3,399) |
| 70% | 21,903 | 25,313 | 27,468 | (2,006) |
| 75% | 24,778 | 28,710 | 30,873 | - |
| 80% | 29,042 | 32,921 | 35,247 | - |
| 85% | 34,776 | 38,102 | 39,830 | - |
| 90% | 41,698 | 44,726 | 46,646 | - |
| 95% | 51,952 | 55,800 | 58,634 | - |
| 100% | 126,178 | 149,826 | 149,826 | - |

Figure 4.1 compares the cost risks associated with the base analysis described in Section 3.1, to the corresponding costs from the sensitivity analysis described above. For example, at the 80$^{th}$ percentile, the costs would be increased from approximately $20 million under the base analysis to approximately $28 million under the sensitivity analysis. Clearly the probabilities selected for this model are important to the outcome and to the determination of project contingencies.

**Figure 4.1: Sensitivity Analysis of Cost Risks during Design-Build Assignment**

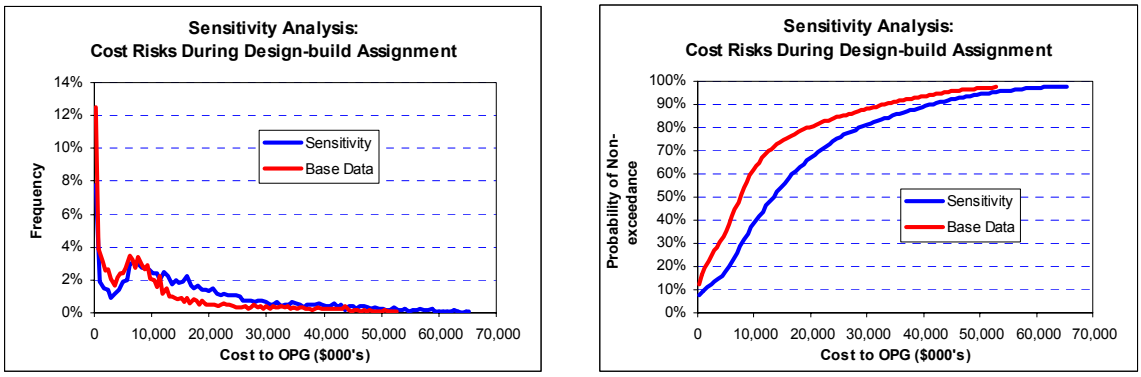



Figure 4.2 shows the sensitivity analysis applied to the economic losses described in Subsection 3.1.2. The sensitivity analysis does not have a significant impact on this distribution, because the most significant contributors to economic losses already had a probability of greater than or equal to 10%, so they were not varied during the sensitivity analysis procedure described above.

**Figure 4.2: Sensitivity Analysis of Economic losses due to Delay in Project Completion**

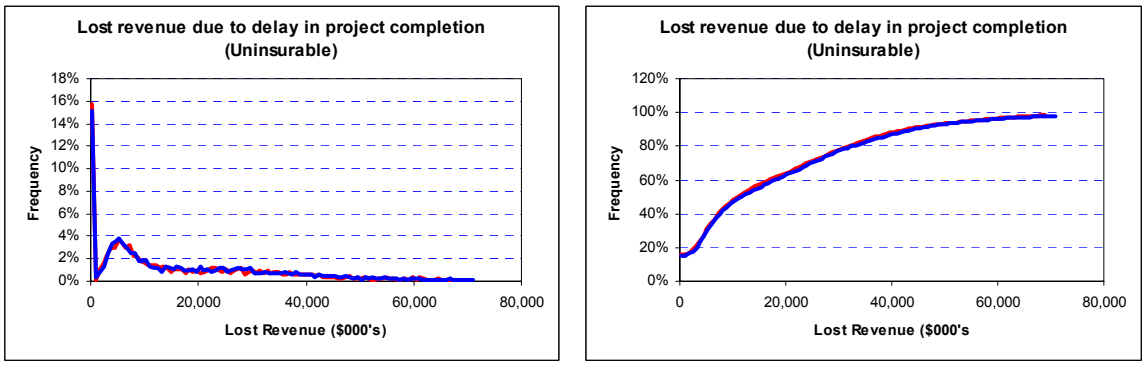
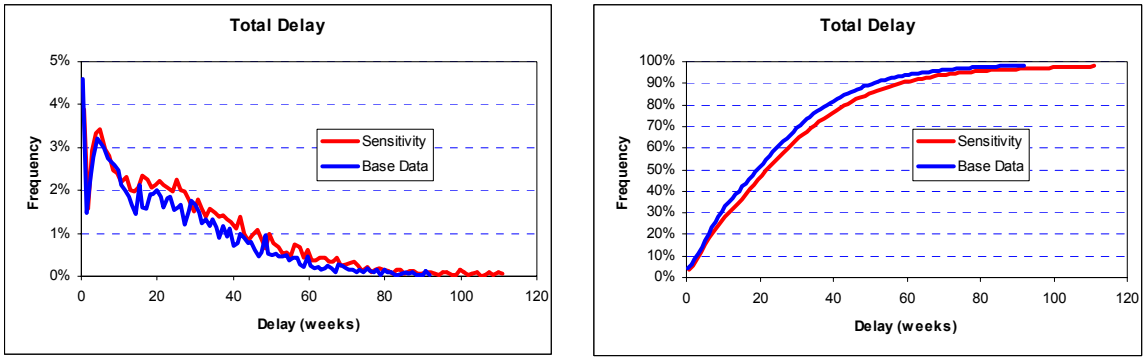


Figure 4.3 shows the sensitivity analysis for total project delay. The probability curve is slightly higher than the base case. For example, the 80th percentile has increased from approximately 38 weeks to approximately 43 weeks.

**Figure 4.3: Sensitivity Analysis of Total Project Delay**



The objectives of this Project Risk Assessment and Analysis have been:

1) to quantify cost, schedule and economic-loss hazards associated with the proposed work,

2) to estimate a likely distribution of the overall values of these costs and delays for planning purposes, and

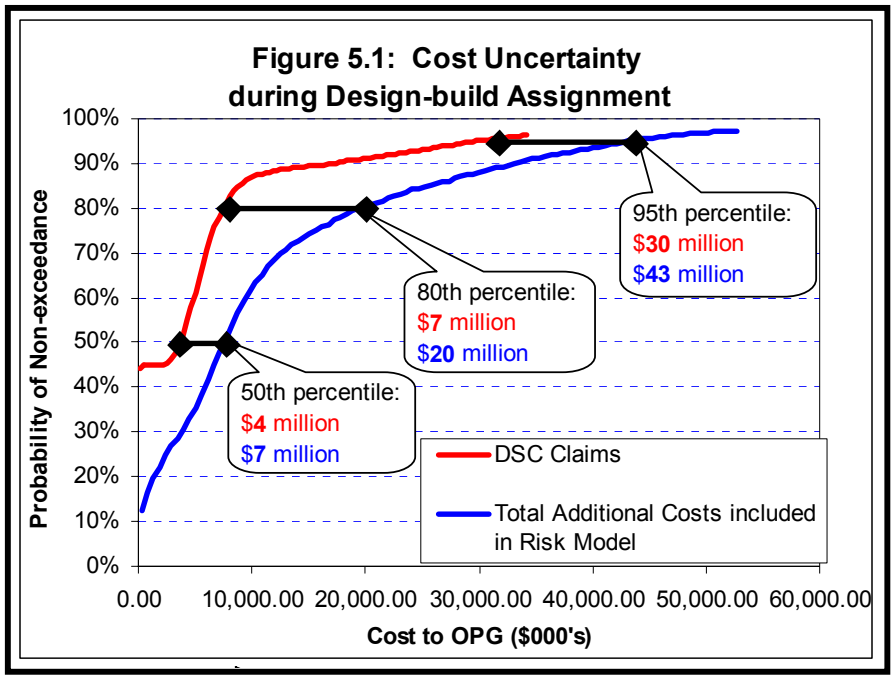
3) to provide, in conjunction with the qualitative analysis report submitted earlier, a framework for future risk assessment and mitigation as the project proceeds

This section discusses the conclusions and recommendations of the analysis described in this report.

## 5.1 CONCLUSIONS

### 5.1.1 Cost Contingency Amount

Figure 5.1 shows the cost uncertainty of the project, with the costs for Differing Site Condition (DSC) claims shown separately in red, and the total cost uncertainty shown in blue. Based on the assessment of individual hazards and their probabilities, as provided by the Project Expert Panel, the cost contingency required for the project would be approximately $20 million at the 80th percentile, meaning that ***unplanned project costs could be expected to be less than or equal to $20 million, with an 80% probability***, which is the level of confidence generally accepted for project contingencies. For DSC claims alone, the estimated amount at the 80th percentile would be $7 million.




As shown in Figure 5.1, an alternative choice would be a $43 million contingency, which would cover unexpected extra costs 95% of the time.

### 5.1.2 Comments on the Magnitude of the Cost Contingency Amount

There are many cost consequences in the project that accrue to the design-build contractor rather than to OPG. As a result, the cost uncertainty is expected to be lower than normal for this assignment, while the total contract price is expected to be higher.

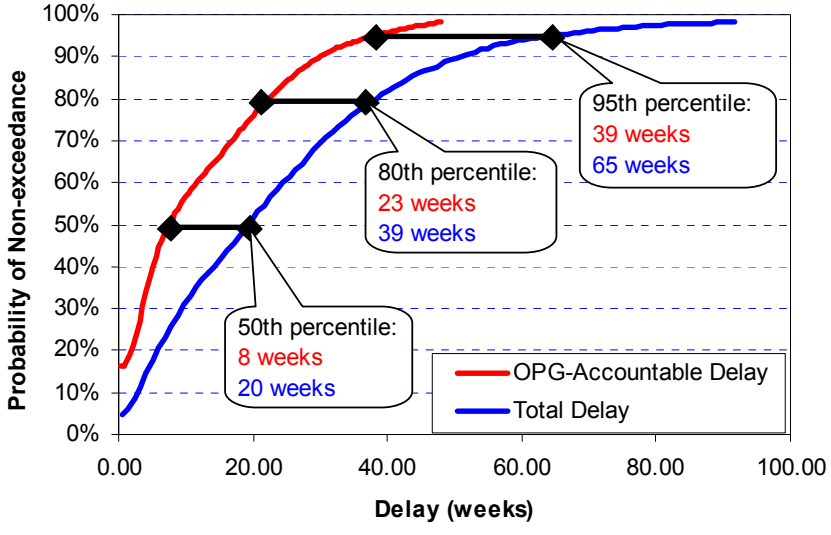
URS would like to caution that some of the key probabilities and consequences described in this analysis are difficult to forecast at this time, in the absence of knowing the makeup of the contractor to be selected for the design-build assignment, and significant elements of the technical approach to the project. For example: What type of TBM will be selected? Where will the TBM be manufactured? What tunnel lining system will be selected? Where will the tunnel lining be manufactured? In addition to these technical questions, elements of human performance are difficult to predict, particularly in a project as complex as this one.

The unusually high level of responsibility for the contractor under the proposed contract could lead to a higher-than-normal probability that the contractor may default; however this eventuality would be covered by a performance bond and is therefore not included in the contingency amount. The probability of not collecting on the performance bond was considered to be too low (1/1000) to include in the quantitative analysis. The Expert Panel identified that the shortlisted contractors were all well established and of excellent reputation, and therefore highly unlikely to be driven into bankruptcy by this project. That being the case, the selected contractor can be expected to apply considerable resources and sophistication to any claims under the contract, including finding ways to place onto OPG some of the liabilities attributed to the contractor in the contract documents.

### 5.1.3 Delay Estimate

Figure 5.2 shows the estimated delay amounts at the 50th, 80th and 95th percentiles. The two curves show the delay for which OPG would be held accountable (i.e. for which the contractor would not be liable for liquidated damages), and the total estimated delay amount during the design-build contract (i.e. not including delays relating to getting the design-build contract awarded and under way).

