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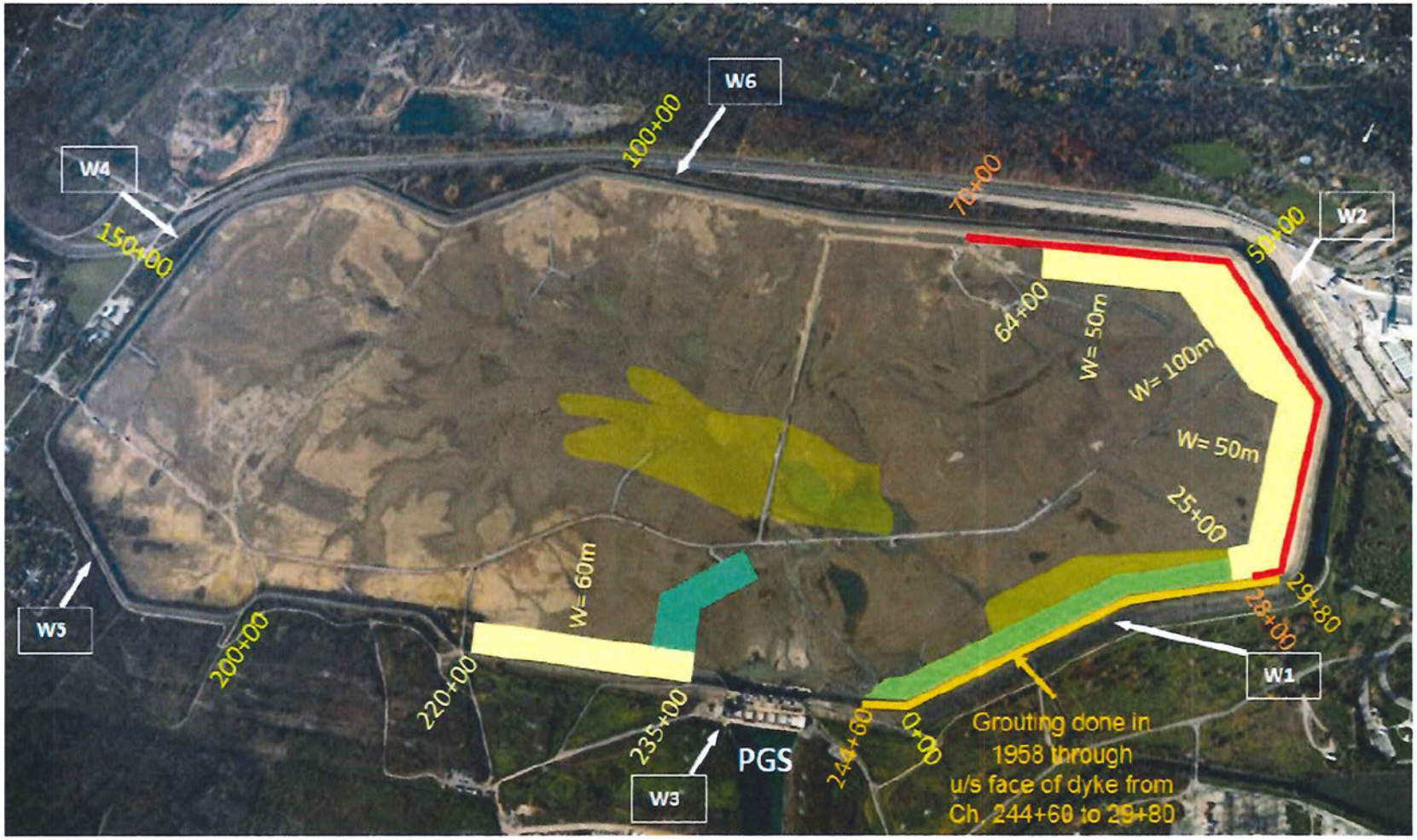
SAB PGS Reservoir Refurbishment Project

Comprehensive Post Implementation Review

January 31, 2018



Major Remedial Measures

SAB PGS Reservoir Refurbishment Project

Comprehensive Post Implementation Review

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EXECUTIVE SUMMARY

The Sir Adam Beck Pump Generating Station (SAB PGS) is the only pumped storage plant in Canada. The station was commissioned in 1957. The plant's 300 ha reservoir is retained by a 7.4 km long ring dyke. The dyke's clay core is supported by rockfill shells with filter and transition zones.

A leakage incident occurred in June 1958, only a year after the first filling. Approximately 1 km long section of the dyke was remediated by grouting the bedrock foundation from Ch. 244+60 (east of headworks) to Ch. 29+80. The reservoir was returned to service in October 1958.

Since the 1980s a number of sinkholes and depressions have developed both within the reservoir and downstream of the dyke, raising the concern that there might be an on-going process of piping in the dyke foundation and the dyke integrity could be compromised. Historical information indicated that the bedrock may contain open and continuous joints that extend below the dyke. In 2008, OPG launched a program to determine whether a systematic deterioration of the foundation was occurring and if any remediation was required.

The project Concept Phase study was completed by [redacted]. in early 2011. Due to uncertainty in the nature and distribution of the bedrock voids, especially in the ancestral channels, [redacted] proposed an impervious liner over the entire reservoir footprint with additional bedrock grouting in some areas where master joints sets might be present. In 2011, [redacted] in conjunction with [redacted]. was retained by OPG to carry out the project Definition Phase study. [redacted] involvement was mainly to investigate the potential expansion of the reservoir storage. Around mid-2012, OPG concluded that the reservoir expansion was not economically feasible and [redacted] was no longer involved in the project.

Based on the historical information and analysis of the geotechnical investigations carried out in 2011, [redacted] developed the conceptual and detailed designs for the Short-Term and Long-Term Remedial Measures to improve the reservoir safety.

The Short-Term Remedial Measures were intended to improve the reservoir surveillance through a combination of site grading, drainage improvements and an upgrade of the geotechnical instrumentation at the site. This work was carried out between 2013 and 2015 by the Niagara Operations.

Construction of the Long-Term Remedial Measures was carried out from April 1, 2016 to January 17, 2017, during which the PGS reservoir was taken out of service and dewatered for construction. The major remedial measures included:

- Installation of a geosynthetic liner along the upstream toe of the dyke between Ch. 25+00 and Ch. 64+25 and between Ch. 220+00 and Ch. 235+00, and interior within the reservoir from Ch. 225+00 to Ch. 239+00;
- Carrying out the bedrock grouting program through the dyke core from Ch. 28+00 to Ch. 70+00;
- Construction of a downstream toe berm from approximately Ch. 53+00 to Ch. 60+00;
- Construction of a sediment blanket along the dyke upstream toe from Ch. 245+00 to Ch. 25+00; and
- Regrading and spreading of sediment at the historic Smeaton Creek tributary.

The construction activities to implement the remedial measures were completed in general conformance with the Technical Specifications developed during the Definition Phase. The As-Built Report summarizes the factual information obtained during the construction phase.

The reservoir commissioning was carried out between January 18 and February 1, 2017 by gradually filling the reservoir with a comprehensive monitoring program. A reservoir static head test was conducted on February 1 - 3, 2017 over 45 hours at the reservoir elevation of 625 ft. (IGLD55 datum; 190.65 m in IGLD85 datum). The reservoir elevation was raised to the maximum operating level of 627 ft (191.26 m) in the morning of February 4 as the last test of the commissioning. The reservoir was returned to service at 5:00 pm on February 4, 2017. Another static head test was carried out on July 18-20, 2017 to provide a baseline for the future static head tests.

Data collected between February 4, 2017 and July 20, 2017 revealed that the pore pressures beneath the liner had been reduced compared to the pore pressures in areas outside the liner footprint. This observation supports the benefit of the liner system to impede seepage flow paths near the upstream toe of the dyke and reduce the potential for sinkhole development. The data also confirms the increase in the seepage flow path and corresponding reduction in the hydraulic gradients below the dyke as intended from implementation of the Long-Term Remedial Measures. The rest of the data collected around the dyke are generally consistent with the historic trends and observations. In conclusion, the available data and observations do not indicate any reservoir performance issues and the reservoir should continue to operate safely for many decades to come as long as the appropriate operation, maintenance, and surveillance activities are carried out.

The project was completed within the budget: The estimated cost of the project, including the concept, definition and execution phases was $58.2M as indicated in the Execution Phase BCS. The actual cost of the project was $52.2M, about $6.0M below the estimated cost. The construction was completed ahead of the schedule: The estimated date to return the reservoir to normal operation was April 1, 2017 as indicated in the BCS. Actual date of in-service was February 4, about eight weeks ahead of the schedule.

This Comprehensive Post Implementation Review (CPIR) provides an overview of the project history with emphasis on the Execution Phase activities. At the end of each section, references were made to the lessons learned listed in Appendix A. A chronological list of major Execution Phase activities is provided in Appendix. B. The CPIR was prepared based on the Project Execution Report (PER) issued by [redacted] on December 21, 2017. The PER was prepared by [redacted] in cooperation with the OPG project team members. The draft CPIR was internally reviewed by Tony Bennett (Director, Dam & Public Safety), Peter Hassan (Director, Plant Engineering Services), Paul Burroughs (Director, Project Management) and Bryan Shaddock (Finance Controller) before submission for approval.

1. INTRODUCTION

SAB PGS and its storage reservoir are integral parts of the SAB hydroelectric complex. Along with its ability to store water during off-peak hours and generate power during higher priced on-peak hours, the PGS also helps to control the diversion flow to the SAB complex, and enables the SAB1 and SAB2 generating stations to provide additional peaking power and services such as Automated Generation Control and Operating Reserve.

The SAB PGS was commissioned in 1957. Its 300-ha reservoir is retained by a 7.4m long ring dyke. The dyke clay core is supported by rockfill shells with filter and transition zones. The reservoir normal operating range is from 600 ft. to 627 ft. (in IGLD55 datum; 183.03 m to 191.26 m in IGLD85 datum).

In 2008, OPG initiated the Reservoir Refurbishment Project to improve the safety of the reservoir. The project was carried out in three phases:

- Concept Phase: Investigation of the root causes of sinkholes and depressions observed over the years. It was carried out by [redacted] ([redacted]) between 2008 and 2011.
- Definition Phase: Detailed characterization of the site conditions, assessment of the PGS reservoir performance, conceptual and detailed design of the refurbishment activities. It was carried out by [redacted] ([redacted]) between 2011 and 2015.
- Execution Phase: Implementation of the refurbishment activities developed during the Definition Phase. The Execution Phase was carried out in two stages: Short-Term and Long-Term Remedial Measures. Implementation of the Short-Term Remedial Measures was carried out by OPG's Niagara Operations between 2013 and 2015 and included the work outside the reservoir to improve the monitoring and surveillance programs. The Long-Term Remedial Measures were constructed inside the reservoir from April 2016 through January 2017 when the reservoir was fully dewatered.

This Comprehensive Post Implementation Review provides a summary of the major project activities from start, with emphasis on implementation of the Long-Term measures and associated lessons learned.