**Figure 5.2: Total Delay During the Design-Build Contract**

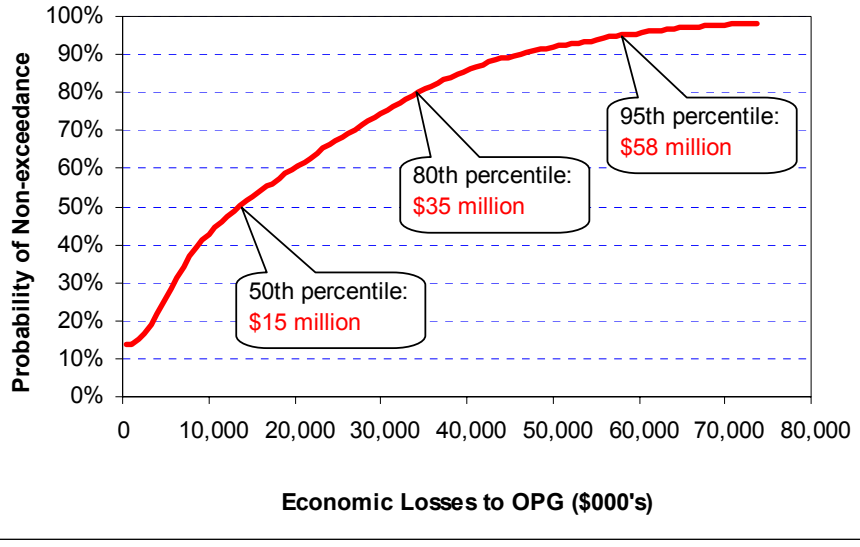



Note that the delays in this estimate would be over and above any delays that the contractor may already have built into its bid.

### 5.1.4 Estimate of Economic Losses

The estimated economic losses for the project, due to either delays in opening the new tunnel, or disputes in contractor payments to OPG, are shown in Figure 5.3. This distribution was derived using primarily the delays from Figure 5.2, and the liquidated damages amount of $200,000 per day, included in the Proposal Invitation in the event that the contract is not completed within the expected time horizon. The economic losses are clearly a larger dollar amount than the contingencies shown in Figure 5.1 (compare $35 million in economic losses to $20 million in costs, at the 80th percentile).

**Figure 5.3: Economic Losses**




## 5.2 RECOMMENDATIONS

The Niagara Tunnel project management team has been thoroughly and continually involved in the process and decisions that led to these estimates. It is important that the project management team consider the items which contribute to this number. The actual project contingency amount to be included in the project budget will likely be higher than this estimate, to include items which are reasonably expected to occur (with greater than 50% probability) and which were, as a result, not included in this analysis.

The risk analysis matrix prepared under this assignment contains information known by the project team and provided to URS as of the bid period. Many of the unknowns identified during this assessment will become known once the prospective design/build teams have submitted their bids, and more again when the bids have been evaluated. The risk assessment should be updated at that time, and continually throughout the design/build period, in order to understand the changing risks to cost and schedule. Where hazards are retired, it should be noted in the risk register the reason for retiring the hazard, an indication of whether it occurred or not and, if so, its magnitude. This process can be done in parallel with updates to the project qualitative risk register.

# Appendix A:

# Niagara Tunnel Project Quantitative Risk Assessment Matrix

| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence | Schedule Position | Start date | Undelayed End Date | Probability | 5th percentile cost | mean cost | 95th percentile cost | 5th percentile schedule | mean schedule | 95th percentile schedule | float (weeks) | Contractor Accountable for Delay | Omitted from Project Contingencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10202 | Permits not obtained due to OPG delay | Required Permits not obtained | OPG did not submit in time | Schedule Delay | C1 | 15-Oct-04 | 28-Jan-05 | 0.01 | 500 | 1,400 | 3,000 | 7.4 | 15 | 30 | 25 | | |
| 40101 | High Insurance Premiums due to inadequate Risk Management process | Insurance Premiums prohibitively high | Inadequate Risk Management process in place (i.e. not acceptable to insurer.) | Cost impact to project budget | B | 05-Jan-05 | 20-Jul-05 | 0.001 | 10,000 | 25,000 | 50,000 | | | | | | |
| 40102 | High Insurance Premiums due to market conditions | Insurance Premiums prohibitively high | Insurance market conditions / capacity | Cost impact to project budget | B | 05-Jan-05 | 20-Jul-05 | 0.01 | 3,000 | 5,800 | 10,000 | | | | | | |
| | base bid price | normal variability in bid price | unknown bid price | cost impact | A2 | 18-Mar-05 | 03-Jun-05 | 1 | 450,000 | 520,000 | 600,000 | | | | | | 1 |
| 61104 | no bids accepted due to lack of confidence in 90 year service | project design criteria not met | no contractor submits conforming bid (90 year life span) | | A2 | 18-Mar-05 | 03-Jun-05 | 0.01 | 75,000 | 150,000 | 300,000 | 50 | 104 | 200 | | | 1 |
| 41401 | 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 | A2 | 18-Mar-05 | 03-Jun-05 | 0.1 | 500 | 1,400 | 3,000 | | | | | | |
| 30102 | no conforming contractors, resolved through negotiations | Unprogrammed extension to procurement Bid phase | All contractors fail to comply with Contract requirements for detailed design and/or construction | project delay caused by (successful) negotiations | A2 | 18-Mar-05 | 03-Jun-05 | 0.05 | | | | 2.3 | 4 | 7 | | | 1 |
| 30103 | no conforming contractors, leading to re-bid | Unprogrammed extension to procurement Bid phase | All contractors fail to comply with Contract requirements for detailed design and/or construction | unsuccessful negotiations leading to a requirement for overhaul of RFP documents | A2 | 18-Mar-05 | 03-Jun-05 | 0.001 | | | | 27 | 52 | 100 | | | 1 |
| 30202 | GBR incomplete causing high contractor contingencies | Contract documents insufficiently detailed and imprecise | Deficiencies in GBR (i.e. something not covered in GBR) | Increased bid prices (contingency) | A2 | 18-Mar-05 | 03-Jun-05 | 0.01 | 10,000 | 25,000 | 50,000 | 7.4 | 15 | 30 | | | 1 |
| 10109 | 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 | C2 | 12-Jun-05 | 16-Oct-05 | 0.1 | 4,000 | 10,000 | 25,000 | | | | | | |
| 10103 | MOE not in agreement with proposed work | Not meeting terms and conditions of EA Approval | MOE not in agreement with proposed work | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | | | | 7.4 | 15 | 30 | 40 | 1 | |
| 10104 | MNR not in agreement with proposed work | Not meeting terms and conditions of EA Approval | MNR not in agreement with proposed work | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | | | | 10 | 20 | 50 | 40 | 1 | |
| 10105 | NRCA not in agreement with Welland River impact | Not meeting terms and conditions of EA Approval | Conservation authority not in agreement with the impact on the Welland River | Unexpected additional costs to avoid project delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.1 | 4,000 | 10,000 | 25,000 | | | | | | |
| 10106 | Other 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 | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | 500 | 1,400 | 3,000 | 1 | 2 | 4 | 40 | 1 | |
| 10107 | Unexpected results from Groundwater study | Not meeting terms and conditions of EA Approval | Unexpected results from Groundwater study | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.1 | | | | 7.4 | 15 | 30 | 40 | 1 | |
| 10110 | Unforeseen new requirement added by MOE | Not meeting terms and conditions of EA Approval | Unforeseen new requirement added by MOE | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | 3,000 | 5,800 | 10,000 | 2.3 | 4 | 7 | 40 | | |
| 10111 | Other regulator adds new requirements | Not meeting terms and conditions of EA Approval | Other regulator adds new requirements | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | 3,000 | 5,800 | 10,000 | 7.4 | 15 | 30 | 40 | | |
| 10201 | Permits not obtained due to contractor delay | Required Permits not obtained | Contractor did not submit in time | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | 500 | 1,400 | 3,000 | 7.4 | 15 | 30 | 40 | 1 | |
| 10203 | Late response from third party to regulator | Required Permits not obtained | Late response from third party to regulator | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | | | | 2.3 | 4 | 7 | 40 | 1 | |
| 10204 | negative decision by regulatory authority | Required Permits not obtained | Failure to issue permit by regulatory authority (I.e. a negative decision) | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.001 | | | | 7.4 | 15 | 30 | 40 | 1 | |
| 10205 | Additional study required by regulatory authority | Required Permits not obtained | Additional study required by regulatory authority | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | 50 | 200 | 500 | 7.4 | 15 | 30 | 40 | 1 | |
| 10206 | multiple re-submissions required by regulatory authority | Required Permits not obtained | multiple re-submissions required by regulatory authority | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | | | | 7.4 | 15 | 30 | 40 | 1 | |
| 10207 | required permit not identified | Required Permits not obtained | required permit not identified | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.001 | | | | 7.4 | 15 | 30 | 40 | 1 | |
| 10208 | permit conditions not acceptable to OPG | Required Permits not obtained | permit conditions not acceptable to OPG | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.001 | | | | 7.4 | 15 | 30 | 40 | | |
| 11001 | Fisheries Act terms not met | project does not meet terms and conditions of the Fisheries Act authorizations | | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | | | | 2.3 | 4 | 7 | 40 | 1 | |
| 11101 | NPCA does not agree with Fish compensation plan | inability to obtain approval on Fish Habitat Compensation Plan | NPCA does not agree with plan | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | | | | 2.3 | 4 | 7 | 40 | 1 | |
| 11102 | residents do not agree with Fish Compensation plan | inability to obtain approval on Fish Habitat Compensation Plan | property owners/residents do not agree with plan | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.1 | | | | 2.3 | 4 | 7 | 40 | 1 | |

| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence | Schedule Position | Start date | Undelayed End Date | Probability | 5th percentile cost | mean cost | 95th percentile cost | 5th percentile schedule | mean schedule | 95th percentile schedule | float (weeks) | Contractor Accountable for Delay | Omitted from Project Contingencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41601 | 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 | C2 | 12-Jun-05 | 16-Oct-05 | 0.002 | 1,800 | 3,000 | 5,000 | | | | | | |
| 10102 | EA approval terms not met due to OPG delay | Not meeting terms and conditions of EA Approval | OPG did not submit/ resubmit in time | Schedule Delay | C2 | 12-Jun-05 | 16-Oct-05 | 0.01 | | | | 0.5 | 1 | 2 | | 1 | |
| 10701 | Treaty on water usage is dissolved and entitlement changes | Treaty on water usage is dissolved and entitlement changes | International issue between Canada and US | Project terminated | C2 | 12-Jun-05 | 16-Oct-05 | 0.001 | | | | 50 | 104 | 200 | | | 1 |
| 10901 | Withdrawal of project approval by the Government in power | Withdrawal of project approval by the Government in power | Change of government with 2007 Provincial election leading to change in energy policy | Project halted or terminated | C2 | 12-Jun-05 | 16-Oct-05 | 0.001 | | | | 50 | 104 | 200 | | | 1 |
| 50201 | TBM late due to late order by Contractor | Late availability of TBM | Late Submittal/ ordering | Schedule Delay | D1 | 12-Jun-05 | 30-Jun-06 | 0.01 | | | | 7.4 | 15 | 30 | | 1 | |
| 50202 | TBM late due to manufacturing problems | Late availability of TBM | Manufacturing problems | Schedule Delay | D1 | 12-Jun-05 | 30-Jun-06 | 0.2 | | | | 7.4 | 15 | 30 | | 1 | |
| 50203 | TBM late due to shipping delays | Late availability of TBM | Shipping delays (due to weather) | Schedule Delay | D1 | 12-Jun-05 | 30-Jun-06 | 0.01 | | | | 2.3 | 4 | 7 | | 1 | |
| 60801 | loss of cross-sectional area in canal due to blasting | loss of cross-sectional area in canal | construction debris - primarily due to blasting | loss of revenue and schedule delay for project completion carrying out remediation | A5 | 22-Jun-05 | 17-May-06 | 0.1 | 500 | 1,000 | 2,000 | | | | | | |
| 70301 | Tunnel Dewatering activities significantly alter groundwater | Tunnel Dewatering activities significantly alter groundwater levels or flow patterns impacting area users | Effects of dewatering activities on groundwater flow regime under estimated | Mitigation costs, reputation, regulatory enforcement | A5 - A7 | 22-Jun-05 | 24-Apr-09 | 0.01 | 500 | 1,400 | 3,000 | | | | | | |
| 70401 | 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 | A5 - A7 | 22-Jun-05 | 24-Apr-09 | 0.001 | 500 | 1,400 | 3,000 | | | | | | |
| 70201 | 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 | A5 - A7 | 22-Jun-05 | 24-Apr-09 | 0.01 | 500 | 1,400 | 3,000 | 1 | 2 | 4 | | 1 | |
| 70601 | Dewatering shaft and/or tunnel create route for cross-contamination | Dewatering shaft and/or tunnel create route for cross-contamination | Inadequate design and/or construction | Mitigation costs, third party claims | A5 - A7 | 22-Jun-05 | 24-Apr-09 | 0.001 | 500 | 1,400 | 3,000 | 1 | 2 | 4 | | 1 | |
| 80401 | 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 | A5 - A7 | 22-Jun-05 | 24-Apr-09 | 0.001 | | | | 7.4 | 15 | 30 | | 1 | |
| 40201 | inability to make insurance claim: loss not covered | inability to make insurance claim | insurance does not cover claim | Cost impact to project budget | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 10,000 | 25,000 | 50,000 | | | | | | |
| 40202 | inability to make insurance claim: failure to apply properly | inability to make insurance claim | failure to apply properly | Cost impact to project budget | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 10,000 | 25,000 | 50,000 | | | | | | |
| 41501 | Dispute Review Board interprets Agreement incorrectly | Dispute Review Board interprets Agreement incorrectly | | financial, schedule delays | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 3,000 | 5,800 | 10,000 | | | | | | |
| 41701 | Lost revenue due to delay in project startup (Uninsurable) | uninsurable delay | delay in contract completion leading to lost revenue (not insurable) | uncompensated loss of revenue | A3 - A8 | 26-Feb-06 | 05-Aug-09 | | | calculated from project delays | | | | | | | 1 |
| 20101 | Failure to address Community Issues, causing financial impact on communities | Failure to address Community Issues | Financial impacts on municipalities from project | demands / possible lawsuits for financial compensation to municipalities | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.001 | 3,000 | 5,800 | 10,000 | 0.5 | 1 | 2 | | 1 | |
| 30201 | Deficiencies in QC by Owner and Engineer | Contract documents insufficiently detailed and imprecise | Deficiencies in QC by Owner and Engineer | Inadequate communication of design requirements to Contractor | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.001 | 3,000 | 5,800 | 10,000 | 7.4 | 15 | 30 | | 1 | |
| 30203 | Major 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) | Major Type 2 DSC claims | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.1 | 10,000 | 25,000 | 50,000 | 7.4 | 15 | 30 | | | |
| 30204 | 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 | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.5 | 3,000 | 5,800 | 10,000 | 2.3 | 4 | 7 | | | |
| 30205 | inadequate and/or inappropriate design criteria | Contract documents insufficiently detailed and imprecise | Deficiencies in concept Design | inadequate and/or inappropriate design criteria requiring issuance of multiple change orders | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 3,000 | 5,800 | 10,000 | 1 | 2 | 4 | | | |

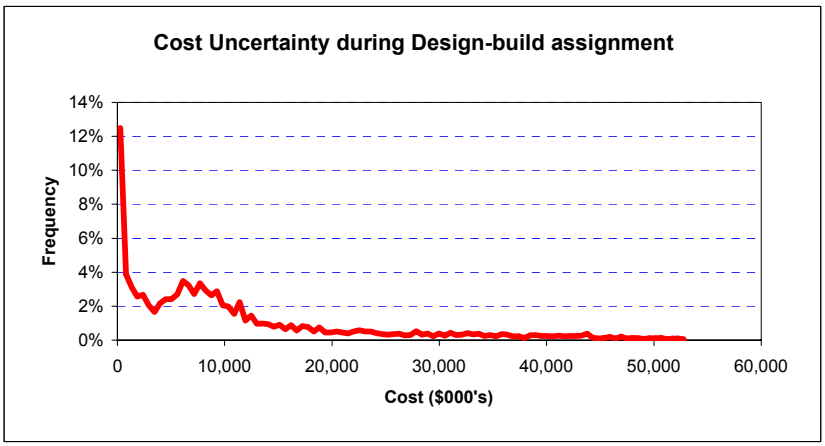
| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence | Schedule Position | Start date | Undelayed End Date | Probability | 5th percentile cost | mean cost | 95th percentile cost | 5th percentile schedule | mean schedule | 95th percentile schedule | float (weeks) | Contractor Accountable for Delay | Omitted from Project Contingencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30601 | suboptimal team performance | performance of project team is suboptimal | various | cost and schedule overruns | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 10,000 | 25,000 | 50,000 | 7.4 | 15 | 30 | | 1 | |
| 30606 | poor communication between project team and Board | performance of project team is suboptimal | poor communication between project team and Board | cost and schedule overruns | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.2 | | | | 2.3 | 4 | 7 | | | |
| 30701 | inadequate project processes and procedures | inadequate project processes and procedures | various | cost, schedule and quality | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.13 | | | | 2.3 | 4 | 7 | | 1 | |
| 30901 | political or third party pressures | external pressure on project configuration | political or third party pressures | cost, schedule and quality | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 10,000 | 25,000 | 50,000 | 7.4 | 15 | 30 | | | |
| 40603 | 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 | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.001 | 3,000 | 5,800 | 10,000 | 2.3 | 4 | 7 | | | |
| 40607 | 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 | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 5,000 | 10,000 | 20,000 | | | | | | |
| 50301 | regional power outage | Interrupted power supply for site works | regional power outage | Lack of electrical power for lighting, ventilation, drainage pumps and TBM | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 500 | 1,400 | 3,000 | 0.5 | 1 | 2 | | 1 | |
| 50302 | site power outage | Interrupted power supply for site works | site-based power outage | Lack of electrical power for lighting, ventilation, drainage pumps and TBM | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 50 | 200 | 500 | 0.5 | 1 | 2 | | 1 | |
| 50501 | adverse weather | Work impeded by adverse weather conditions | Storms, extreme temperature, winter weather | Schedule delay, primarily at inlet and outlet works | A3 - A8 | 26-Feb-06 | 05-Aug-09 | 0.2 | | | | 1 | 2 | 4 | | 1 | |
| 61601 | 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 | A3-A8 | 26-Feb-06 | 05-Aug-09 | 0.001 | | | | 7.4 | 15 | 30 | | 1 | |
| 61101 | contractor non-compliance | project design criteria not met | contractor non-compliance | | A3-A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 500 | 1,400 | 3,000 | | | | | | |
| 61102 | tunnel lining failure | project design criteria not met | failure of tunnel lining system | | A3-A8 | 26-Feb-06 | 05-Aug-09 | 0.01 | 500 | 1,400 | 3,000 | | | | | | |
| 50204 | TBM assembly problems | Late availability of TBM | Assembly and commissioning problems | schedule delay | D2 | 01-Jul-06 | 21-Jul-06 | 0.2 | | | | 2.3 | 4 | 7 | | 1 | |
| 50402 | 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 | A6 | 25-Jul-06 | 11-Nov-08 | 0.01 | | | | 15 | 26 | 40 | | 1 | |
| 50403 | Inadequate QC at segment Manufacturer | Segments not available in timely manner | Inadequate QC at Manufacturer | Schedule delay, possibly leading to stopping forward progress of TBM | A6 | 25-Jul-06 | 11-Nov-08 | 0.02 | | | | 2.3 | 4 | 7 | | 1 | |
| 60103 | inundation of tunnel outlet work, including inundation of tunnel excavation and TBM | Flooding of the works during construction | breach at outlet works | inundation of tunnel outlet work, including mucking operation and active mining tunnel portal, including inundation of tunnel excavation and TBM | A6 - A8 | 25-Jul-06 | 05-Aug-09 | 0.001 | 50 | 200 | 500 | 7.4 | 15 | 30 | | 1 | |
| 61801 | DSC claim due to rock strength | Encountering Ground Conditions more adverse than advertised in Contract | Rock Strength higher than anticipated | Submittal of DSC claim - legal proceedings against owner; | A6 | 25-Jul-06 | 11-Nov-08 | 0.1 | | | | 7.4 | 15 | 30 | | | |
| 61802 | DSC claim due to abrasivity | Encountering Ground Conditions more adverse than advertised in Contract | Rock abrasivity higher than anticipated | Submittal of DSC claim - legal proceedings against owner; | A6 | 25-Jul-06 | 11-Nov-08 | 0.1 | | | | 2.3 | 4 | 7 | | | |
| 61803 | DSC claim due to high inflows - fracturing | Encountering Ground Conditions more adverse than advertised in Contract | High inflows at tunnel heading above Queenston Shale (e.g. intense fracturing in bedrock) | Submittal of DSC claim - legal proceedings against owner; | A6 | 25-Jul-06 | 11-Nov-08 | 0.2 | 3,000 | 5,800 | 10,000 | 1 | 2 | 4 | | | |
| 61804 | DSC claim due to fault zone | Encountering Ground Conditions more adverse than advertised in Contract | Encountering an unexpected fault zone | Submittal of DSC claim - legal proceedings against owner; | A6 | 25-Jul-06 | 11-Nov-08 | 0.01 | | | | 7.4 | 15 | 30 | | | |
| 61805 | DSC claim due to BTEX | 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; | A6 | 25-Jul-06 | 11-Nov-08 | 0.01 | | | | 1 | 2 | 4 | | | |
| 61806 | DSC claim due to slabbing overbreak | Encountering Ground Conditions more adverse than advertised in Contract | slabbing overbreak is higher than expected | Submittal of DSC claim - legal proceedings against owner; | A6 | 25-Jul-06 | 11-Nov-08 | 0.1 | 3,000 | 5,800 | 10,000 | 7.4 | 15 | 30 | | | |

| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence | Schedule Position | Start date | Undelayed End Date | Probability | 5th percentile cost | mean cost | 95th percentile cost | 5th percentile schedule | mean schedule | 95th percentile schedule | float (weeks) | Contractor Accountable for Delay | Omitted from Project Contingencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 61807 | 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 | A6 | 25-Jul-06 | 11-Nov-08 | 0.2 | 3,000 | 5,800 | 10,000 | 7.4 | 15 | 30 | | | |
| 61808 | DSC claim due to deformation to surface structures | Encountering Ground Conditions more adverse than advertised in Contract | Deformation to surface structures due to time dependent deformations | Submittal of DSC claim - legal proceedings against owner; | A6 | 25-Jul-06 | 11-Nov-08 | 0.1 | 3,000 | 5,800 | 10,000 | | | | | | |
| 60201 | 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 | A6,A7,G | 25-Jul-06 | 06-Sep-09 | 0.001 | 500 | 1,400 | 3,000 | 15 | 30 | 60 | | 1 | |
| 60202 | tunnel collapse due to ground conditions | Tunnel collapse | Unforeseen ground conditions | Submittal of DSC claim - legal proceedings against owner; lining overstressing and failure | A6 | 25-Jul-06 | 11-Nov-08 | 0.001 | 10,000 | 25,000 | 50,000 | 15 | 30 | 60 | | | |
| 60203 | tunnel collapse due to poor contractor workmanship | Tunnel collapse | Inadequate Contractor workmanship | Lining overstressing and failure | A6 - A8 | 25-Jul-06 | 05-Aug-09 | 0.01 | | | | 7.4 | 15 | 30 | | 1 | |
| 60301 | TBM breakdown | TBM forward progress impeded | TBM breakdown | Significant project delay to restore TBM progress | A6 | 25-Jul-06 | 11-Nov-08 | 0.1 | | | | 10 | 26 | 52 | | 1 | |
| 60401 | Gas in tunnel - higher concentrations than anticipated | Encountering gas in higher concentrations than anticipated. | Naturally occuring gas in rock formations - higher concentration than currently anticipated | Increased ventilation of all tunnel equipment to meet appropriate regulatory requirements | A6 | 25-Jul-06 | 11-Nov-08 | 0.1 | 50 | 200 | 500 | 0.5 | 1 | 2 | | 1 | |
| 70101 | Unexpected subsurface contamination | Excavated material is more contaminated than expected | Unexpected subsurface contamination (natural or anthropogenic) | Increased materials handling and disposal costs | A6 | 25-Jul-06 | 11-Nov-08 | 0.01 | 10,000 | 20,000 | 40,000 | 10 | 26 | 52 | | 1 | |
| 60102 | 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 | A7 | 21-Nov-08 | 24-Apr-09 | 0.01 | 50 | 200 | 500 | 2.3 | 4 | 7 | 5 | 1 | |
| 60101 | 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 | A4 | 27-Dec-08 | 04-Jul-09 | 0.01 | 50 | 200 | 500 | 2.3 | 4 | 7 | | 1 | |
| 40801 | liquidated damages dispute over tunnel flow rates | Inability to enforce liquidated damages clause for actual flow less than design criteria from flow test | Inappropriate gauging locations for flow test, or other reasons | Dispute over payment of liquidated damages | F | 30-Sep-09 | 31-Mar-10 | 0.1 | 5,000 | 12,000 | 25,000 | | | | | | 1 |
| 41201 | inability to enforce warranty or discharge lien due to insufficient funds | inability to enforce warranty or discharge lien | insufficient funds withheld for holdback and lien | financial impact | F | 30-Sep-09 | 31-Mar-10 | 0.01 | 500 | 1,400 | 3,000 | | | | | | |
| 40802 | liquidated damages dispute over delay in project completion | Inability to enforce liquidated damages clause for contractor-caused delay to project completion | lack of clarity regarding responsibility for delay | Dispute over payment of liquidated damages | F | 30-Sep-09 | 31-Mar-10 | 0.1 | | 0 | 1 | | | | | | 1 |
| 41702 | additional project costs due to project delay | additional costs of project oversight, etc.during contract extension period | project delays not covered by liquidated damages amount | additional project management/oversight costs | F | 30-Sep-09 | 31-Mar-10 | | | calculated from project delays | | | | | | | |
| 40901 | roughness increasing over time (I.e. zebra mussels) | Long-term degradation of flow below design requirement at construction completion | Inadequate specification for long-term performance of tunnel to account for roughness buildup over time | loss of revenue due to flow reduction (e.g. from zebra mussel buildup on rough tunnel lining) | G | 30-Sep-09 | 06-Sep-09 | 0.1 | 10,000 | 25,000 | 50,000 | | | | | | |
| 41002 | lining deformation over time | Uncertainties with capital expenditure on maintenance of civil works over "design life" of tunnel | Deformation of the lining in time (e.g., increased steps between concrete modules and change in tunnel cross section) | Loss of revenue due to increased losses in tunnel | G | 30-Sep-09 | 06-Sep-09 | 0.1 | 10,000 | 25,000 | 50,000 | | | | | | |
| 61809 | swelling in Queenston shale during tunnel operation | Encountering Ground Conditions more adverse than advertised in Contract | Unexpectedly high degree of swelling of Queenston Shale | Lining integrity impacted - Submittal of DSC claim | G | 25-Jul-06 | 11-Nov-08 | 0.2 | 50,000 | 200,000 | 500,000 | | | | | | |
| 41003 | tunnel lining requires high maintenance during operation | Uncertainties with capital expenditure on maintenance of civil works over "design life" of tunnel | Durability and performance of proposed of construction materials in the pertaining ground conditions | impact to Capital Improvement Plan | G | 30-Sep-09 | 06-Sep-09 | 0.01 | 50,000 | 200,000 | 500,000 | | | | | | |

# Appendix B

# Niagara Tunnel Project
# Quantitative Risk Assessment
# Detailed Model Output

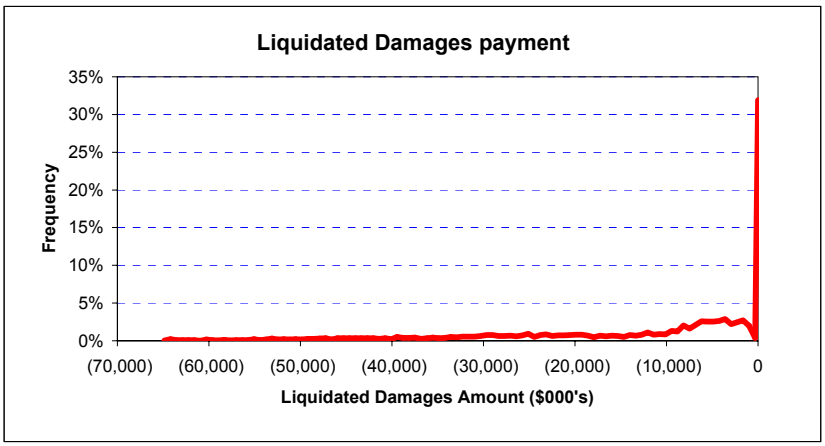
**Forecast: Risks during Design-build assignment**




| Statistics: | Forecast values |
|---|---|
| Trials | 5,000 |
| Mean | 12,530 |
| Median | 7,818 |
| Mode | 0 |
| Standard Deviation | 14,471 |
| Variance | 209,401,343 |
| Skewness | 2.01 |
| Kurtosis | 7.63 |
| Coeff. of Variability | 1.15 |
| Minimum | 0 |
| Maximum | 113,569 |
| Range Width | 113,569 |
| Mean Std. Error | 205 |

| Percentiles: | Forecast values |
|---|---|
| 0% | 0 |
| 5% | 0 |
| 10% | 298 |
| 15% | 843 |
| 20% | 1,668 |
| 25% | 2,720 |
| 30% | 4,089 |
| 35% | 5,203 |
| 40% | 6,094 |
| 45% | 6,908 |
| 50% | 7,818 |
| 55% | 8,676 |
| 60% | 9,713 |
| 65% | 11,132 |
| 70% | 12,817 |
| 75% | 15,875 |
| 80% | 19,937 |
| 85% | 25,708 |
| 90% | 33,249 |
| 95% | 43,542 |
| 100% | 113,569 |

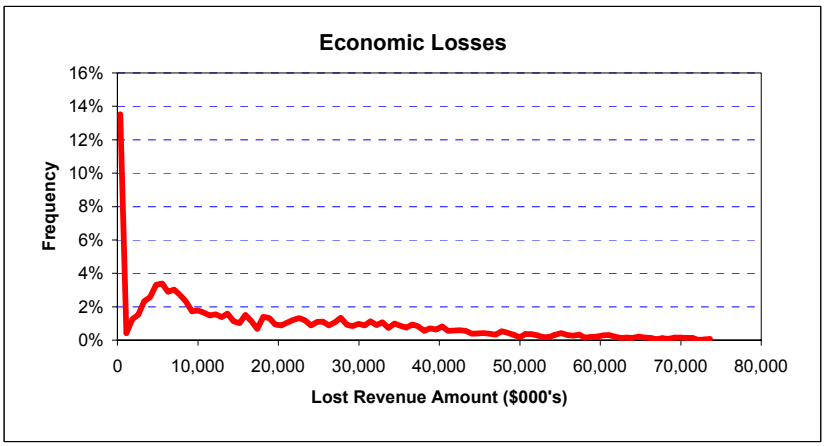
**Forecast: Liquidated Damages payment**




| Statistics: | Forecast values |
|---|---|
| Trials | 5,000 |
| Mean | (14,235) |
| Median | (6,041) |
| Mode | 0 |
| Standard Deviation | 18,192 |
| Variance | 330,949,628 |
| Skewness | -1.53 |
| Kurtosis | 4.70 |
| Coeff. of Variability | -1.28 |
| Minimum | (72,800) |
| Maximum | 0 |
| Range Width | 72,800 |
| Mean Std. Error | 257 |

| Percentiles: | Forecast values |
|---|---|
| 0% | (72,800) |
| 5% | (53,429) |
| 10% | (41,496) |
| 15% | (32,959) |
| 20% | (27,712) |
| 25% | (23,181) |
| 30% | (18,687) |
| 35% | (13,621) |
| 40% | (9,817) |
| 45% | (7,633) |
| 50% | (6,041) |
| 55% | (4,789) |
| 60% | (3,598) |
| 65% | (2,303) |
| 70% | (956) |
| 75% | 0 |
| 80% | 0 |
| 85% | 0 |
| 90% | 0 |
| 95% | 0 |
| 100% | 0 |

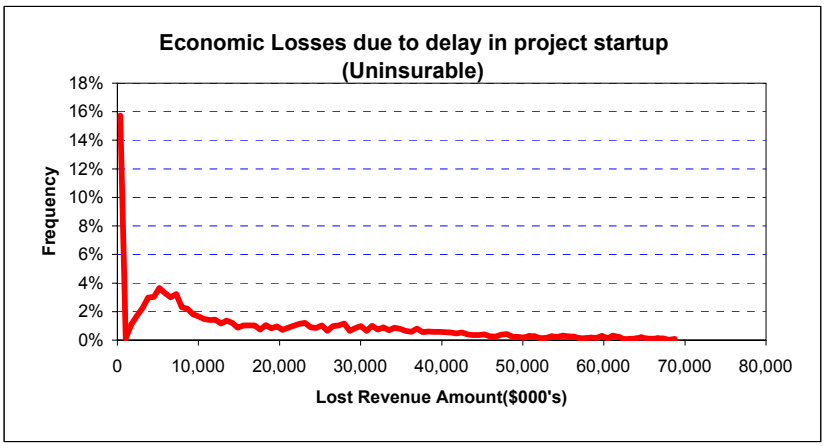
**Forecast: Economic Losses**




| Statistics: | Forecast values |
|---|---|
| Trials | 5,000 |
| Mean | 19,961 |
| Median | 13,861 |
| Mode | 0 |
| Standard Deviation | 19,308 |
| Variance | 372,793,658 |
| Skewness | 1.35 |
| Kurtosis | 5.17 |
| Coeff. of Variability | 0.97 |
| Minimum | 0 |
| Maximum | 148,449 |
| Range Width | 148,449 |
| Mean Std. Error | 273 |

| Percentiles: | Forecast values |
|---|---|
| 0% | 0 |
| 5% | 0 |
| 10% | 0 |
| 15% | 2,163 |
| 20% | 3,981 |
| 25% | 5,187 |
| 30% | 6,330 |
| 35% | 7,572 |
| 40% | 9,186 |
| 45% | 11,302 |
| 50% | 13,861 |
| 55% | 16,845 |
| 60% | 20,261 |
| 65% | 23,491 |
| 70% | 27,143 |
| 75% | 30,759 |
| 80% | 34,637 |
| 85% | 39,538 |
| 90% | 46,452 |
| 95% | 58,423 |
| 100% | 148,449 |

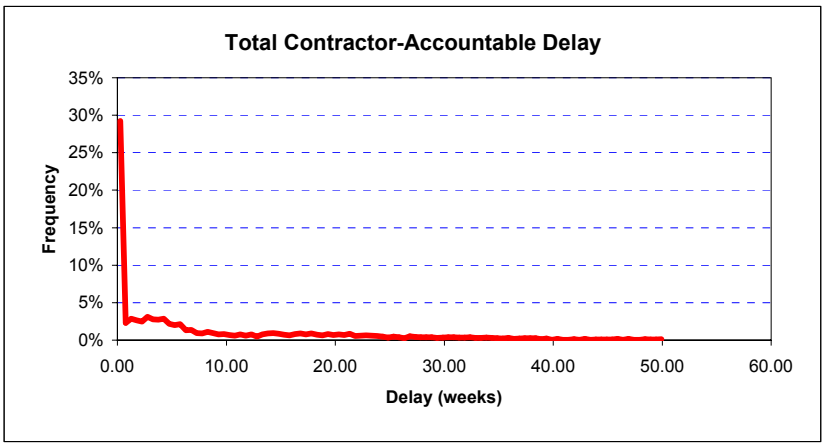
**Forecast: Economic Losses due to delay in project startup (Uninsurable)**




| Statistics: | Forecast values |
|---|---|
| Trials | 5,000 |
| Mean | 17,960 |
| Median | 11,195 |
| Mode | 0 |
| Standard Deviation | 18,259 |
| Variance | 333,380,279 |
| Skewness | 1.40 |
| Kurtosis | 5.27 |
| Coeff. of Variability | 1.02 |
| Minimum | 0 |
| Maximum | 148,449 |
| Range Width | 148,449 |
| Mean Std. Error | 258 |

| Percentiles: | Forecast values |
|---|---|
| 0% | 0 |
| 5% | 0 |
| 10% | 0 |
| 15% | 0 |
| 20% | 3,168 |
| 25% | 4,429 |
| 30% | 5,423 |
| 35% | 6,450 |
| 40% | 7,561 |
| 45% | 9,107 |
| 50% | 11,195 |
| 55% | 13,785 |
| 60% | 17,064 |
| 65% | 21,133 |
| 70% | 24,509 |
| 75% | 28,044 |
| 80% | 32,294 |
| 85% | 36,868 |
| 90% | 43,020 |
| 95% | 55,149 |
| 100% | 148,449 |