2. PROJECT HISTORY AND OBJECTIVES

A major leakage was observed in 1958, only one year after the first filling in 1957 through the dyke at about Ch. 5+76. Following this incident, approximately 1 km long section of the dyke founded on bedrock was remediated by grouting the bedrock foundation from Ch. 244+60 to Ch. 29+80, and reconstructing approximately a 120 m long dyke section around Ch. 5+76. Additional clay blanket material was placed over the reservoir floor to seal areas of seepage concern as well as to cover the ancestral channels within the reservoir. The reservoir was returned to service in October 1958 after four months of repair work, and it has operated satisfactorily since then.

Since the 1980s, a number of sinkholes and depressions have developed both within the reservoir and downstream of the dyke, raising the concern that there might be an on-going process of piping in the dyke foundation and the dyke integrity could be compromised. Such mechanism was regarded as the main cause of the 1958 incident.

Although the containment dyke is still stable, the underlying bedrock may contain open, continuous joints below the dyke, which could result in water seepage from the reservoir over time and cause migration of fine-grained soils into the open joints. The northeast corner of the reservoir is the main area of concern,

as this is where the water depth is the highest and a strong downward seepage gradient exists. Such bedrock characteristics could make the foundation, and potentially the dyke itself, susceptible to sinkhole formation, which could lead to a dyke breach. A dyke breach would result in significant financial impact to OPG and its reputation, along with major safety and environmental effects to the surrounding community.

The objectives of the project Concept and Definition Phases studies were as follows:

(a) Determine whether a systematic deterioration of the foundation was occurring that would require remediation;
(b) If required, design remedial measures to mitigate the potential risks to allow for the continued safe operation of the SAB PGS reservoir; and
(c) Study the option of expansion of the reservoir capacity

In the 2015 Business Case Summary for the Execution Phase the overall project objective was stated as follows: "The Project will ensure that the PGS can continue to operate safely for the next 50 years. The project will also help to ensure that OPG can maintain its reputation as a safe dam operator and a trusted community partner."

3. PROJECT CONCEPT AND DEFINITION PHASES

3.1 Concept Phase

The root cause of sinkholes and depressions observed over the years around the reservoir was investigated during the Concept Phase and alternative conceptual designs were developed for remediation work. The Concept Phase study was completed by [redacted] in January 2011. A geotechnical investigation was not part of the Concept Phase. Key aspects of the work carried out by [redacted] included the following:

- Review of existing geotechnical, geological, and performance records;
- Assessment of the karst characteristics of the foundation;
- Seepage modelling;
- Assessment of possible mitigation measures that could be employed to reduce the risk; and,
- Development of alternatives for expanding the reservoir capacity.

[redacted] identified that the reservoir floor materials were primarily composed of non-engineered natural materials, which included sandy silt interbedded with fine sand seams. [redacted] considered that this material had too high hydraulic conductivity to provide a primary safeguard against excessive seepage into the underlying bedrock. This was considered to be the primary weakness of the facility. The bedrock characteristics, combined with the reservoir floor materials were identified as the root-cause for the sinkhole/depression formations observed.

The seepage modelling carried by [redacted] identified that the seepage gradients under the dyke could be reduced to acceptable levels by constructing a low permeability liner over the entire reservoir floor. [redacted] recommended that a Geosynthetic Clay Liner (GCL) or High Density Polyethylene (HDPE) liner be utilized, as they provided a balance between cost and service life. [redacted] also identified the need for localized bedrock grouting where master joint sets were present, to reduce seepage gradients to acceptable levels.

The liner and grout curtain were considered "long-term" remedial measures due to the time required to design, procure, and implement the work. In the interim period, [redacted] recommended that several short-term measures be undertaken, to improve monitoring of the reservoir performance.

[redacted] also developed conceptual designs of three alternatives to increase the reservoir capacity, i.e., footprint expansion, excavating the reservoir bottom where the elevations are higher than the minimum operating level and increasing the dyke elevations.

At the end of the Concept Phase, OPG decided to study in more detail the following items during the project Definition Phase.

- Remedial measures: Installation of an engineered liner to cover the entire bottom of the reservoir along with grouting of the dyke foundation in certain areas.
- Reservoir expansion: Excavation of the reservoir bottom and raising the dyke elevation to increase the reservoir capacity up to 35%. The option of raising of the dyke crest elevation was limited to a maximum of 2.0 m.

Together, these two work items were called the "Preferred Alternative" for the Definition Phase.

3.2 Definition Phase

3.2.1 Overview

At the conclusion of a competitive RFP process, the Owner's Representative (OR) Services Agreement was signed with [redacted] in April 2011 to procure the OR services for the Definition Phase with a provision of extending the agreement to cover the OR services during the Execution Phase.

The Definition Phase involved the following activities to further develop the "Preferred Alternative":

- Review of available historical information;
- Preliminary Geotechnical Investigation (PGI);
- Comprehensive Geotechnical Investigation (CGI);
- Reservoir expansion;
- Conceptual Design of remedial measures;
- Detailed design of remedial measures; and,
- Construction drawings and specifications.

3.2.2 Technical oversight

At the beginning of the definition phase, in March 2011, OPG's Director of Dam Safety and Emergency Preparedness established a panel of independent international experts, called the "Dam Safety Review Panel". The Panel's mandate was to provide advice and guidance to OPG on the technical aspects of the Project, and it reported directly to the Director.

The Panel was composed of the following members:

- Kaare Hoeg – Special Adviser at Norwegian Geotechnical Institute. Panel member since March 2011.
- Ray Stewart – Director of Dam Safety at BC Hydro. Panel member between March 2011 and July 2012.
- Joseph Ehasz – Vice President at URS Corporation. Panel member since June 2011.
- Kerry Rowe – Professor at Geo-Engineering Centre of Queens's University. Panel member since June 2011.

A total of 12 panel meetings (including 3 conference calls) were held with the Panel throughout the project Definition and Execution Phases.

3.2.3 Geotechnical Investigations

Two geotechnical investigations were carried out in 2011 to better understand the condition of the reservoir foundation. The key objectives of these investigations were as follows:

- Obtain geotechnical and geological information to enhance the overall understanding of the subsurface conditions;
- Assess the hydrogeological regime around the reservoir;
- Identify and characterize areas of concern with respect to dyke safety and reservoir leakage;
- Obtain data for the design of remediation works; and,
- Install additional geotechnical instrumentation to monitor reservoir performance and aid in the design of remediation works.

Preliminary Geotechnical Assessment

The purpose of the PGI was to obtain geotechnical information to assist with planning of the Comprehensive Geotechnical Investigation that would be conducted later. The PGI was carried out from May 30 to June 25, 2011 inside and outside the reservoir. For the in-reservoir investigation, the reservoir water level was lowered to elevation 608 ft on June 4-17, 2011 to expose only the western side of the reservoir floor.

Comprehensive Geotechnical Investigation

The CGI was carried out from September 26 through December 20, 2011 inside and outside of the reservoir. Dewatering of the reservoir commenced on October 17, 2011 to start the investigation inside the reservoir. The reservoir was re-watered and returned to service on December 2, 2011.

The investigations carried out during the CGI were similar to that of the PGI (borehole drilling, geoprobes, test pitting, etc.), however, the scope of work was expanded to cover the remaining areas of the reservoir bottom.

3.2.4 Conceptual Design Development

Based on the analysis of the PGI and CGI results and available historical information, [redacted] concluded that a failure of the PGS dyke could occur as a result of a sequence of events beginning with water moving through joints in the bedrock or through permeable bedrock fractures near the interface with the overlying soils. This flow of water has the potential to cause soil infill materials within open joints and factures in the bedrock to erode over time. Should a hydraulic connection occur below the dyke foundation to the eroded open joint/fracture, a failure of the dyke through a mechanism commonly referred to as piping, will in all likelihood be realized. Piping of the dyke foundation soils and filter materials could lead to deformation, slope erosion and ultimately a breach of the dyke. The residual risks posed by the reservoir and its long-term operation can be mitigated by reducing seepage gradients in critical areas of the dyke foundation, and providing an early detection system of the deteriorating conditions.

The proposed reservoir foundation improvement program focused primarily on the northeast and east section of the reservoir, where a number of features that could impact the dyke performance. Results of the PGI and CGI did not reveal any safety concerns that required immediate attention. The recommended upgrades were, therefore, proposed to be undertaken in a staged approach, as suggested by [redacted] in the Concept Phase study. The Short-Term Remedial Measures (STRM) entailed an upgrade of the existing surveillance and instrumentation monitoring system downstream of the PGS dyke. The Long-Term Remedial Measures (LTRM), which required complete dewatering of the reservoir, included installation of a grout curtain on the eastern side of the reservoir through the upstream shell of the dyke

and the placement of a partial liner. The STRM were recommended to be completed by 2014, while the LTRM be completed as soon as an extended outage could be arranged. OPG planned to execute the LTRM over a 12-month period from April 1, 2016 to March 31, 2017. [redacted] issued the final Conceptual Design Report to OPG on May 28, 2013.

3.2.5 Detailed Engineering

Following acceptance of the conceptual design by OPG, [redacted] proceeded with the detailed engineering in early 2013 with the following main tasks:

- Refining the conceptual design of the STRM and LTRM,
- Final design drawings and construction specifications for the STRM and LTRM.
- Basis of Estimate document for detailed cost estimate for construction of the LTRM
- Construction sequencing and scheduling.

Scope of Short-Term Remedial Measures

The objective of the STRM was to address the immediate need to enhance the instrumentation monitoring, landscaping and drainage system outside of the dyke. The scope of work of the STRM primarily focused on the following:

- Improving the grading of the existing perimeter ditch to better facilitate monitoring activities;
- Installation of a subdrain and infilling of surface depressions between Ch. 43+00 and Ch. 50+00;
- Construction of a deflector berm and sheet pile wall from Ch. 127+00 to Ch. 143+00 to direct surface runoff to Weir #4 and Weir #6, to better allow for detection of reservoir leakage;
- Upgrade of the existing piezometers to enhance groundwater monitoring downstream of the dyke;
- Installation of new pressure relief wells in areas of upward seepage gradients; and,
- Drilling of boreholes in areas where potential for liquefaction was identified.

The STRM program was implemented between 2013 and 2015 by OPG's Niagara Operations. During the STRM implementation, a potentially liquefiable material zone was identified between Ch. 54+80 and Ch. 57+80 at the downstream (outside) toe of the dyke. To improve the dyke stability under seismic loading, it was decided to include a stabilizing toe berm as part of the LTRM scope.

Scope of Long-Term Remedial Measures

The LTRM include those activities to mitigate the potential failure modes for the dyke identified early in the Definition Phase. The major scope of work items included the following:

- Dewatering of the reservoir, including the rescue and relocation of native fish species;
- Construction of access roads;
- Removal of sediment within the liner footprints;
- Installation of liner along the upstream toe of the dyke between Ch. 25+00 and Ch. 64+25 and between Ch. 220+00 and Ch. 235+00, and interior within the reservoir from Ch. 232+00 to Ch. 239+00;
- Construction of the grouting access platform from approximate Ch. 28+00 to Ch. 70+00;
- Carrying out of the trial grouting activities outside the dyke at Ch. 38+00 and Ch. 48+00;
- Carrying out production grouting activities from Ch. 28+00 and Ch. 70+00;
- Construction of a downstream toe berm from approximately Ch. 53+00 to Ch. 60+00;
- Construction of a sediment blanket along the dyke upstream toe from Ch. 245+00 to Ch. 5+00;
- Regrading and spreading of sediment within the historic Smeaton Creek tributary.

Construction of the LTRM was carried out from April 1, 2016 to January 17, 2017 during the project Execution Phase as described in Section 4.

4. PROJECT EXECUTION PHASE / PRE-CONSTRUCTION

4.1 Project Delivery Strategy

A design-bid-build contracting approach was selected for the project to minimize costs while maintaining a high level of control over the design and technical aspects of the project.

4.2 Procurement

4.2.1 Owner's Representative Services

The OR agreement was signed with [redacted] in April 2011 for the Definition Phase and it was amended in February 2016 to retain [redacted] to perform the OR services during the Execution Phase as well.

4.2.2 Construction Services

The procurement process for the construction services started with a public advertisement by OPG on November 4, 2014, to invite general contractors for prequalification. The construction of the remedial measures included two major activities: Grouting and liner installation. To ensure the quality construction work, the grouting and liner companies were also prequalified along with the (general) contractors. A significant amount of project technical information was shared with the prequalification proponents.

The results of the prequalification were announced in February 2015. OPG issued the Request for Proposal (RFP) to four prequalified general contractors ([redacted]) on March 16, 2015. The general contractors were required to select a grouting and a liner supply/installation partner from the prequalification list. The RFP closed on May 12, 2015. OPG selected [redacted] as the preferred contractor in June 2015, subject to final negotiations and the OPG Board's approval of the funding release for the Execution Phase. The Construction Services Agreement (CSA) was signed by OPG and [redacted] by the end of August 2015 after the release of the project funding by the OPG Board.

4.3 Project Team

4.3.1 OPG Team

Key members of the OPG project team involved in the construction:

- Project management: Mahir Aydin, Clara Greco, Andre Friedmann
- Technical support: Peter Hassan, Paul Toth, Alain Diallo, Jie Lao, Tareq Salloum
- Environmental support: Ed Naval, Dave Stanley
- PGS FLMs: Dave Thom, Ray Dejonge
- Public relations: Steve Repergel
- Supply chain: Kim Severin, Diane Anderson
- Legal support: John Kalm
- Finance control: Mark Del Frari

4.3.2 Owner's Representative

Key members of the OPG project team involved in the construction:

- Project management: Peter Merry
- Technical support: Shu Kam (senior advisor), Frank Barone (liner specialist), Vafa Rombough (grouting specialist), Mike Lemon (hydrotechnical specialist and deputy project manager), Brian Andruchow (site engineer)
- Field support: Carl Linyard, Natalie Solis, Simon Lutz, Chad Springer, Jeremy Hoy, Caitlyn Cartwright, Roman Elazar
- Environmental support: Alyson Beal, Brett Thomson
- Document management: Shanti Vaz

4.3.3 Contractor

Key members of the [redacted] project team:

- Project management: [redacted]
- Construction superintendent: [redacted]

[redacted] major subcontractors:

- Dewatering: [redacted]
- Fish recue and environmental services; [redacted]
- Grouting: [redacted]
- Liner supply and installation: [redacted]

4.3.4 Technical Oversight

As described in Section 3.2.2, the project technical oversight was provided by an independent panel of three geotechnical experts, reporting directly to Tony Bennett, the Director of the Dam Safety and Emergency Preparedness.

4.4 Project Approval Process

This was the first Hydro-Thermal Operations project that has gone through the Gate Review Board (GRB) process. A project introduction meeting was held with GRB on May 29, 2015. The following key documents were submitted to GRB for review on July 6: Business case Summary (BCS), draft Board Memo, Project Execution Plan, Project Definition Rating Index report, Risk register, and [redacted] RFP response.

A second meeting was held with GRB on July 13, 2015 to discuss the board members' comments. The GRB issued its concurrence report to the Senior Vice President of HTO on July 21, 2015. The OPG Board approved the release of the project fund on August 21, 2015 following a review by the Executive Leadership Team, recommendation by the Senior Vice President, approval by the President, and recommendation by the Board Risk Oversight Committee of the BCS and Board Memo,

4.5 Overview of Business Case Summary

4.5.1 Release Amount

The estimated cost of the Execution Phase of the Sir Adam Beck Pump Generating Station Reservoir Refurbishment Project is $47.4M. Since the Definition Phase was underspent by $2M, the release amount requested was $45.4M for the project execution. The release value was based on Class 2 quality estimate, with a 95% confidence level. The estimated $47.4M included $10.2M contingency. Combined with the costs of the Concept and Definition Phases, the total project cost would be $58.2M.

4.5.2 Preferred Alternative

The preferred alternative for the Execution Phase is to carry out the reservoir refurbishment work to reduce the risk of seepage from the reservoir that can lead to a dam safety event. The project was identified in the facility's Life Cycle Plan (2014) and included in the 2014-2016 business Plan. The project is in line with the OPG's mandate to maintain and develop hydroelectric resources.

The financial evaluation of the project in 2015 based on the updated System Economic Values and the project cost showed that the continued operations of the PGS would provide a Net Present Value (NPV) of $528M to the Ontario electricity system over the next 30 years. The PGS is a regulated hydroelectric asset and receives regulated rate for energy. The impact on regulated Hydro rates to recover the cost of this project was estimated to be less than $0.2/MWh in 2016. The work was scheduled for execution between April 1, 2016 and March 31, 2017.

4.5.3 Other Alternatives

(a) Base case: Decommission reservoir (no refurbishment)

This alternative was not recommended because it would result in the shutdown and removal of the SAB PGS from operations because of the dam safety concerns. The cost of shutting down the station and putting it in a safe state was estimated around $56M. This option had a NPV of negative $25M over the 30-year assessment period.

(b) Delay refurbishing reservoir

This alternative was not recommended because deferring the refurbishment of the PGS Reservoir for a long time would expose OPG to a greater risk of seepage and bedrock piping under the dyke, which can lead to potential sinkhole formation or dyke failure in certain areas. Given the analysis and site investigation completed during the Definition Phase, it is prudent for OPG to implement remedial measures to address the issues discovered as soon as possible. If a dam safety event were to occur during the time that the reservoir refurbishment is deferred, it would have severe impacts on OPG's reputation as a safe dam operator and its standing in the community. The cost and net present value of this alternative was not assessed. Given the dam safety and reputational risks related to this alternative, it was ruled out prior to being financially evaluated.

(c) Refurbish reservoir and expand reservoir capacity

This alternative was not recommended. During the definition phase, three options of reservoir expansion were studied:

- Expanding the reservoir footprint;
- Raising the height of the PGS dyke perimeter; and
- Excavating the reservoir bottom where elevations are higher than the minimum operation level.

Although, increasing the height of the dyke perimeter appeared to be the lowest cost per volume increase, a financial analysis carried out by OPG in 2012 showed that even this expansion option was not economical under a wide range of market conditions.

4.5.4 Risk Assessment

Qualitative Risk Assessment:

The following major risks were identified in the BCS:

Risk-1: Inclement weather impact on the construction schedule and cost (probability: high; impact: high)

- Definition: Extended periods of rain are the biggest threats, as they affect dewatering, sediment removal and relocation, and liner installation. Windy weather may also result in safety concerns during liner installation.
- Mitigating strategies: (a) Weather forecasts will be considered in scheduling the critical work; (b) The construction schedule includes a 3-month contingency for adverse weather conditions and other delays.

Risk-2: Unexpected conditions of the dyke core and bedrock (probability: medium; impact: high)

- Definition: The grouting work may be extended due to potential damage to the dyke core and filters during drilling and grouting, unexpected conditions of the core and excessive grout take in bedrock.
- Mitigating strategies: (a) Dyke core and bedrock conditions had been extensively studied during the Concept and definition Phases, (b) OR developed the grouting strategies in consultation with the Panel and OPG experts, (c) OR will provide the QA services and participate grouting decisions during work execution. Historical information Grouting specifications developed by [redacted] have been reviewed and commented by OPG, Dam Safety Panel and the grouting companies.

Risk-3: Scope changes due to new discoveries (probability: medium; impact: high)

- Definition: The potential new discoveries during the construction may require changes in the scope of work.
- Mitigating strategies: (a) Contingencies are included in the project cost and schedule; (b) OR will have resources at the site to respond quickly to changing site conditions.

Risk-4: Excessive sediment over the reservoir floor (probability: medium; impact: high)

- Definition: Sediment volume that is significantly more than the estimated amount may delay the construction activities due to the additional volume and longer drying times of the sediment.
- Mitigating measures: (a) Contingencies are included in the project cost and schedule; (b) the risk and sediment management alternatives were extensively discussed with the general contractors participated in the RFP process.

Risk-5: Liner not connected properly to the dyke tongue (probability: medium; impact: medium)

- Definition: If the liner is not properly connected to the dyke tongue in the key trench, new seepage pathways may be created through the dyke foundation. This risk will arise especially if the tongue material cannot be clearly identified during the key trench excavation.
- Mitigating strategies: (a) The key trench design has been extensively studied, (b) OR will be present and provide QA services during the key trench excavation and liner installation.

Risk-6: Excessive liner rework (probability: medium; impact: medium)

- Definition: Poor quality liner manufacturing or damage to the liner during installation could result in extensive liner rework, schedule delay and cost increase.
- Mitigating strategies: (a) Quality assurance practices by the prequalified liner suppliers had been assessed during the procurement process, (b) technical specifications were developed for QC/QA of liner handling, storage and installation; (c) OR will provide quality assurance services during liner installation.

Quantitative Risk Assessment:

A quantitative risk assessment was carried out to calculate these contingencies. The following areas of uncertainty were included in the assessment:

- Cost Estimate Uncertainty: The OR issued a Basis of Estimate (BOE) report to estimate the construction cost based on Class 2 quality estimate. The document was prepared in cooperation with the cost estimate expert of OPG RGPM PM Office. The BOE included over 60 cost items. For the quantitative risk analysis, best case, worst case and most likely estimates were determined for each cost item.
- Schedule Uncertainty – The OR and OPG Project Manager estimated the best case, worst case and most likely scenario for the project in-service date.

A Monte Carlo Simulation was run based on the quantified cost and schedule uncertainties to develop the project cost distribution curve. The process was similar to the project cost model developed for the Lower Mattagami River Project and New Post Creek Project. The model also took into account potential variability in interest rates and escalation rates.

As result of the quantitative risk analysis a cost contingency of $10.2M was determined to cover the project costs at a 95% confidence level. The cost estimate for the execution phase (excluding the contingency) was $37.2M, and with the contingency, it totaled to $47.4M. The cost breakdown is provided below:

Cost Item	Budget in BCS ($M)
Project Management and Administration	1.1
Owner's Representative	3.7
Construction	30.4
Interest During Construction (IDC)	2.0
Subtotal	37.2
Contingency	10.2
Total	47.4

4.6 Owner Only Contract Execution

The construction was managed based on OPG's Owner Only approach to assign the contractor as the constructor as defined in the OHSA. Prior to the construction commencement, a master copy of a Memorandum of Understanding (MOU) was prepared by OPG in agreement with the contractor. The MOU included the Construction Island (CI) boundaries required by the contractor, communication protocol for emergency and non-emergency situations, site access, security, etc. The MOU and the Control of Hazardous Energies Walkdown Sheet were updated and signed by OPG and the Contractor whenever the Contractor required changes to the CIs.