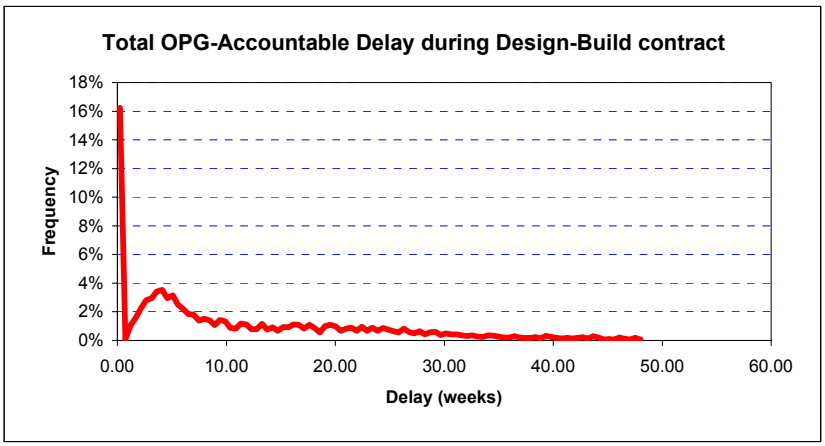
**Forecast: Total Contractor-Accountable Delay**




| Statistics: | Forecast values |
|---|---|
| Trials | 5,000 |
| Mean | 10.47 |
| Median | 4.31 |
| Mode | 0.00 |
| Standard Deviation | 14.18 |
| Variance | 201.12 |
| Skewness | 2.07 |
| Kurtosis | 8.47 |
| Coeff. of Variability | 1.36 |
| Minimum | 0.00 |
| Maximum | 117.31 |
| Range Width | 117.31 |
| Mean Std. Error | 0.20 |

| Percentiles: | Forecast values |
|---|---|
| 0% | 0.00 |
| 5% | 0.00 |
| 10% | 0.00 |
| 15% | 0.00 |
| 20% | 0.00 |
| 25% | 0.00 |
| 30% | 0.68 |
| 35% | 1.64 |
| 40% | 2.57 |
| 45% | 3.42 |
| 50% | 4.31 |
| 55% | 5.45 |
| 60% | 7.01 |
| 65% | 9.72 |
| 70% | 13.35 |
| 75% | 16.55 |
| 80% | 19.79 |
| 85% | 23.53 |
| 90% | 29.64 |
| 95% | 38.14 |
| 100% | 117.31 |

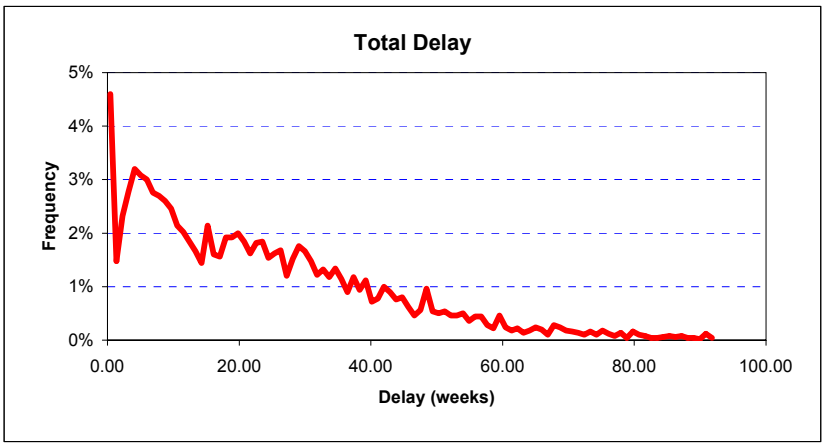
**Forecast: Total OPG-Accountable Delay during Design-Build contract**




| Statistics: | Forecast values |
|---|---|
| Trials | 5,000 |
| Mean | 12.53 |
| Median | 7.79 |
| Mode | 0.00 |
| Standard Deviation | 12.76 |
| Variance | 162.78 |
| Skewness | 1.36 |
| Kurtosis | 4.85 |
| Coeff. of Variability | 1.02 |
| Minimum | 0.00 |
| Maximum | 82.24 |
| Range Width | 82.24 |
| Mean Std. Error | 0.18 |

| Percentiles: | Forecast values |
|---|---|
| 0% | 0.00 |
| 5% | 0.00 |
| 10% | 0.00 |
| 15% | 0.00 |
| 20% | 2.14 |
| 25% | 3.08 |
| 30% | 3.80 |
| 35% | 4.52 |
| 40% | 5.30 |
| 45% | 6.33 |
| 50% | 7.79 |
| 55% | 9.60 |
| 60% | 11.86 |
| 65% | 14.52 |
| 70% | 17.06 |
| 75% | 19.75 |
| 80% | 22.61 |
| 85% | 25.89 |
| 90% | 30.19 |
| 95% | 38.58 |
| 100% | 82.24 |

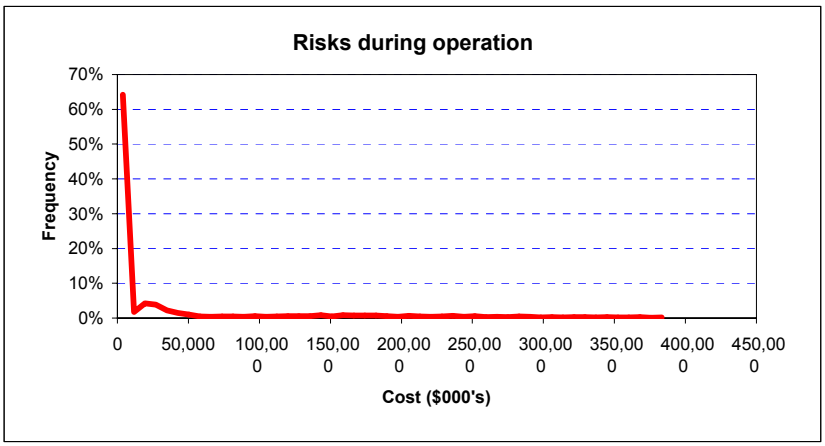
**Forecast: Total Delay**




| Statistics: | Forecast values |
|---|---|
| Trials | 5,000 |
| Mean | 24.88 |
| Median | 19.75 |
| Mode | 0.00 |
| Standard Deviation | 24.06 |
| Variance | 578.88 |
| Skewness | 2.91 |
| Kurtosis | 20.01 |
| Coeff. of Variability | 0.97 |
| Minimum | 0.00 |
| Maximum | 307.35 |
| Range Width | 307.35 |
| Mean Std. Error | 0.34 |

| Percentiles: | Forecast values |
|---|---|
| 0% | 0.00 |
| 5% | 1.22 |
| 10% | 3.27 |
| 15% | 4.78 |
| 20% | 6.34 |
| 25% | 7.97 |
| 30% | 9.76 |
| 35% | 11.93 |
| 40% | 14.70 |
| 45% | 17.19 |
| 50% | 19.75 |
| 55% | 22.33 |
| 60% | 25.02 |
| 65% | 28.10 |
| 70% | 30.83 |
| 75% | 34.50 |
| 80% | 38.72 |
| 85% | 43.94 |
| 90% | 51.09 |
| 95% | 64.86 |
| 100% | 307.35 |

**Forecast: Risks during operation**




| Statistics: | Forecast values |
|---|---|
| Trials | 5,000 |
| Mean | 55,287 |
| Median | 0 |
| Mode | 0 |
| Standard Deviation | 118,571 |
| Variance | 14,058,969,419 |
| Skewness | 2.93 |
| Kurtosis | 13.55 |
| Coeff. of Variability | 2.14 |
| Minimum | 0 |
| Maximum | 1,198,016 |
| Range Width | 1,198,016 |
| Mean Std. Error | 1,677 |

| Percentiles: | Forecast values |
|---|---|
| 0% | 0 |
| 5% | 0 |
| 10% | 0 |
| 15% | 0 |
| 20% | 0 |
| 25% | 0 |
| 30% | 0 |
| 35% | 0 |
| 40% | 0 |
| 45% | 0 |
| 50% | 0 |
| 55% | 0 |
| 60% | 0 |
| 65% | 13,039 |
| 70% | 22,682 |
| 75% | 33,156 |
| 80% | 76,384 |
| 85% | 150,986 |
| 90% | 212,455 |
| 95% | 316,563 |
| 100% | 1,198,016 |

# Appendix C

# Niagara Tunnel Project
# Key Risk Contributors

**Figure C-1: Contribution to Cost Uncertainty during Design-build assignment**

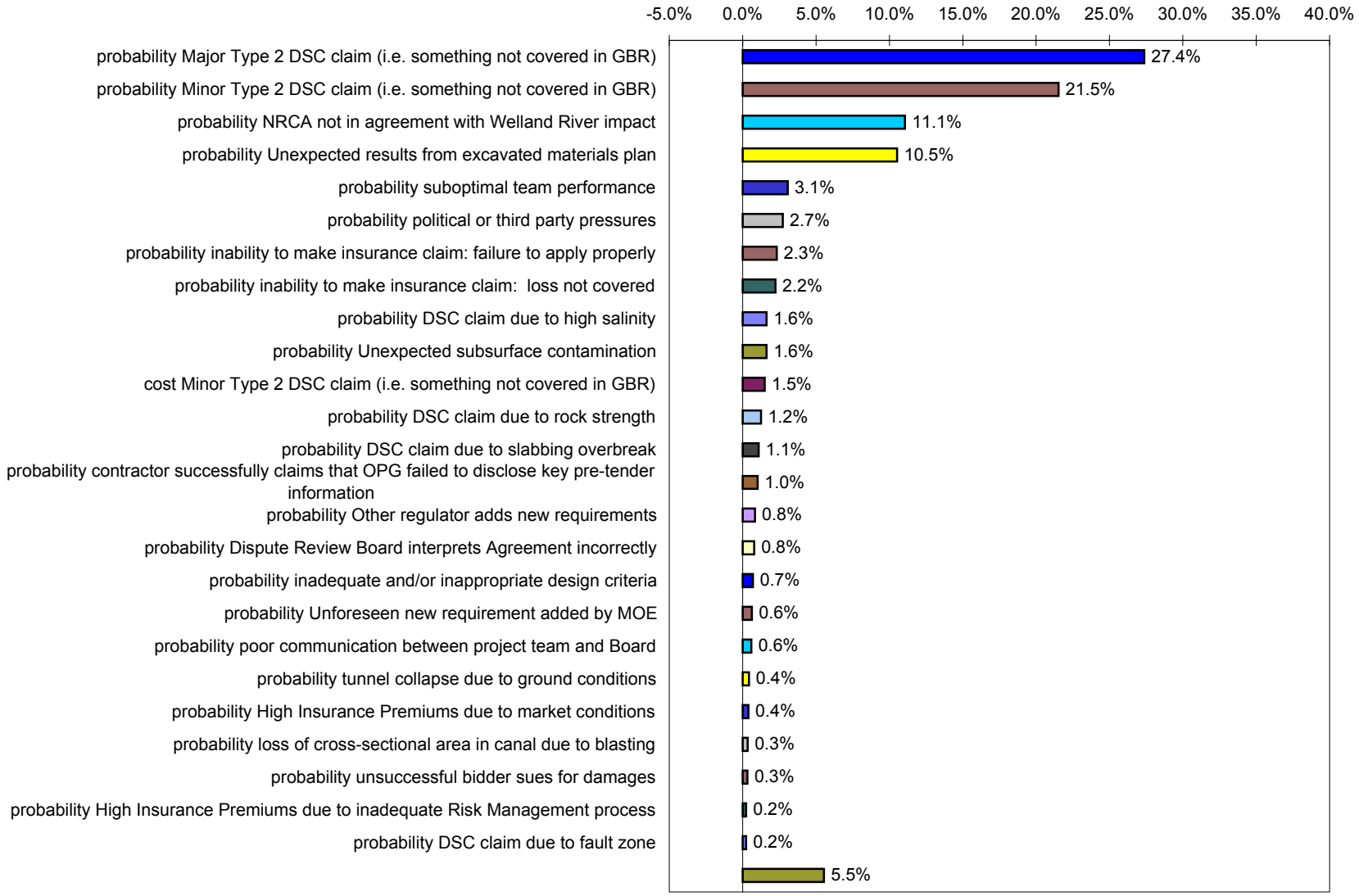


**Figure C-2: Contribution to Project Delay**

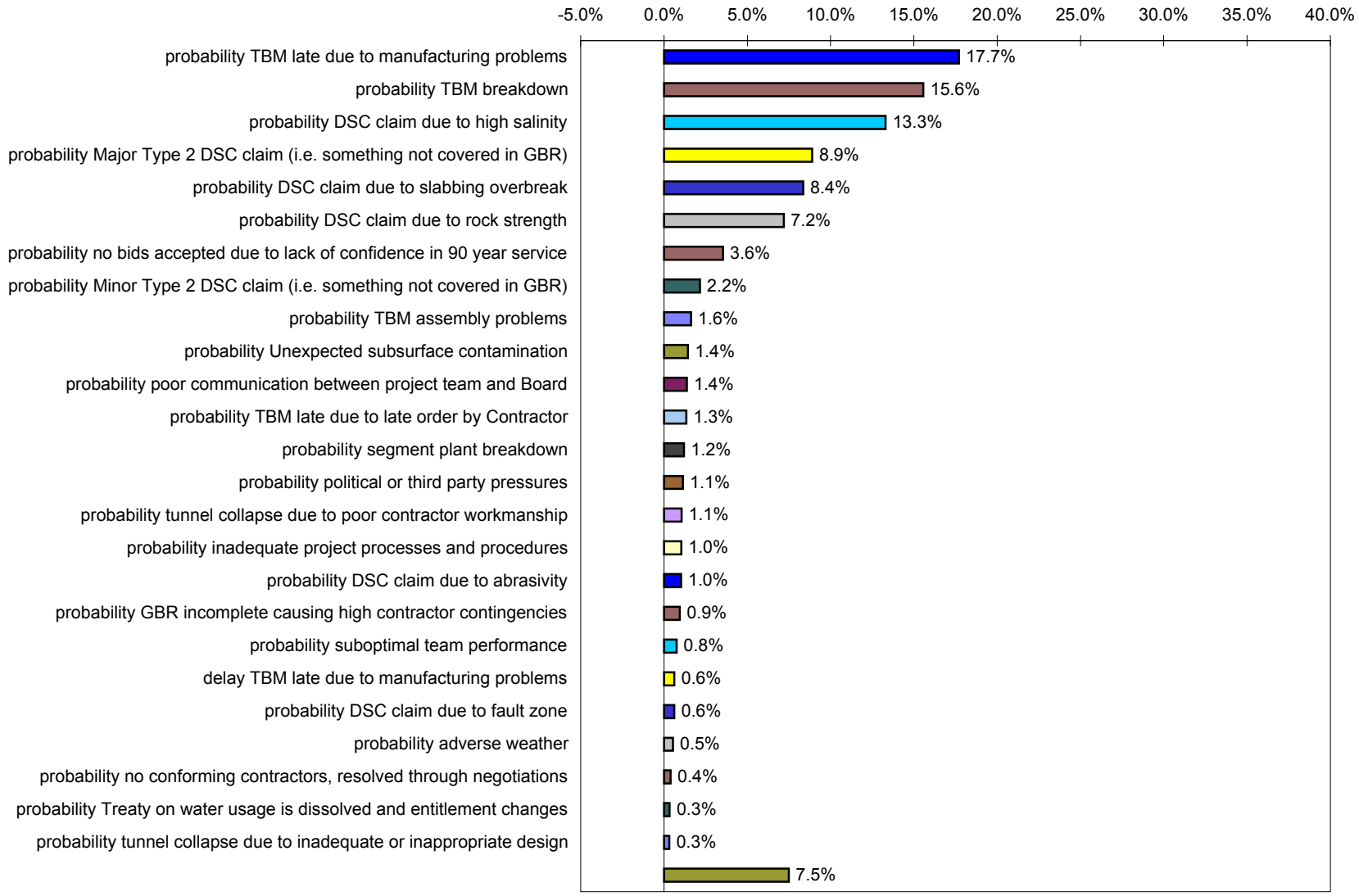
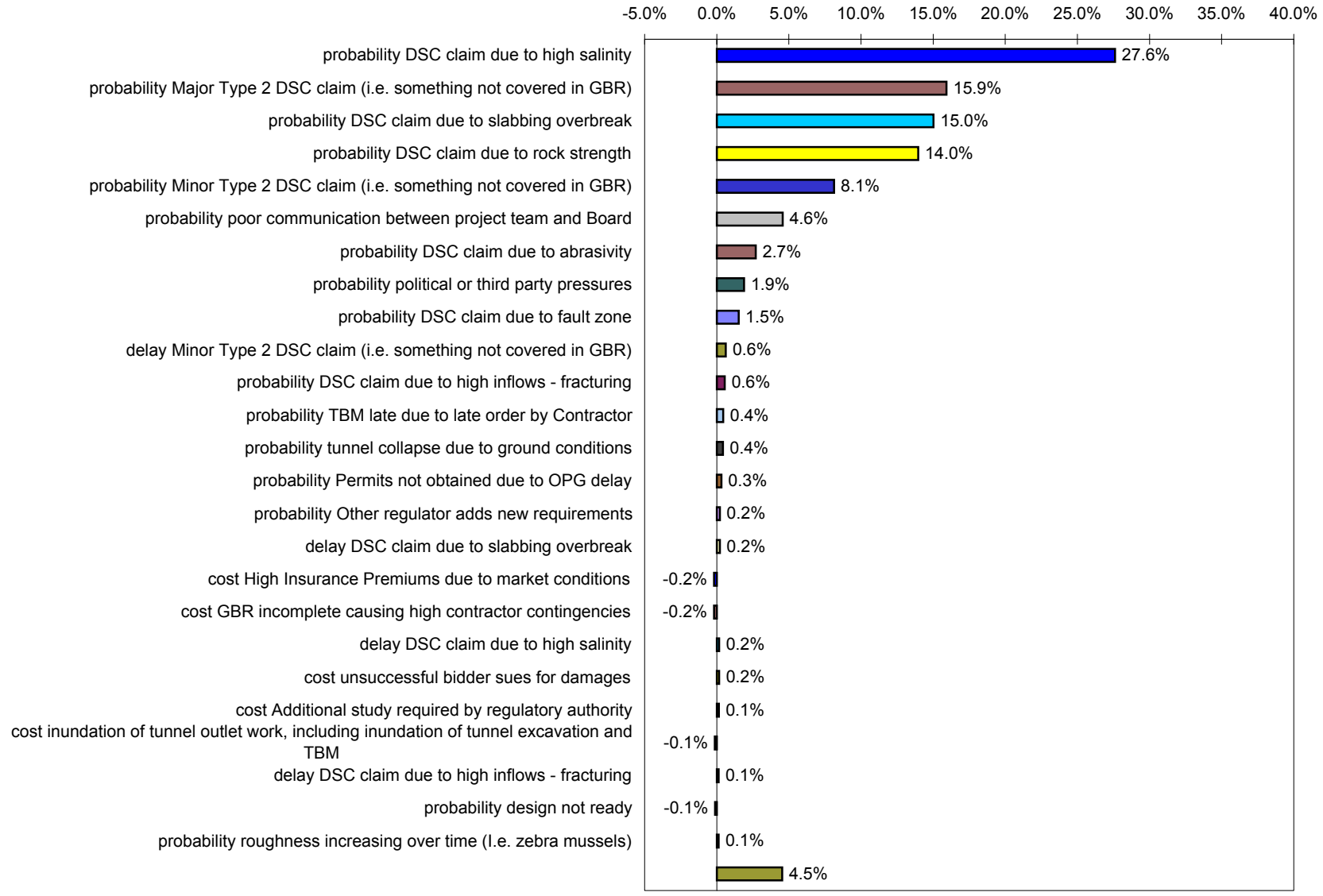


**Figure C-3: Contribution to Economic Losses due to delay in project startup (Uninsurable)**



# Appendix D

# Hazards during Operation of the Niagara Tunnel

The analysis described in the main body of this report refers only to the construction project itself and not to hazards which would occur during operation.

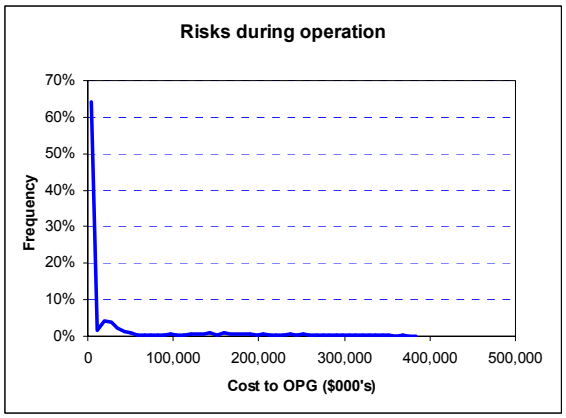
However, four hazards were identified during the Risk Assessment workshops that are a direct result of the design/build contract. They were included in the analysis as part of the overall risk cost but were not shown in any of the analysis described in the main body of this report, so as not to confuse these costs with the costs of the design/build assignment.

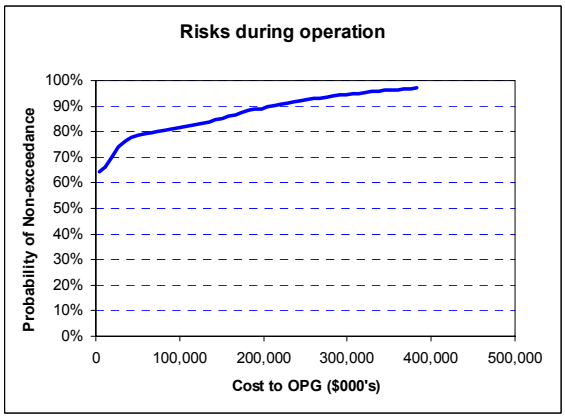
These hazards are:

- 40901: roughness over time
- 41002: lining deformation
- 41003: durability of tunnel lining
- 61809: swelling in the Queenston shale

The resulting cost impact of these items is shown in Figure D.1.