4.7 Construction Planning

4.7.1 Construction Planning Meetings

Between September and December 2015, a series of meetings were held between OPG, [redacted] and the Contractor (including their subcontractors in some meetings). The main purpose of these meetings was to clarify the scope of work and optimize the work execution.

The construction contract (i.e., CSA) included a provision where, if accepted, the savings associated with a design revision proposed by the Contractor would be shared equally between both parties. The Contractor proposed several design revisions for cost savings. The most significant of these revisions

was the reduction in the width of the grouting access platform from 10.0 m to 8.5 m. The original design of 10 m-wide access platform would extend over the liner area which would necessitate the liner completion before construction of the platform. The width reduction reduced the construction volumes, but more importantly, decoupled the partial liner and grouting work schedules, allowing each activity to be carried out independently. Other significant scope revisions made prior to start-up of the construction activities included upgrades to the site roads outside the reservoir, inclusion of a ramp into the reservoir at Ch. 70+00 to provide access to the grouting access platform prior to complete dewatering of the reservoir, and revision to the liner outer access road construction method.

Negotiation of the cost impacts of the proposed changes was finalized in March 2016. The result of the negotiation was OPG's acceptance of the scope revisions proposed by the Contractor, and a net reduction in the total cost of the work.

4.7.2 Construction Execution Plan

The Technical Specifications required the Contractor to submit a Construction Execution Plan (CEP) to OPG for review before construction. CEP was a detailed overview on the plans and processes the Contractor would follow to execute the work. It included a detailed description of the construction schedule, work sequence, quality control program, environmental management plan, health and safety policies, security, etc. However, the Contractor was not contractually obligated to follow the CEP and had the flexibility to deviate from it to refine its work execution as the work progressed. Based on the discussions at the construction planning meetings and the content prescribed in the Technical Specification, the Contractor issued the CEP to OPG by the end of December 2015.

4.7.3 Use of Niagara Tunnel Material

Prior to start-up of the construction activities, the granular material of the Niagara Tunnel boring machine stockpile was investigated for potential use as construction material. It was found suitable as general fill and for access road/ramp construction. The stockpile of coarse rockfill remained from the Niagara Tunnel canal excavation was also crushed and utilized for construction of the grouting access platform. Part of this material was recovered during the access platform removal and spread out as the erosion protection cover over the liner.

4.7.4 Pre-Construction Static Head Test

A Static Head Test (SHT) was carried out on January 18 -19, 2016 at the reservoir water elevation of 625.0 ft (2ft below the maximum reservoir elevation of 627ft). The results of the SHT indicated that there was no measurable seepage from the reservoir.

4.8 Lessons Learned from Pre-Construction Activities

- See Appendix A, Section 2.1 and for OPG and OR teams' and Panel's involvement in the project.
- See Appendix A, Section 2.2 for procurement of the construction services.
- See Appendix A, Section 2.3 for content of the Construction Services Agreement.
- See Appendix A, Section 2.4 for OR team's presence at the site during construction.
- See Appendix A, Section 2.5 for the payment process for the construction work.
- See Appendix A, Section 3.1 for scope clarification and construction planning meetings.
- See Appendix A, Section 3.2 for the CEP.

5. PROJECT EXECUTION PHASE / CONSTRUCTION

5.1 Dewatering and Fish Rescue

Dewatering of the reservoir commenced April 1, 2016. The duration and pond elevation at each stage was determined based on 2011 CGI dewatering experience. The bulk volume of the reservoir was dewatered by gravity drainage through the headgate PG6B.

The fish rescue operation took place between April 2 and May 26, 2016. The program focused on the capture and relocation of native species in the early stages of dewatering, and capture of the invasive species during the later stages of dewatering. Native fish were relocated to the Niagara River at the Queenston Dock and invasive fish were euthanized.

As part of the permit to dewater the reservoir, the Ministry of Environment and Climate Change (MOECC) imposed limits on the turbidity of the water discharged from the site and the impact to downstream receiving water bodies. These conditions included the requirement to implement a comprehensive turbidity monitoring program during active dewatering. Monitoring was undertaken by [redacted] and the Contractor. Turbidity of water within the reservoir and the power canals was monitored almost daily between April 11, 2016 and May 6, 2016, and periodically until October 2016 during active discharge of the rain water from the reservoir. Turbidity was monitored at six locations (inside the reservoir, PGS tailrace, SAB1 and SAB2 forebays, SAB1 canal and Niagara Tunnel outlet canal). Turbidity levels were typically less than the turbidity target, with only two reported incidents of visible sediment plume at the PGS tailrace. In each case, the headgate was quickly closed to stop further discharge and MOECC was immediately informed of the incident. The work continued inside the reservoir without interruption.

5.2 Access Road Construction

Construction of the liner inner and outer access roads, as well as upgrading of general haul routes within the reservoir, commenced soon after completion of the dewatering activity. The liner inner access road was constructed in accordance with the design. Haul roads within the reservoir were widened using granular material sourced from the Niagara Tunnel Boring Machine (NTBM) stockpile. During widening of old Portage Rd, at the eastern extents of the reservoir, tar was encountered. Tar was removed as part of the road widening and disposed of at an appropriate offsite facility. Following discussion with OPG, it was decided that the extents of the tar would not be chased, and would remain undisturbed in-place.

5.3 Trial Grouting

Trial grouting was carried out between March 28 and June 8, 2016, and involved construction of two 24 m long trial sections located downstream of the reservoir at approximate Ch. 48+00 (North Grout Trial Area) and Ch. 38+00 (South Grout Trial Area). The intent of the trial was to refine the specified grouting procedures to be used for the main production grouting program. The trial also permitted partial commissioning of ACT's grouting equipment ahead of the main production work.

On April 28, 2016, the trial grouting program was suspended following a report of a grout release to the Queenston Seep. At the time of the incident, the trial grouting program had been largely completed and the expected information had already been gathered. The key changes to the production grouting program as a result of the trial grouting experience and grout release, included:

- Elimination of the need to treat the overburden/bedrock contract. All grouting efforts to focus solely on bedrock treatment; and
- Revised grouting protocols to reduce the potential for further grout transport to the Queenston Seep.

5.4 Queenston Seep

The Queenston Seep provides habitat for the provincially endangered Allegheny Mountain Dusky Salamander. As stated above, the trial program was suspended on April 28, 2016, following a report of a grout connection to the Queenston Seep, located along the nearby Niagara Gorge. The incident was immediately reported to the Ministry of Natural Resources and Forestry (MNRF), MOECC and Niagara Parks Commission (NPC).

At the request of OPG, the Contractor retained Beacon to prepare a Remediation Plan for the grout clean-up efforts to be undertaken at the Queenston Seep. Following the agencies' concurrence, the Remediation Plan was implemented on May 19 – 20, 2016.

The Project was registered with the MNRF as a "health and safety project" under the Endangered Species Act. This registration included a mitigation strategy to prevent future grout releases to the habitat. The strategy required construction of a diversion system at the Queenston Seep and revised grouting protocols. A dye tracer test was also carried out and it confirmed that Queenston seep was hydraulically connected to the bedrock at the North Grout trial area but not to the South Grout trial area.

The Detailed Mitigation Strategy was accepted by the agencies and they granted permission for the production grouting activity to continue. No further off-site transport of grout was observed for the rest of the construction. The Queenston Seep diversion system was decommissioned after completion of the production grouting activity.

As a result of the Queenston Seep connection, the MNRF required OPG to implement a long-term strategy, including salamander surveys up to seven years, to ensure sustainability of the salamander habitat.

5.5 Grouting Access Platform Construction and Exploration Drilling

A grouting access platform was constructed on the upstream slope of the dyke for the grouting equipment. A temporary ramp was built on the downstream slope of the dyke to start the construction of the grouting access platform while the dewatering activities continued.

Early in the Execution Phase, when the Contractor decoupled the grouting activities from the liner installation by making the grouting access platform narrower, it was identified that exploration drilling along the platform would be required to verify the grout curtain alignment. The results of the exploration drilling confirmed that the design alignment was appropriate, with only a minor adjustment required between Ch. 28+00 and Ch. 30+00.

Following completion of the production grouting activity, the grouting access platform was removed, and the dyke rip rap restored to its original condition. The volume of rockfill recovered from the grouting access platform was approximately 80% of the fill volume placed. The 20% material loss appeared to be the result of the platform rockfill infilling the larger voids of the existing dyke rip rap. The rockfill loss was made up with material sourced from an offsite quarry and the on-site TBM stockpile.

5.6 Liner Installation

5.6.1 Sediment Removal

The sediment volume and consistency at the bottom of the reservoir was identified a major risk item at the end of the Definition Phase.

The Contractor commenced the sediment stripping activity following advancement of the liner outer access road. By this time, the sediment had sufficiently dewatered to allow for it to be stripped by

excavator. The warmer and relatively dry summer of 2016 helped significantly in drying of the sediment. Once dried the material was hauled to the final placement location.

Review of the post-stripping survey data suggested that, during bulk sediment removal, the Contractor removed some of the native reservoir floor material. While the depth of excavation was relatively thin, the volume of over-stripping was significant due to the large footprint of the work area.

Sediment stripped from the liner footprint was placed as a blanket along the dyke upstream toe from Ch. 245+00 to Ch. 5+00, and within the interior of the reservoir at the low-lying area of the historic Smeaton Creek tributary.

The sediment volume in the contract was estimated based on sediment thickness measurements taken during the CGI and PGI. At the time of the CGI and PGI, the sediment was not exposed long enough to allow for sufficient desiccation and strength gain to support foot traffic. The average sediment thickness assessed at the time of the CGI was 0.3-0.5 m. The actual average sediment thickness during construction was about 0.7 m.

5.6.2 Liner placement

The HDPE liner was supplied and installed by [redacted]. Installation was carried out following the industry-standard procedures. The Technical Specifications required that [redacted] welding technicians hold certification from the International Association of Geosynthetic Installers (IAGI). At the Contractor's request, this requirement was removed, to allow for [redacted] to increase their crew size and take advantage of good weather conditions. However, to maintain a high quality of work additional constraints were introduced on the welding technician's experience and QA testing was increased.

Liner installation commenced at the Ch. 220+00 to Ch. 235+00 liner area, and then proceeded from Ch. 25+00 towards Ch. 64+25. Continuous grading of the subgrade was required up to and immediately preceding the liner deployment, to repair damage resulting from precipitation and heavy equipment traffic. Significant effort was also required to maintain suitable condition of the key trenches.

GCL was also supplied by [redacted] and manufactured by [redacted] based in the U.S.A. Installation of the GCL within the HDPE liner key trenches and at the "GCL only" area was carried out by the Contractor. The GCL seaming and repair process did not involve specialty equipment and training as did the HDPE liner.