**Figure D.1: Risks during Operation**



# Appendix E

# Glossary of Project Hazards

# Appendix E1: Glossary of Hazards (Numerical Order)

| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence |
|---|---|---|---|---|
| 10102 | EA approval terms not met due to OPG delay | Not meeting terms and conditions of EA Approval | OPG did not submit/ resubmit in time | Schedule Delay |
| 10103 | MOE not in agreement with proposed work | Not meeting terms and conditions of EA Approval | MOE not in agreement with proposed work | Schedule Delay |
| 10104 | MNR not in agreement with proposed work | Not meeting terms and conditions of EA Approval | MNR not in agreement with proposed work | Schedule Delay |
| 10105 | NRCA not in agreement with Welland River impact | Not meeting terms and conditions of EA Approval | Conservation authority not in agreement with the impact on the Welland River | Unexpected additional costs to avoid project delay |
| 10106 | Other 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 |
| 10107 | Unexpected results from Groundwater study | Not meeting terms and conditions of EA Approval | Unexpected results from Groundwater study | Schedule Delay |
| 10109 | 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 |
| 10110 | Unforeseen new requirement added by MOE | Not meeting terms and conditions of EA Approval | Unforeseen new requirement added by MOE | Schedule Delay |
| 10111 | Other regulator adds new requirements | Not meeting terms and conditions of EA Approval | Other regulator adds new requirements | Schedule Delay |
| 10201 | Permits not obtained due to contractor delay | Required Permits not obtained | Contractor did not submit in time | Schedule Delay |
| 10202 | Permits not obtained due to OPG delay | Required Permits not obtained | OPG did not submit in time | Schedule Delay |
| 10203 | Late response from third party to regulator | Required Permits not obtained | Late response from third party to regulator | Schedule Delay |
| 10204 | negative decision by regulatory authority | Required Permits not obtained | Failure to issue permit by regulatory authority (I.e. a negative decision) | Schedule Delay |
| 10205 | Additional study required by regulatory authority | Required Permits not obtained | Additional study required by regulatory authority | Schedule Delay |
| 10206 | multiple re-submissions required by regulatory authority | Required Permits not obtained | multiple re-submissions required by regulatory authority | Schedule Delay |
| 10207 | required permit not identified | Required Permits not obtained | required permit not identified | Schedule Delay |
| 10208 | permit conditions not acceptable to OPG | Required Permits not obtained | permit conditions not acceptable to OPG | Schedule Delay |
| 10701 | Treaty on water usage is dissolved and entitlement changes | Treaty on water usage is dissolved and entitlement changes | International issue between Canada and US | Project terminated |
| 10901 | Withdrawal of project approval by the Government in power | Withdrawal of project approval by the Government in power | Change of government with 2007 Provincial election leading to change in energy policy | Project halted or terminated |
| 11001 | Fisheries Act terms not met | project does not meet terms and conditions of the Fisheries Act authorizations | | Schedule Delay |
| 11101 | NPCA does not agree with Fish compensation plan | inability to obtain approval on Fish Habitat Compensation Plan | NPCA does not agree with plan | Schedule Delay |
| 11102 | residents do not agree with Fish Compensation plan | inability to obtain approval on Fish Habitat Compensation Plan | property owners/residents do not agree with plan | Schedule Delay |
| 20101 | Failure to address Community Issues, causing financial impact on communities | Failure to address Community Issues | Financial impacts on municipalities from project | demands / possible lawsuits for financial compensation to municipalities |
| 30102 | no conforming contractors, resolved through negotiations | Unprogrammed extension to procurement Bid phase | All contractors fail to comply with Contract requirements for detailed design and/or construction | project delay caused by (successful) negotiations |
| 30103 | no conforming contractors, leading to re-bid | Unprogrammed extension to procurement Bid phase | All contractors fail to comply with Contract requirements for detailed design and/or construction | unsuccessful negotiations leading to a requirement for overhaul of RFP documents |
| 30201 | Deficiencies in QC by Owner and Engineer | Contract documents insufficiently detailed and imprecise | Deficiencies in QC by Owner and Engineer | Inadequate communication of design requirements to Contractor |
| 30202 | GBR incomplete causing high contractor contingencies | Contract documents insufficiently detailed and imprecise | Deficiencies in GBR (i.e. something not covered in GBR) | Increased bid prices (contingency) |
| 30203 | Major 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) | Major Type 2 DSC claims |
| 30204 | 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 |
| 30205 | inadequate and/or inappropriate design criteria | Contract documents insufficiently detailed and imprecise | Deficiencies in concept Design | inadequate and/or inappropriate design criteria requiring issuance of multiple change orders |
| 30601 | suboptimal team performance | performance of project team is suboptimal | various | cost and schedule overruns |
| 30606 | poor communication between project team and Board | performance of project team is suboptimal | poor communication between project team and Board | cost and schedule overruns |
| 30701 | inadequate project processes and procedures | inadequate project processes and procedures | various | cost, schedule and quality |
| 30901 | political or third party pressures | external pressure on project configuration | political or third party pressures | cost, schedule and quality |
| 40101 | High Insurance Premiums due to inadequate Risk Management process | Insurance Premiums prohibitively high | Inadequate Risk Management process in place (i.e. not acceptable to insurer.) | Cost impact to project budget |
| 40102 | High Insurance Premiums due to market conditions | Insurance Premiums prohibitively high | Insurance market conditions / capacity | Cost impact to project budget |

# Appendix E1: Glossary of Hazards (Numerical Order)

| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence |
|---|---|---|---|---|
| 40201 | inability to make insurance claim: loss not covered | inability to make insurance claim | insurance does not cover claim | Cost impact to project budget |
| 40202 | inability to make insurance claim: failure to apply properly | inability to make insurance claim | failure to apply properly | Cost impact to project budget |
| 40603 | 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 |
| 40607 | 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 |
| 40801 | liquidated damages dispute over tunnel flow rates | Inability to enforce liquidated damages clause for actual flow less than design criteria from flow test | Inappropriate gauging locations for flow test, or other reasons | Dispute over payment of liquidated damages |
| 40802 | liquidated damages dispute over delay in project completion | Inability to enforce liquidated damages clause for contractor-caused delay to project completion | lack of clarity regarding responsibility for delay | Dispute over payment of liquidated damages |
| 40901 | roughness increasing over time (I.e. zebra mussels) | Long-term degradation of flow below design requirement at construction completion | Inadequate specification for long-term performance of tunnel to account for roughness buildup over time | loss of revenue due to flow reduction (e.g. from zebra mussel buildup on rough tunnel lining) |
| 41002 | lining deformation over time | Uncertainties with capital expenditure on maintenance of civil works over "design life" of tunnel | Deformation of the lining in time (e.g., increased steps between concrete modules and change in tunnel cross section) | Loss of revenue due to increased losses in tunnel |
| 41003 | tunnel lining requires high maintenance during operation | Uncertainties with capital expenditure on maintenance of civil works over "design life" of tunnel | Durability and performance of proposed of construction materials in the pertaining ground conditions | impact to Capital Improvement Plan |
| 41201 | inability to enforce warranty or discharge lien due to insufficient funds | inability to enforce warranty or discharge lien | insufficient funds withheld for holdback and lien | financial impact |
| 41401 | 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 |
| 41501 | Dispute Review Board interprets Agreement incorrectly | Dispute Review Board interprets Agreement incorrectly | | financial, schedule delays |
| 41601 | 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 |
| 41701 | Lost revenue due to delay in project startup (Uninsurable) | uninsurable delay | delay in contract completion leading to lost revenue (not insurable) | uncompensated loss of revenue |
| 41702 | additional project costs due to project delay | additional costs of project oversight, etc.during contract extension period | project delays not covered by liquidated damages amount | additional project management/oversight costs |
| 50201 | TBM late due to late order by Contractor | Late availability of TBM | Late Submittal/ ordering | Schedule Delay |
| 50202 | TBM late due to manufacturing problems | Late availability of TBM | Manufacturing problems | Schedule Delay |
| 50203 | TBM late due to shipping delays | Late availability of TBM | Shipping delays (due to weather) | Schedule Delay |
| 50204 | TBM assembly problems | Late availability of TBM | Assembly and commissioning problems | schedule delay |
| 50301 | regional power outage | Interrupted power supply for site works | regional power outage | Lack of electrical power for lighting, ventilation, drainage pumps and TBM |
| 50302 | site power outage | Interrupted power supply for site works | site-based power outage | Lack of electrical power for lighting, ventilation, drainage pumps and TBM |
| 50402 | 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 |
| 50403 | Inadequate QC at segment Manufacturer | Segments not available in timely manner | Inadequate QC at Manufacturer | Schedule delay, possibly leading to stopping forward progress of TBM |
| 50501 | adverse weather | Work impeded by adverse weather conditions | Storms, extreme temperature, winter weather | Schedule delay, primarily at inlet and outlet works |
| 60101 | 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 |
| 60102 | 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 |
| 60103 | inundation of tunnel outlet work, including inundation of tunnel excavation and TBM | Flooding of the works during construction | breach at outlet works | inundation of tunnel outlet work, including mucking operation and active mining tunnel portal, including inundation of tunnel excavation and TBM |
| 60201 | 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 |

# Appendix E1: Glossary of Hazards (Numerical Order)

| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence |
|---|---|---|---|---|
| 60202 | tunnel collapse due to ground conditions | Tunnel collapse | Unforeseen ground conditions | Submittal of DSC claim - legal proceedings against owner; lining overstressing and failure |
| 60203 | tunnel collapse due to poor contractor workmanship | Tunnel collapse | Inadequate Contractor workmanship | Lining overstressing and failure |
| 60301 | TBM breakdown | TBM forward progress impeded | TBM breakdown | Significant project delay to restore TBM progress |
| 60401 | Gas in tunnel - higher concentrations than anticipated | Encountering gas in higher concentrations than anticipated. | Naturally occuring gas in rock formations - higher concentration than currently anticipated | Increased ventilation of all tunnel equipment to meet appropriate regulatory requirements |
| 60801 | loss of cross-sectional area in canal due to blasting | loss of cross-sectional area in canal | construction debris - primarily due to blasting | loss of revenue and schedule delay for project completion carrying out remediation |
| 61101 | contractor non-compliance | project design criteria not met | contractor non-compliance | |
| 61102 | tunnel lining failure | project design criteria not met | failure of tunnel lining system | |
| 61104 | no bids accepted due to lack of confidence in 90 year service | project design criteria not met | no contractor submits conforming bid (90 year life span) | |
| 61601 | 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 |
| 61801 | DSC claim due to rock strength | Encountering Ground Conditions more adverse than advertised in Contract | Rock Strength higher than anticipated | Submittal of DSC claim - legal proceedings against owner; |
| 61802 | DSC claim due to abrasivity | Encountering Ground Conditions more adverse than advertised in Contract | Rock abrasivity higher than anticipated | Submittal of DSC claim - legal proceedings against owner; |
| 61803 | DSC claim due to high inflows - fracturing | Encountering Ground Conditions more adverse than advertised in Contract | High inflows at tunnel heading above Queenston Shale (e.g. intense fracturing in bedrock) | Submittal of DSC claim - legal proceedings against owner; |
| 61804 | DSC claim due to fault zone | Encountering Ground Conditions more adverse than advertised in Contract | Encountering an unexpected fault zone | Submittal of DSC claim - legal proceedings against owner; |
| 61805 | DSC claim due to BTEX | 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; |
| 61806 | DSC claim due to slabbing overbreak | Encountering Ground Conditions more adverse than advertised in Contract | slabbing overbreak is higher than expected | Submittal of DSC claim - legal proceedings against owner; |
| 61807 | 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 |
| 61808 | DSC claim due to deformation to surface structures | Encountering Ground Conditions more adverse than advertised in Contract | Deformation to surface structures due to time dependent deformations | Submittal of DSC claim - legal proceedings against owner; |
| 61809 | swelling in Queenston shale during tunnel operation | Encountering Ground Conditions more adverse than advertised in Contract | Unexpectedly high degree of swelling of Queenston Shale | Lining integrity impacted - Submittal of DSC claim |
| 70101 | Unexpected subsurface contamination | Excavated material is more contaminated than expected | Unexpected subsurface contamination (natural or anthropogenic) | Increased materials handling and disposal costs |
| 70201 | 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 |
| 70301 | Tunnel Dewatering activities significantly alter groundwater | Tunnel Dewatering activities significantly alter groundwater levels or flow patterns impacting area users | Effects of dewatering activities on groundwater flow regime under estimated | Mitigation costs, reputation, regulatory enforcement |
| 70401 | 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 |
| 70601 | Dewatering shaft and/or tunnel create route for cross-contamination | Dewatering shaft and/or tunnel create route for cross-contamination | Inadequate design and/or construction | Mitigation costs, third party claims |
| 80401 | 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 |

# Appendix E2: Glossary of Hazards (Risk Label Order)

| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence |
|---|---|---|---|---|
| 41702 | additional project costs due to project delay | additional costs of project oversight, etc.during contract extension period | project delays not covered by liquidated damages amount | additional project management/oversight costs |
| 10205 | Additional study required by regulatory authority | Required Permits not obtained | Additional study required by regulatory authority | Schedule Delay |
| 50501 | adverse weather | Work impeded by adverse weather conditions | Storms, extreme temperature, winter weather | Schedule delay, primarily at inlet and outlet works |
| 61101 | contractor non-compliance | project design criteria not met | contractor non-compliance | |
| 40607 | 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 |
| 30201 | Deficiencies in QC by Owner and Engineer | Contract documents insufficiently detailed and imprecise | Deficiencies in QC by Owner and Engineer | Inadequate communication of design requirements to Contractor |
| 61601 | 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 |
| 70601 | Dewatering shaft and/or tunnel create route for cross-contamination | Dewatering shaft and/or tunnel create route for cross-contamination | Inadequate design and/or construction | Mitigation costs, third party claims |
| 41501 | Dispute Review Board interprets Agreement incorrectly | Dispute Review Board interprets Agreement incorrectly | | financial, schedule delays |
| 61802 | DSC claim due to abrasivity | Encountering Ground Conditions more adverse than advertised in Contract | Rock abrasivity higher than anticipated | Submittal of DSC claim - legal proceedings against owner; |
| 61805 | DSC claim due to BTEX | 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; |
| 61808 | DSC claim due to deformation to surface structures | Encountering Ground Conditions more adverse than advertised in Contract | Deformation to surface structures due to time dependent deformations | Submittal of DSC claim - legal proceedings against owner; |
| 61804 | DSC claim due to fault zone | Encountering Ground Conditions more adverse than advertised in Contract | Encountering an unexpected fault zone | Submittal of DSC claim - legal proceedings against owner; |
| 61803 | DSC claim due to high inflows - fracturing | Encountering Ground Conditions more adverse than advertised in Contract | High inflows at tunnel heading above Queenston Shale (e.g. intense fracturing in bedrock) | Submittal of DSC claim - legal proceedings against owner; |
| 61807 | 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 |
| 61801 | DSC claim due to rock strength | Encountering Ground Conditions more adverse than advertised in Contract | Rock Strength higher than anticipated | Submittal of DSC claim - legal proceedings against owner; |
| 61806 | DSC claim due to slabbing overbreak | Encountering Ground Conditions more adverse than advertised in Contract | slabbing overbreak is higher than expected | Submittal of DSC claim - legal proceedings against owner; |
| 10102 | EA approval terms not met due to OPG delay | Not meeting terms and conditions of EA Approval | OPG did not submit/ resubmit in time | Schedule Delay |
| 20101 | Failure to address Community Issues, causing financial impact on communities | Failure to address Community Issues | Financial impacts on municipalities from project | demands / possible lawsuits for financial compensation to municipalities |
| 11001 | Fisheries Act terms not met | project does not meet terms and conditions of the Fisheries Act authorizations | | Schedule Delay |
| 60401 | Gas in tunnel - higher concentrations than anticipated | Encountering gas in higher concentrations than anticipated. | Naturally occuring gas in rock formations - higher concentration than currently anticipated | Increased ventilation of all tunnel equipment to meet appropriate regulatory requirements |
| 30202 | GBR incomplete causing high contractor contingencies | Contract documents insufficiently detailed and imprecise | Deficiencies in GBR (i.e. something not covered in GBR) | Increased bid prices (contingency) |
| 70201 | 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 |
| 40101 | High Insurance Premiums due to inadequate Risk Management process | Insurance Premiums prohibitively high | Inadequate Risk Management process in place (i.e. not acceptable to insurer.) | Cost impact to project budget |
| 40102 | High Insurance Premiums due to market conditions | Insurance Premiums prohibitively high | Insurance market conditions / capacity | Cost impact to project budget |
| 41201 | inability to enforce warranty or discharge lien due to insufficient funds | inability to enforce warranty or discharge lien | insufficient funds withheld for holdback and lien | financial impact |
| 40201 | inability to make insurance claim: loss not covered | inability to make insurance claim | insurance does not cover claim | Cost impact to project budget |
| 40202 | inability to make insurance claim: failure to apply properly | inability to make insurance claim | failure to apply properly | Cost impact to project budget |
| 30205 | inadequate and/or inappropriate design criteria | Contract documents insufficiently detailed and imprecise | Deficiencies in concept Design | inadequate and/or inappropriate design criteria requiring issuance of multiple change orders |
| 30701 | inadequate project processes and procedures | inadequate project processes and procedures | various | cost, schedule and quality |

# Appendix E2: Glossary of Hazards (Risk Label Order)

| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence |
|---|---|---|---|---|
| 50403 | Inadequate QC at segment Manufacturer | Segments not available in timely manner | Inadequate QC at Manufacturer | Schedule delay, possibly leading to stopping forward progress of TBM |
| 60102 | 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 |
| 60101 | 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 |
| 60103 | inundation of tunnel outlet work, including inundation of tunnel excavation and TBM | Flooding of the works during construction | breach at outlet works | inundation of tunnel outlet work, including mucking operation and active mining tunnel portal, including inundation of tunnel excavation and TBM |
| 10203 | Late response from third party to regulator | Required Permits not obtained | Late response from third party to regulator | Schedule Delay |
| 41002 | lining deformation over time | Uncertainties with capital expenditure on maintenance of civil works over "design life" of tunnel | Deformation of the lining in time (e.g., increased steps between concrete modules and change in tunnel cross section) | Loss of revenue due to increased losses in tunnel |
| 40802 | liquidated damages dispute over delay in project completion | Inability to enforce liquidated damages clause for contractor-caused delay to project completion | lack of clarity regarding responsibility for delay | Dispute over payment of liquidated damages |
| 40801 | liquidated damages dispute over tunnel flow rates | Inability to enforce liquidated damages clause for actual flow less than design criteria from flow test | Inappropriate gauging locations for flow test, or other reasons | Dispute over payment of liquidated damages |
| 60801 | loss of cross-sectional area in canal due to blasting | loss of cross-sectional area in canal | construction debris - primarily due to blasting | loss of revenue and schedule delay for project completion carrying out remediation |
| 70401 | 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 |
| 41701 | Lost revenue due to delay in project startup (Uninsurable) | uninsurable delay | delay in contract completion leading to lost revenue (not insurable) | uncompensated loss of revenue |
| 30203 | Major 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) | Major Type 2 DSC claims |
| 30204 | 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 |
| 10104 | MNR not in agreement with proposed work | Not meeting terms and conditions of EA Approval | MNR not in agreement with proposed work | Schedule Delay |
| 10103 | MOE not in agreement with proposed work | Not meeting terms and conditions of EA Approval | MOE not in agreement with proposed work | Schedule Delay |
| 10206 | multiple re-submissions required by regulatory authority | Required Permits not obtained | multiple re-submissions required by regulatory authority | Schedule Delay |
| 10204 | negative decision by regulatory authority | Required Permits not obtained | Failure to issue permit by regulatory authority (I.e. a negative decision) | Schedule Delay |
| 61104 | no bids accepted due to lack of confidence in 90 year service | project design criteria not met | no contractor submits conforming bid (90 year life span) | |
| 30103 | no conforming contractors, leading to re-bid | Unprogrammed extension to procurement Bid phase | All contractors fail to comply with Contract requirements for detailed design and/or construction | unsuccessful negotiations leading to a requirement for overhaul of RFP documents |
| 30102 | no conforming contractors, resolved through negotiations | Unprogrammed extension to procurement Bid phase | All contractors fail to comply with Contract requirements for detailed design and/or construction | project delay caused by (successful) negotiations |
| 11101 | NPCA does not agree with Fish compensation plan | inability to obtain approval on Fish Habitat Compensation Plan | NPCA does not agree with plan | Schedule Delay |
| 10105 | NRCA not in agreement with Welland River impact | Not meeting terms and conditions of EA Approval | Conservation authority not in agreement with the impact on the Welland River | Unexpected additional costs to avoid project delay |
| 10111 | Other regulator adds new requirements | Not meeting terms and conditions of EA Approval | Other regulator adds new requirements | Schedule Delay |
| 10106 | Other 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 |
| 40603 | 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 |
| 10208 | permit conditions not acceptable to OPG | Required Permits not obtained | permit conditions not acceptable to OPG | Schedule Delay |
| 10201 | Permits not obtained due to contractor delay | Required Permits not obtained | Contractor did not submit in time | Schedule Delay |
| 10202 | Permits not obtained due to OPG delay | Required Permits not obtained | OPG did not submit in time | Schedule Delay |
| 30901 | political or third party pressures | external pressure on project configuration | political or third party pressures | cost, schedule and quality |
| 30606 | poor communication between project team and Board | performance of project team is suboptimal | poor communication between project team and Board | cost and schedule overruns |
| 41601 | 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 |

# Appendix E2: Glossary of Hazards (Risk Label Order)

| Hazard ID Number | Risk Label (title for Quick Identification) | Hazard | Cause of Hazard | Potential Consequence |
|---|---|---|---|---|
| 50301 | regional power outage | Interrupted power supply for site works | regional power outage | Lack of electrical power for lighting, ventilation, drainage pumps and TBM |
| 10207 | required permit not identified | Required Permits not obtained | required permit not identified | Schedule Delay |
| 11102 | residents do not agree with Fish Compensation plan | inability to obtain approval on Fish Habitat Compensation Plan | property owners/residents do not agree with plan | Schedule Delay |
| 40901 | roughness increasing over time (I.e. zebra mussels) | Long-term degradation of flow below design requirement at construction completion | Inadequate specification for long-term performance of tunnel to account for roughness buildup over time | loss of revenue due to flow reduction (e.g. from zebra mussel buildup on rough tunnel lining) |
| 50402 | 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 |
| 80401 | 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 |
| 50302 | site power outage | Interrupted power supply for site works | site-based power outage | Lack of electrical power for lighting, ventilation, drainage pumps and TBM |
| 30601 | suboptimal team performance | performance of project team is suboptimal | various | cost and schedule overruns |
| 61809 | swelling in Queenston shale during tunnel operation | Encountering Ground Conditions more adverse than advertised in Contract | Unexpectedly high degree of swelling of Queenston Shale | Lining integrity impacted - Submittal of DSC claim |
| 50204 | TBM assembly problems | Late availability of TBM | Assembly and commissioning problems | schedule delay |
| 60301 | TBM breakdown | TBM forward progress impeded | TBM breakdown | Significant project delay to restore TBM progress |
| 50201 | TBM late due to late order by Contractor | Late availability of TBM | Late Submittal/ ordering | Schedule Delay |
| 50202 | TBM late due to manufacturing problems | Late availability of TBM | Manufacturing problems | Schedule Delay |
| 50203 | TBM late due to shipping delays | Late availability of TBM | Shipping delays (due to weather) | Schedule Delay |
| 10701 | Treaty on water usage is dissolved and entitlement changes | Treaty on water usage is dissolved and entitlement changes | International issue between Canada and US | Project terminated |
| 60202 | tunnel collapse due to ground conditions | Tunnel collapse | Unforeseen ground conditions | Submittal of DSC claim - legal proceedings against owner; lining overstressing and failure |
| 60201 | 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 |
| 60203 | tunnel collapse due to poor contractor workmanship | Tunnel collapse | Inadequate Contractor workmanship | Lining overstressing and failure |
| 70301 | Tunnel Dewatering activities significantly alter groundwater | Tunnel Dewatering activities significantly alter groundwater levels or flow patterns impacting area users | Effects of dewatering activities on groundwater flow regime under estimated | Mitigation costs, reputation, regulatory enforcement |
| 61102 | tunnel lining failure | project design criteria not met | failure of tunnel lining system | |
| 41003 | tunnel lining requires high maintenance during operation | Uncertainties with capital expenditure on maintenance of civil works over "design life" of tunnel | Durability and performance of proposed of construction materials in the pertaining ground conditions | impact to Capital Improvement Plan |
| 10109 | 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 |
| 10107 | Unexpected results from Groundwater study | Not meeting terms and conditions of EA Approval | Unexpected results from Groundwater study | Schedule Delay |
| 70101 | Unexpected subsurface contamination | Excavated material is more contaminated than expected | Unexpected subsurface contamination (natural or anthropogenic) | Increased materials handling and disposal costs |
| 10110 | Unforeseen new requirement added by MOE | Not meeting terms and conditions of EA Approval | Unforeseen new requirement added by MOE | Schedule Delay |
| 41401 | 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 |
| 10901 | Withdrawal of project approval by the Government in power | Withdrawal of project approval by the Government in power | Change of government with 2007 Provincial election leading to change in energy policy | Project halted or terminated |