5.6.3 Granular Cover Layers

Following the installation of HDPE liner, the Contractor commenced spreading of the 32 mm minus granular cover. It was typically carried out in the morning due to the risks of thermal expansion of the liner and wrinkling typically during the afternoon. The use of a white surfaced geomembrane on the top side (bottom side was black) was a key aspect for reducing the liner temperature and thermal expansion.

The Contractor was not able to locally source the suitable 32 mm minus granular cover layer material. At the Contractor's request, OPG/[redacted] accepted a locally available material with increased fines content. While the material satisfied the design intent, the higher fines content increased the material's moisture sensitivity. This resulted in additional effort from the Contractor to repair erosion and manage saturated conditions. During the long period (several weeks) between spreading of the 32mm minus material and later 200mm rockfill cover layer, frequent grading and erosion from precipitation resulted in thinning of the 32 mm minus granular cover to less than the design thickness. In response, [redacted] and the Contractor undertook a detailed investigation to ensure the proper thickness of the 32 mm minus granular cover by adding extra material.

5.7 Production Grouting

The production grouting activities were delayed as a result of the grout connection to the Queenston Seep. On June 17, 2016, OPG received approval from the regulatory agencies to proceed with the planned bedrock drilling and grouting activities between Ch. 55+00 and 70+00 until the revised grouting procedures were developed and the Queenston Seep diversion system was installed. This section of the dyke was the furthest from the Queenston Seep and considered unlikely to connect to the seep based on Golder's understanding of the bedrock hydrogeology. Throughout the work progression, additional modifications were made to the grouting procedures to accommodate field conditions.

The production grouting activity became the project critical path. To recover delays associated with grout release, [redacted] was requested to mobilize a third grout plant to the site which was subsequently commissioned on September 20, 2016. This allowed [redacted] to simultaneously inject grout at an increased number of holes, increasing the overall production rate. The bedrock grouting activity was successfully completed on December 15, 2016 without any new grout release.

5.8 Communication with Contractor

Prior to the construction, a communication protocol was established between OPG, [redacted] and the Contractor. Three formal document types were utilized throughout the construction to create a transparent paper trail for the key decisions:

- Request for Information (RFI): Issued by [redacted] or the Contractor to provide a formal request for information transfer between parties for design clarifications, scope clarifications, requests for data, and requests for additional scope.
- Field Communication (FC): Issued by [redacted] to the Contractor to provide formal instructions on technical issues.
- Project Change Directive (PCD): Issued by OPG to the Contractor to document the cost and schedule impacts of the agreed scope changes.

A weekly construction meeting was held between OPG, [redacted], and the Contractor at the site, attended by the management teams from all three parties. The meetings were facilitated and meeting minutes were issued by [redacted]

5.9 Lessons Learned from Construction Activities

- See Appendix A, Section 4.1 for lessons learned from Owner Only contract execution.
- See Appendix A, Section 4.2 for communication between OPG/OR and Contractor.
- See Appendix A, Section 4.3 for Contractor's construction management.
- See Appendix A, Section 4.4 for the site security and safety during construction.
- See Appendix A, Section 4.5 for the construction environmental management.
- See Appendix A, Section 5.1 for the reservoir dewatering activities.
- See Appendix A, Section 5.2 for sediment removal from the bottom of the reservoir.
- See Appendix A, Section 5.3 for the road construction and use of the material stockpiles remained from the Niagara Tunnel project.
- See Appendix A, Section 5.4 for liner installation.
- See Appendix A, Section 5.5 for grout trial.
- See Appendix A, Section 5.6 for production grouting
- See Appendix A, Section 5.7 for grout release at Queenston Seep

6. PROJECT EXECUTION PHASE / POST-CONSTRUCTION

6.1 Reservoir Commissioning and Return to Service

In the weeks preceding completion of the construction activities, OPG and [redacted] carried out several site tours with the Contractor to identify outstanding work items that must be completed prior to their site demobilization. Upon completion of the outstanding items inside the reservoir, [redacted] issued a letter to OPG to confirm that the construction activities within the reservoir had been completed in accordance with the Technical Specifications, and that OPG could proceed with the planned commissioning activities documented in the Commissioning Plan prepared OPG and [redacted].

Commissioning of the reservoir was carried out from January 18 to February 1, 2017. The reservoir was rewatered in a staged approach, allowing time for observations and data collection before further filling, including daily visual observations from the dyke crest and around the dyke perimeter, piezometer and weir measurements and, visual observations and flow measurements at the Queenston and Smeaton Creek seeps.

Following the commissioning work, a Static Head Test (SHT) was carried out on February 1-3, 2017. After the SHT, the reservoir elevation was raised to the maximum operating level of 191.26 m (627 ft) in the morning of February 4 with further monitoring. During commissioning monitoring, increases in groundwater response, most notably at the vibrating wire piezometers located within the reservoir, were observed compared to historic data. A similar trend was observed during the SHT. This increase in groundwater response was attributed to re-saturation of the reservoir floor material.

Upon completion of the commissioning on February 4, 2017, [redacted] issued a letter to OPG indicating the following:

- The results of the commissioning and SHT were in general accordance with historic trends and observations;
- The available data did not indicate any issues for the reservoir performance; and
- OPG could return the reservoir to regular service.

The reservoir was returned to service at 5:00 pm on February 4.

6.2 Post-Commissioning Activities

As recommended in the Commissioning Plan, OPG continued with monitoring of the reservoir following completion of the commissioning activities.

6.2.1 Bubbling over Liner Areas

During a routine inspection on February 7, 2017, gas bubbling was observed approximately 30 m upstream of the dyke crest at Ch. 220+00. At the time of observation, it was thought that the bubbling resulted from the release of gas trapped below the liner. The gas could be ambient air and/or biogas produced from decay of organic material. In response, OPG carried out inspections of the reservoir with increased frequency, anticipating that further gas release may occur at other local topographic highs of the liner areas as well. On March 13, 2017, OPG observed another gas bubbling approximately 30 m upstream of the dyke crest at Ch. 34+00. On an August 23, 2017, gas bubbling was also observed at Ch. 55+00 (65 m upstream of dyke crest) and at Ch. 64+25 (35 m upstream of dyke crest).

Initial inspections at the Ch. 220+00 area were conducted on February 9, at a time when the reservoir water elevation was lower than 188.7 m (618.6 ft) to permit safe access on foot. The inspection revealed the presence of pressurized gas below the liner and a localized blister.

The bubbling area at Ch. 34+00 remains submerged under normal operating conditions, and so initial investigations were conducted using OPG's multibeam sonar equipment on May 9 and 12 and the Remotely Operated Vehicle (ROV) on August 4. The ROV inspection confirmed the presence of a blister in the liner, similar to that observed at the Ch. 220+00 area. In response, OPG lowered the reservoir water level to the elevation of 183.03 m (600 ft) on August 23, exposing the blister and allowing for a foot inspection.

The blistered liner was intentionally punctured to vent the pressurized gas at the Ch. 220+00 and Ch. 34+00 areas on February 14 and August 23, respectively. A basic, self-actuating vent was then constructed to allow for continuous venting of gas, while impeding the inflow of water to below the liner. The gas emanating from both the Ch. 220+00 and Ch. 34+00 area was sampled and assessed to be primarily ambient air, with a small component of biogas. The main source of the gas was most likely the ambient air trapped in the unsaturated pore space of the reservoir floor material during the construction.

Another ROV investigation was carried out on November 6, 2017, around all four gas bubbling areas, and no gas bubbling or liner blisters were observed. Monitoring of all four locations will continue in the future along with the regular visual inspections.

6.2.2 Construction of a New Toe Drain

During the spring of 2017, seepage and runoff was observed flowing across the downstream access road at Ch. 46+50, causing rutting and overall wet conditions in the area. These conditions were similar to previous years and were typically limited to spring occurrences and periods of heavy rain. To promote drainage off the roadway, a toe drain was installed along the downstream toe of the dyke with a drainage pipe that conveys the water through a pipe beneath the access road. The pipe outlets into the perimeter ditch where the flow rate can be observed during future routine monitoring. This work was carried out in late August 2017.

6.2.3 July 2017 Static Head Test

Periodic SHTs are conducted to monitor the reservoir performance over 45 hours under steady reservoir elevation around 625 ft (IGLD55, 190.65 m in IGLD85). Another SHT was scheduled for June 27-29, 2017 after about 5 months of reservoir operation. However, the test had to be rescheduled due to heavy rain and it was carried out between July 18, 8am and July 20, 5am as over 45 hrs as planned.

The key objectives of the July 2017 SHT were as follows:

- Measure the reservoir losses under steady-state conditions;
- Measure the groundwater response and compare the results to previous SHTs;
- Assess the impacts of the Long-Term remedial measures on the reservoir performance; and
- Provide a baseline for future SHTs to be conducted in every 5 years, preferably in June or July with no or minimal rain event.

At the start of the test, the reservoir elevation was 625.35 ft (190.76 m). Throughout the test a team of OPG and [redacted] personnel visually monitored the reservoir for key performance indicators (e.g. slope stability, presence of seepage, etc.). The groundwater response to filling of the reservoir was also measured at select piezometers located around the reservoir perimeter and interior.

The following conclusions were drawn from the July 2017 SHT results:

- The reservoir elevation dropped by about 1 cm over 45 hrs. About 75 percent of the drop was due to evaporation. The remaining 2-3 mm drop was expected due to the headgate leakage.
- There is no measurable seepage from the reservoir.
- The measured pore pressures measured by the Vibrating Wire Piezometers (VWP) installed under the liner demonstrated a reduction in pore pressure beneath the liner, compared to the pore pressures in areas outside of the partial liner footprint. This observation supports the benefit of the liner system to impede seepage flow paths near the upstream toe of the dyke and reduce the potential for sinkhole development. The test results confirm also that the liner was effective at reducing hydraulic gradients under the dyke.
- The groundwater response to filling of the reservoir in the grouting area (Ch. 28+00 to Ch. 70+00) was similar to that measured during previous SHTs. The primary purpose of the grout curtain was to reduce subsurface flow paths and impede the subsurface migration of overburden materials (i.e. mitigate potential mechanism for sinkhole formation). As documented in the As-Built Report, the grouting program was successful in achieving the design reduction in bedrock permeability.

7. PROJECT OUTCOMES

7.1 Effectiveness of Executed Work in Meeting Business Need

As indicated in Section 2, the overall project objective was to ensure that the PGS can continue to operate safely for the next 50 years and OPG can maintain its reputation as a safe dam operator and a trusted community partner.

Detailed geotechnical investigations carried out in 2011 were instrumental in characterizing the condition of the reservoir and its foundation. The main objective of these investigations was to assess whether a systematic deterioration of the foundation was occurring, that would require remediation. The investigations revealed that there was a deterioration risk of the reservoir foundation in some areas. Based on the results of the investigations, designs of the remedial measures were developed that would allow continued safe operation of the SAB PGS reservoir.

The remedial measures were broken down into two phases: Short-Term and Long-Term Remedial measures. The STRM were aimed at improving the instrumentation monitoring and visual surveillance outside the reservoir. The primary components of the LTRM were construction of a bedrock grout curtain beneath the dyke and installation of liners in critical areas of the reservoir with the objective of lowering the seepage gradients and hydraulic conductivity beneath the dyke foundation. The construction activities to implement the remedial measures were completed in general conformance with the Technical Specifications and design intent developed during the Definition Phase. The As-Built Report summarizes the factual information obtained during the construction phase.

Data collected between returning the reservoir to service on February 4, 2017 and the end of the last reservoir static head test on July 20, 2017 revealed that the pore pressures beneath the liner had been reduced compared to the pore pressures in areas outside of the partial liner footprint. This observation supports the benefit of the liner system to impede seepage flow paths near the upstream toe of the dyke and reduce the potential for sinkhole development. The data also confirms the increase in the seepage flow path and corresponding reduction in the hydraulic gradients below the dyke as intended from implementation of the Long-Term Remedial Measures. The rest of the data collected around the dyke are generally consistent with the historic trends and observations. In conclusion, the available data and observations do not indicate any reservoir performance issues and the reservoir should continue to

operate safely for many decades to come as long as the appropriate operation, maintenance, and surveillance activities are carried out.

7.2 Safety and Security

Contractor's overall safety performance was satisfactory considering the challenging site conditions encountered within the Reservoir and at the Queenston Seep. There was no lost time or serious injuries during the construction. The contractor indicated that they had safety meetings daily, weekly and as-required basis. In addition, [redacted] produced a site-orientation video for safety training for all its employees on their first day at the site.

There was no security incident at the construction site. OPG's regular security patrol by the OPG and the [redacted] security staff continued throughout the construction. The Contractor was allowed to enter the site only through the entrance at the Stanley Avenue. The Contractor hired [redacted] to provide the additional security check at that entrance during the working hours.

At the beginning of the construction, OPG did not require security clearance for workers working inside the reservoir because there they did not have any contact with the OPG equipment. Near the end of the work, the rules had changed and all new workers were required to have their security clearances from OPG. The impact of this change on the work progress was minimal.

More information on the site safety and security, and the lessons learned is provided in Appendix A, Section 4.4.

7.3 Environmental Management

Beyond the turbidity monitoring of water discharged from the reservoir described in Section 5.1 and the grout release at the Queenston Seep described in Sections 5.4, only minor environmental issues had been experienced such as small fuel or oil leaks from the construction vehicles. These issues were quickly handled by the Contractor.

The Environmental Management Plan describes management of the potential environmental issues that can be encountered during the construction. As part of the Definition Phase activities [redacted] had drafted an EMP for construction based on the 2011 dewatering and geotechnical experience. This document was shared with the Contractor during the construction planning stage and proved to be very useful especially in planning the dewatering and fish rescue work. The Contractor used this document to prepare its own EMP.

OPG's and [redacted] environmental staff were available to provide assistance to [redacted] whenever needed. Environmental representatives from OPG, [redacted] and the Contractor participated in weekly teleconferences. [redacted] periodically reviewed the Contractor's environmental management to confirm its compliance with the Environmental Management Plan (EMP) submitted by the Contractor prior to the construction. [redacted] had issued eight reports to the Contractor to track and mitigate the non-conformances issues which were mainly related to management of excess grout, hydraulic fluid leaks, turbidity monitoring, dusting, and release of grout to the Queenston Seep.

7.4 Cost

The estimated cost of the project was $58.2M as indicated in the Execution Phase BCS approved in August 2015, including the concept phase ($3.5M), definition phase ($7.3M) and execution phase ($47.4M). The actual cost of the project came to $52.2M, about $6.0M below the estimated cost.

A breakdown of the Execution Phase budget and actual costs, and the variances are provided in the following table.

Cost Item	Budget (costs in BCS) ($M)	Actual Cost ($M)	Variance ($M)	Variance (%)
Project Management and Administration	1.1	1.3	0.2	+20%
Owner's Representative	3.7	3.3	-0.4	-11%
Construction	30.4	35.7	5.3	+17%
Interest During Construction (IDC)	2.0	1.1	−0.9	-45%
Subtotal	37.2	41.4	4.2	+11%
Contingency	10.2			
Total	47.4	41.4	-6.0	-13%

Here is a brief description of each cost item:

Project Management and administration costs:

This item covers OPG's own costs on the project management, technical and environmental reviews, reservoir monitoring during the static head tests and post-commissioning activities.

The variance (increase of 0.2M) was due to the following:

- Additional labour for more extensive monitoring during the reservoir commissioning,
- Post-commissioning investigations of the bubbling activities through the liner at four locations within the reservoir,
- Construction of the toe drain after the reservoir commissioning, which was not part of the original scope of work.

Owner's Representative costs:

The estimated cost for OR services was $3,589,000 based on Amendment 3 of the Owner's Representative Services Agreement. The amendment was finalized in early 2016. The budget ($3.7M) was based on the cost estimate prepared before approval of the BCS in August 2015.

The variance (decrease of 0.3M) was due to the following:

- [redacted] updated cost estimate ($3.589M) in Amendment 3 was less than the budget estimate ($3.7M).
- [redacted] estimate was based on the reservoir's return-to-service date of April 1, 2017. The earlier return date (February 4, 2017) resulted in reductions in the labour costs and expenses.

Construction costs:

The budget estimate ($30.4M) was included in the Contract Services Agreement. The actual construction costs totalled to $37.5M with an increase of $5.3M. The variances in the main construction activities are shown in the following table:

Construction Cost Item	Budget ($M)	Actual ($M)	Variance ($M)	Major factors contributing to variances
1. Dewatering & fish rescue	2.0	2.0	0.0	None
2. Site access roads	0.4	0.4	0.0	None
3. Geotechnical investigation	0.1	0.1	0.0	None
4. Earthwork	3.3	2.8	-0.5	• Savings (-$1.0M) of using NTBM stockpile as the granular material for the access platform construction instead of buying new material, • Additional cost (+$0.5M) of sediment spread.
5. Liner installation	12.6	12.3	-0.3	• Additional cost (+0.9M) of sediment removal over the original estimate of $1.1M • Savings (-$0.3M) of using NTBM stockpile on road construction around the liner areas, • Savings (-$0.3m) in improvements made in the liner subgrade construction, • Savings (-$0.3M) in removal of the access platform, • Savings (-$0.2M) in key trench backfill.
6. Grout curtain	7.9	10.5	+2.6	• Additional costs (+$2.5M) of modifying the grouting procedure to prevent new grout releases at the Queenston Seep. • Savings (-$1.1M) of eliminating the overburden/rock interface grouting • Additional cost (+$0.5M) of rock grouting • Additional cost (+$0.4M) of the third grout plant to make up the delay caused by the grout release • Additional cost (+$0.3M) of equipment winterization for one-month extension of the grouting work.
7. Other direct costs	1.0	4.0	+3.0	Costs of miscellaneous construction activities that were not part of the original scope of work: • Construction of the demudding berm ($650k), • Installation and removal of the external ramp at Ch.70+00 ($160k), • Placing granular material on the surface of the access platform ($150k), • Payment to [redacted] for 50% share of the agreed cost savings ($310k), • Cost of the exploration drilling ($180k), • Phase 1-3 work for the salamander habitat remediation ($630k), • Installation of the new vibrating wire piezometers in the liner area ($130k), • 28 items with less than $100k each (total: $790k).

8. Indirect costs	3.0	3.6	+0.6	Indirect costs included the site mobilization-demobilization, and [redacted] and [redacted] general site expenses. The variance of $0.6M was due to the extension of the construction duration mostly as a result of the grout release issue.
9. EPSCA Management	0.1	0	-0.1	• EPSCA charges were small ($11k)
Total	30.4	35.7	5.3	

Interest during construction (IDC):

The budget for the IDC ($2.0M) was estimated based on the interest rates in early 2015. The actual IDC for the Execution Phase came to $1.1M, about $0.9M less than the budget because of the lower interest rates and lower contingency use during the execution phase.

Contingency:

The contingency was estimated using three different methods:

- Quantitative analysis: OPG and [redacted] project staff estimated the potential variances for each cost item in the Basis of Estimate spreadsheet prepared by [redacted] and a Monte Carlo simulation was applied on these variations by OPG to determine the cost contingency.
- Review of civil projects: This project is basically a geotechnical project with inherently higher uncertainties than other civil projects. OPG's Niagara Tunnel and Lower Mattagami Project costs had been reviewed to identify the potential cost increases in civil components. Finally, an article documenting the cost increases in 25 Canadian hydropower projects in recent years had been reviewed for a statistical review.
- Qualitative analysis: According to the work sequence proposed in the RFP process, the liner installation would advance first, then the grout access platform construction would be completed to proceed with the production grouting program because the toe of the access platform would extend over the liner area. Therefore, the liner installation was originally on the critical path. Furthermore, the liner cannot be installed during the rain events because the GCL and the liner subgrade must be dry before and during the installation. Wet summers are not unusual in southern Ontario and that could have significantly delayed the construction work.

As a result of all three analyses, it was decided to have a cost contingency of $10.2M ($10.2M/$37.2M =27%) which brought the total execution phase cost to $47.5M. In reality, 2016 summer was very dry and only two days were lost due to rain during the liner installation. Instead of the weather, the grout release at the Queenston Seep on April 28, 2016 caused significant schedule delays and costs increases. The direct cost of the salamander issue was about $600k for cleaning of the seep and salamander investigations. The indirect costs (modification of the production grouting program and the costs of recovering the schedule delays) totalled to about $4M which accounted for most of the construction cost increase of $5.3M.

7.5 Schedule

According to the contract terms, the contractor would complete the reservoir dewatering between April 1 and December 30, 2016. Then, OPG would commission and return the reservoir to service by mid-January. According to the contingency analysis described above, OPG decided to add 2.5 months of schedule contingency (i.e., 2.5 months /9 months=26%) to the construction schedule. As a result, the

reservoir in-service date was shown as April 1, 2017 in the BCS. However, due to the measures taken to accelerate the grouting program, most of the delay caused by the grout release issue had been recovered and the construction completion date was delayed by less than three weeks (i.e., actual date was January 18, 2017 instead of the planned date of December 30, 2016). Following the reservoir commissioning activities, the reservoir was returned to service on February 4, about 8 weeks ahead of the planned date of April 1, 2017.

7.6 Quality

The construction activities were completed in general conformance with the Technical Specifications. The OR had field engineers and technicians inspecting all major work activities. This high level of oversight ensured that the work carried out satisfied the design intent, and resulted in a high quality of workmanship and detailed documentation of the site activities. In addition, the [redacted] design engineers for the liner and grouting work visited the site frequently to review the work progress. [redacted] had assigned highly qualified QA staff especially for the liner supply and installation and grouting work. The QA test results are included in the As-Built Report.

7.7 Risks

Review of Risks Identified in BCS

The following major risks were identified in the Execution Phase BCS:

Risk-1: Inclement weather impact on the construction schedule and cost (probability: high; impact: high)

Reality: The 2016 summer was very dry and warmer than normal. The liner installation was delayed by only two days due to rain. Originally about 15-day lost time was assumed for normal weather conditions.

Risk-2: Unexpected conditions of the dyke clay core and bedrock (probability: medium; impact: high)

Reality: The mitigating strategies worked well and no damage occurred to the dyke core. However, some sections of the dyke required more grout than assumed. A third grout plant was installed to recover the lost time due to the delays caused by the excessive grout take and Queenston Seep issue.

Risk-3: Scope changes due to new discoveries (probability: medium; impact: high)

Reality: Apart from the Queenston Seep and excessive sediment issues there was a couple of new discoveries with small impact on the construction cost, such as disposal of tar encountered during the road construction inside the reservoir, removal of old piping found in the key trenches and construction of a new toe-drain outside the dyke. These discoveries had no impact on the construction schedule.

Risk-4: Excessive sediment over the reservoir floor (probability: medium; impact: high)

Reality: The average thickness of the sediment to be removed from liner areas was assumed about 0.3-0.5 m based on the CGI investigation in 2011. The actual average sediment thickness was 0.7 m which almost doubled the cost of sediment removal.

Risk-5: Liner not connected properly to the dyke clay tongue (probability: medium; impact: medium)

Reality: The dyke tongue could be clearly identified in most of the liner areas. New clay material was placed over areas where the clay tongue was relatively thin or could not be identified. The cost impact was relatively small.

Risk-6: Excessive liner rework (probability: medium; impact: medium)

Reality: There was no issue in the HDPE quality. However, the original GCL manufacturer could not supply the material to meet the technical requirements. The contractor was able to find quickly a new manufacturer to supply the required GCL. However, some quality issues were observed during the GCL installation which required rework with no additional cost to OPG. Since the liner work was not on the critical path, the rework did not impact the construction schedule. [redacted] technical expertise in liner design and QA work was instrumental in resolving the liner issues quickly and effectively.

New Risk during Construction:

The only new major risk encountered during the construction was the Queenston Seep issue which is described in detail in Section 5.4. During the CGI planning meetings in 2011, MNR (now MNRF) indicated that if the water source for the Queenston Seep were the leakage from the reservoir, the water supply might be significantly reduced, damaging the salamander habitat with implementation of the LTRM. However, when the reservoir was emptied in October-November 2011 for the CGI, the seep flow continued at the normal rate, proving that the groundwater was likely the water source for the salamander habitat, not the reservoir water. What we could not foresee that the same groundwater network system would be also capable to carry the grout (mainly its bentonite component) about 700 m distance from the trial grouting area to the Queenston Seep. It was a "Black Swan" risk with a significant impact on the project cost and schedule as explained in Sections 7.4 and 7.5 above. However, with sufficient cost and schedule contingencies, the construction was still completed under budget and ahead of schedule.

8. PROJECT CLOSEOUT

The reservoir was returned to service on February 4. The post-construction monitoring and the static head tests carried out in February and July 2017 confirmed that the reservoir can be operated without any limitations.

All critical project documents had been provided in electronic format to the Niagara Document Management. Major documents (such as As-Built report and associated drawings) were also delivered in hard copies.

The financial closure of the project is scheduled for completion by the end of January 2018.

9. CONCLUSIONS

The project results can be summarized as follows:

- Safety: The construction was completed without any lost-time injuries.
- Environment: Effective communication with the MOECC, MNRF and NPC was maintained throughout the project from the CGI in 2011 to the end of the construction in early 2017. The cooperative relationship between OPG and the agencies was instrumental in timely management and resolution of the Queenston Seep/Salamander issue which was the only major environmental concern encountered during the construction. Although the cost and schedule impact was significant, the issue was resolved without any negative effect on OPG's reputation and relationships with the agencies.
- Quality: The construction was completed in compliance with the technical specifications. Minor adjustments were made to the specifications based on the changing site conditions.

- Cost: The total cost of the Execution Phase was $41.4M which is $6.0M below the BCS release of $47.4M.
- Schedule: The reservoir was returned to service on February 4, about 8 weeks ahead of the planned in-service date of April 1, 2017 indicated in the BCS.

As a result of implementation of the STRM and LTRM, the reservoir should continue to operate safely in the future with the appropriate operation, maintenance, and surveillance activities.

10. RECOMMENDATIONS

1. Project Team:

   Continuity of the project team is essential for the project success. There was hardly any changes in the critical project management, technical and environmental members of the OPG and OR project teams from the start of the Definition Phase in 2011 and to the end of the Execution Phase in January 2018.

2. Technical oversight:

   The Panel of three external geotechnical experts provided the technical oversight throughout the project. They made significant contributions especially in analysis of the geological and geotechnical data, and design and constructability of the Long-Term Remedial measures. This practice can be very beneficial for the future large projects especially when significant technical uncertainties are expected.

3. Procurement of Construction Services:

   - Early communication with the construction market can be useful to inform the potential contractors of the upcoming construction and get their feedback on project constructability. When the reservoir was dewatered in 2011 for the CGI, several general contractors and liner suppliers were invited to see the condition of the reservoir bottom. This experience provide them with a general knowledge of the project requirements in advance of the prequalification process started in late 2014, resulting quality submissions by the proponents.
   - Prequalification of the general contractors along and the subcontractors of the major construction activities can provide high quality work. Sharing significant technical information with the prequalification proponents helps them prepare for the following RFP process as well.
   - Qualifications of the site superintendent of the Contractor should be assessed during the construction RFP process along with other critical resources of the Contractor. [redacted] very experienced site superintendent was instrumental in planning and innovative execution of the construction activities.
   - The CSA includes provisions for 50/50 sharing of the cost savings proposed by the Contractor. However the 50/50 ratio seems arbitrary and should be reconsidered based on the Contractor's estimated profit margin to increase OPG's share.
   - Liquidated damage clauses in the CSA may not be applicable for the work with significant uncertainties such at the grouting work.

4. Construction Planning:

- The project schedule should include a construction planning period. OPG, OR, Contractor and its major subcontractors should meet several times to clarify the work scope and responsibilities of the parties. The Contractor should document the conclusions of these meetings in a document called "Project Execution Plan" (PER). The PER should also summarize the Contractor construction approach, i.e., it would be a road map for the construction. The terms of reference for the CEP should be included in the CSA. However, the Contractor should be allowed to deviate from it as the work progresses. The construction planning took about 4 months (September-December 2015) for the present project.
- The project planning meetings should include a briefing by OPG on all site investigations which had been carried out by OPG prior to the construction. It is not realistic to expect the Contractor staff would review and become familiar with all the study documents by themselves in a relatively short time before the construction starts.

5. Construction Execution:

- The Owner Only contract approach worked well for the present project. For the construction sites adjacent to the OPG assets, OPG should prepare the MOU and determine the construction island boundaries in cooperation with the Contractor.
- The local agencies should be briefed on the project early in the project (i.e., during the Concept and Definition Phases) to establish and maintain cooperative relationship. Inviting them to the site at various stages of the project would help in quick resolutions of the potential regulatory issues.
- Availability of skilled workers is becoming a major issue for major projects. Although the EPSCA assignment is the Contractor's responsibility at the beginning of the construction, it might be very beneficial for OPG to have preliminary discussions with the EPSCA Unions on the project requirements in advance of the construction.
- An independent third party should survey the materials that are high cost items, such as the sediment volume to prevent potential conflicts between the parties. The sediment volume is a transient number that varies with the material moisture content.
- For the future liner projects, OPG should consider ordering the material as soon the funding is released to ensure timely delivery of quality products. Installation of venting systems to discharge air or gas captured under the liner at local high points should also be considered in the future liner projects.
- The grouting programs should include contingency plans to quickly respond to unexpectedly high grout takes with special additives, additional equipment and new grouting procedures. The CSA should also include the cost and delivery time of additional grout plant(s) in case unfavourable bedrock conditions are encountered during construction.
- Additional winterization costs are likely be incurred starting mid-November in Southern Ontario. This should be considered in cost and schedule estimation for the Execution Phase.

6. Cost and Schedule Contingencies

- Cost and schedule contingencies should be based on the quantitative and qualitative risk analyses. OPG should establish a database based on the cost changes in various components of the previous projects to provide input to the quantitative and qualitative risk analyses for the future projects.

- Nassim Taleb, the author of "The Black Swan, The Impact of the Highly Improbable" defines the "Black Swans" as the rare events with low predictability and large impacts. Each major project that includes significant uncertainties, such as geotechnical work can have many kinds of Black Swans. Therefore, extensive risk analysis at the beginning of the project and its periodical reviews are required to reduce the chances of Black Swans occurring.

ABBREVIATIONS AND ACRONYMS

[redacted]	[redacted]
BCS:	Business Case Summary
BOE:	Basis of Estimate
CEP:	Construction Execution Plan
CGI:	Comprehensive Geotechnical Investigation
CI:	Construction Island
CSA:	Construction Services Agreement
EMP:	Environmental Management Plan
EPSCA:	Electrical Power Systems Construction Association
FC:	Field Communication
FLM:	First Line Manager
GCL:	Geosynthetic Clay Liner
GRB:	Gate Review Board
IAGI:	International Association of Geosynthetic Installers
HDPE:	High Density Polyethelene
IGLD:	International Great Lakes Datum
LOTO:	Lockout-tagout
LTRM:	Long-Term Remedial Measures
MNRF:	Ministry of Natural Resources and Forestry
MOECC:	Ministry of Environment and Climate Change
MOU:	Memorandum of Understanding
NPC:	Niagara Parks Commission
NPV:	Net Present Value
NTBM:	Niagara Tunnel Boring Machine
OR:	Owner's Representative
OHSA:	Occupational Health and Safety Act
PCD:	Project Change Directive
QA:	Quality Assurance
QC:	Quality Control
PDRI:	Project Definition Rating Index
PEP:	Project Execution Plan
PER:	Project Execution Report
PGI:	Preliminary Geotechnical Investigation
PGS:	Pump Generating Station
PSSEMP:	Project Specific Site Environmental Management Plan
PSSSP:	Project Specific Site Safety Plan
RFP:	Request for Proposal
RFI:	Request for Information
ROV:	Remotely Operated Vehicle
SHT:	Static Head Test
STRM:	Short-Term Remedial Measures
VWP:	Vibrating Wire Piezometer

REFERENCES

The following list includes the main project documents issued from the Concept Phase to the end of Execution Phase. The "As-Built" report and "Environmental Compliance Report for Construction Activities" include several other documents in their appendices.

Document No	Document Title	Issued by	Issue Date
R-NF282-64115-0002	Reservoir Assessment Report	[redacted]	January 2011
R-NF282-10120-004	Geotechnical Investigations Data Report	[redacted]	Oct. 23, 2012
R-NF282-10120-005	Conceptual Design Report	[redacted]	May 29, 2013
R-NF282-10120-006	Detailed Engineering Design Report	[redacted]	Mar. 9, 2015
NF282-REP-10120-001	Project (Instrumentation) Completion Report	CRA	June 2015
NF282-REP-40002-0004	January 2016 Reservoir Static Head Test	[redacted]	Oct. 18, 2016
NF282-REP-40002-0006	February 2017 Reservoir Static Head Test	[redacted]	May 26, 2017
NF282-REP-10120-0006	Reservoir Commissioning Report	[redacted]	Aug. 28, 2017
NF282-REP-18170-0001	Environmental Compliance Report for Construction Activities	[redacted]	Oct. 5, 2017
NF282-REP-10120-0002	Biweekly Progress Reports during Construction	OPG	Dec. 1, 2017
NF282-REP-40002-0005	July 2017 Reservoir Static Head Test	[redacted]	Dec. 11, 2017
NF282-REP-10120-0003	As-Built Report	[redacted]	Dec. 20, 2017
NF282-REP-10120-0004	Project Execution Report	[redacted]	Dec. 21, 2017
NF282-REP-10120-0005	Miscellaneous Documents (includes 13 short reports and memorandums issued for Definition and Execution Phases)	[redacted]	Dec. 2017
NF282-REP-10120-0007	Comprehensive Post Implementation Review	OPG	January 2018

APPENDIX A: LESSONS LEARNED IN EXECUTION PHASE

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1. INTRODUCTION

The execution phase of the Reservoir Refurbishment Project started with signing the Construction Services Agreement ("Contract") with [redacted] at the end of August 2015 and ended with the project closeout in December 2017. The site construction activities were initiated on January 18, 2016 with [redacted] mobilization and ended on January 17, 2017 with the demobilization from the reservoir. The reservoir commissioning was carried out between January 18, 2017 and February 4, 2017. During this period the reservoir was filled gradually with an extensive monitoring program and a static head test was carried on the last day of the commission. The reservoir was returned to normal operation on February 4, 2017.

The scope of major construction activities included the following:

- Reservoir dewatering and fish rescue by [redacted] subcontractors, [redacted] and [redacted]
- Site access and earthworks (including sediment removal and spread over the reservoir bottom) by [redacted]
- Installation of a geosynthetic liner over less than 5% of the reservoir bottom by [redacted] and its subcontractor, [redacted]
- Grout curtain construction in the dyke foundation by [redacted] and its subcontractor, [redacted]

OPG's Owner's Representative ([redacted]) had several staff, including the project manager, present at the site on a full-time basis throughout the construction and reservoir commissioning. [redacted] provided quality assurance (QA) services on all construction activities and responded to [redacted] technical and commercial requests in cooperation with the OPG site representatives.

This document summarizes the major lessons learned during the execution phase of the project. Some of the lessons are based on the discussions at the post-construction meeting held between OPG, [redacted] and [redacted] representatives on February 16, 2017. The rest of the lessons are based on experiences of the project teams of OPG and [redacted]

2. PROJECT MANAGEMENT

2.1 Project Team

Key personnel involved in the project execution phase are listed below. Most of them were involved in the project from the start of the definition phase in 2011.

- OPG project team:
  - Project management: Mahir Aydin, Clara Greco, Andre Friedmann
  - Technical support: Peter Hassan, Paul Toth, Alain Diallo, Jie Lao, Tareq Salloum
  - Environmental support: Ed Naval, Dave Stanley
  - Field support: Tom Disley, Liz Cockburn, Larry McDonald, Paul Martin, Riley Hubers, P Basdeo, Andy Vanderbolt, Wally Skolar
  - PGS FLMs: Dave Thom, Ray Dejonge
  - Supply chain: Kim Severin, Diane Anderson
  - Legal support: John Kalm
  - Finance control: Mark Del Frari
  - Cost estimation: Oleg Kantargi
- [redacted] project team:
  - Project management: [redacted]

- Technical support: [redacted]
- Field support: [redacted]
- Environmental support: [redacted]
- Document management: [redacted]

- [redacted] project team:
  - Project management: [redacted]
  - Construction superintendent: [redacted]

  [redacted] major subcontractors:
  - Dewatering: [redacted]
  - Fish recue and environmental services; [redacted]
  - Grouting: [redacted]
  - Liner supply and installation: [redacted]

- Technical oversight:

  The technical oversight was provided by an independent panel of three geotechnical experts, reporting directly to Tony Bennett, the Director of the Dam Safety and Emergency Preparedness of OPG. The panel included the following members:

  - [redacted] Norwegian Geotechnical Institute, Norway.
  - [redacted] URS Corporation, USA.
  - [redacted], Geo-Engineering Centre of Queens's University, Canada.

  The panel played a critical role especially in review of the geotechnical investigations in 2011, design of the remedial measures, the technical specifications and the construction plan for the production grouting and liner installation.

Lessons Learned

- A dedicated project team of OPG and the OR representative working together for a long time is an important factor in project success.
- The OR's expertise on the critical components of the design and construction work such as grouting and liner installation is essential for successful work execution.
- An independent panel of external experts advising the project team on the design and constructability can be very useful in projects involving significant uncertainties.

2.2 Procurement

Experience:

- Prequalification of contractors, liner suppliers and grouting companies:

  The construction of the remedial measures included two major activities; Grouting and liner installation. To ensure the quality construction work, the grouting and liner companies were prequalified along with the (general) contractors. The prequalification process was carried out from November 2014 to February 2015. A significant amount of project technical information was shared with the prequalification proponents.

- Request for Proposal process:

The construction RFP was issued on March 16, 2015 to four contractors and it was closed on May 12, 2015. The contractors were requested to select a subcontractor from each list of the prequalified grouting and liner companies to participate in the RFP process. The RFP responses were assessed first for their technical content. Only the technically qualified proponents' price submissions were evaluated to ensure quality work performance. [redacted] was selected as the successful proponent in June, 2016. Contract negotiations with [redacted] was completed by early July.

Lessons Learned:

- The entire procurement process was executed satisfactorily with the support of the competent supply chain and legal department representatives.
- [redacted] construction superintendent had decades of construction experience and great leadership skills. He played a major role in satisfactory work execution. RFP selection criteria should include qualification of the superintendent along with other key personnel (e.g., project manager, deputy project managers, H&S manager and environmental manager).
- The contractor's project team must have extensive experience working together to build an effective and cooperative team culture. This can be a challenge, especially in large organizations with ever-changing resource assignments.
- The non-technical items such insurance and warranties for material and equipment should be included in the contract schedules, not in the technical specifications.
- OPG Finance should confirm in writing that the construction insurance is in place for the project before the construction contract is signed.
- The following provisional items should be included in the contract unit pricing:
  - Extensive list of construction equipment even if use of some of the equipment may seem unlikely during the RFP process (e.g., a third grout plant was needed to make up the delay caused by the salamander issue and it was not expected before).
  - Weekly winterization for equipment and road maintenance if there is any chance that the work may extend beyond mid-November for work in Southern Ontario. Different start dates can be considered depending on work location.
  - Costs of the second and third shifts, extended work hours, and working 6 and 7 days a week to catch up the construction schedule.

2.3 Construction Services Agreement (Contract)

Experience:

- The Construction Services Agreement (CSA, "Contract") dated August 24, 2015 was signed by OPG VP-Supply Chain and [redacted] by the end of August.
- [redacted] construction team included the following staff in the contract:
  - Project management: [redacted]
  - Construction superintendent: [redacted]
  - Health & Safety manager: [redacted]
  - Environmental manager: [redacted]
- Early completion Incentive and Liquidated Damages in Contract:

  The contract did not include any incentive for early completion of the construction because of the relatively weak demand for PGS operation in fall. The substantial completion date for construction was December 30, 2016 in the contract. The contract included liquidated damages (LD) for construction completion beyond the substantial completion date. However, due to the schedule impact of the

Queenston Seep (salamander) issue on the production grouting program, delays were incurred and LD could not be enforced on [redacted]

- Sharing of cost savings:

  During the scope review meetings prior to construction, [redacted] identified some design changes which resulted in cost savings in the construction execution. The contract allowed 50/50 sharing of these cost savings with the contractor.

Lessons Learned:

- In projects involving major grouting programs, LD may not be applicable due to the substantial geotechnical uncertainties.
- Incentives for early completion may be worth considering, provided that they do not have a negative impact on the quality of the work to be performed.
- The contractor's profit margin should be considered in determining the ratio of sharing of the cost savings suggested by the contractor. For example, if the contractor suggests a reduction in the work scope or scope improvement to save OPG some costs, and its profit margin is 10%, a 20/80 ratio (i.e., the contractor receives 20% and OPG takes 80% of the saving) might be an effective incentive for the contractor instead of 50%.
- The construction contract should include a requirement for survey data to be submitted within a specific time frame of the work completion. The survey data should be specified to include all completed works, regardless if the survey quantity is connected with the payment value.

2.4 Owner's Representative's presence at site during construction

Experience:

- Resources:

  [redacted] had several staff at the site on a full-time basis: A project manager, a project engineer, and QA representatives for liner installation, production grouting and other miscellaneous activities. Senior design engineers on liner installation and grouting also visited the site frequently. Two environmental staff who participated in the 2011 reservoir dewatering were present at the site during the 2016 dewatering and the salamander investigations.

- Benefits

  It was very beneficial to have the [redacted] staff on-site on a full-time basis to resolve technical issues and provide design updates. [redacted] was able to promptly respond to [redacted] questions during the work execution. [redacted] was also responsible for reviewing [redacted] submissions of invoices and additional cost increase requests. The presence of both [redacted] and [redacted] staff at the site also accelerated this review process.

Lessons Learned:

- The OR staff with the right technical skills to resolve issues should be present at site especially for large projects.

2.5 Payment for construction work

Experience:

- Milestone payment method:

[redacted] was paid based on a milestone payment schedule (i.e., completion of the construction tasks) according to the contract. For smaller tasks, 100% completion; for larger tasks certain percentage of completion (e.g., 25%, 50%, 75% and 100%) was required for the payment. [redacted] indicated that this method created some cash flow problems for the company. [redacted] also expressed concern that this created additional work for [redacted] because they were also required to submit monthly accruals. [redacted] had to review both accruals and invoice submissions on behalf of OPG.

- Payment verification:

  [redacted] had reviewed [redacted] draft invoices to verify them for payment by OPG. [redacted] indicated that in non-OPG projects, the client typically hires a third-party contract administrator to verify the scope changes, work completion and payment submissions instead of the OR retained by OPG. [redacted] felt that, in some cases, their interests were not as fairly represented as they expected. OPG commented that the process had been fair and any outstanding issues had been discussed in detail among all three parties for quick resolutions.

- Ariba invoice submission system:

  OPG's invoice submission system was changed to Ariba in the middle of the project. [redacted] had signed up for the full Ariba system without realizing its high annual cost (about $20k). [redacted] had to pay the system cost to receive the outstanding payments and holdback.

- Change management process:

  [redacted] felt that the change management process was effective (i.e., documenting the issues and resolutions, and providing timely information). Requests for Information, Field Directives and Project Change Directives provided the supporting information in this process.

- Holdback payment:

  OPG's Accounts Payable processing of holdback invoices is cumbersome and needs to be improved.

Lessons Learned:

- The entire payment process, including the Ariba system, should be discussed and agreed with the contractor before signing the contract. OPG should help the contractor to register with "Ariba Lite" at much lower cost than the full-Ariba system.
- Monthly payment method based on percentage work completion is recommended for similar projects in the future.
- The change management process used in this project was effective and it can be used in future projects.
- The future project teams should be aware of the delays in the OPG Accounts Payable (AP) process for the holdback payments. The PMO should work with the AP to improve the holdback process.

3. CONSTRUCTION PLANNING

3.1 Scope clarification and construction planning meetings

Experience:

- The contractors' RFP submissions are usually prepared by the company's cost and schedule estimators, with limited involvement by the project team. Therefore, it is very important to have extensive discussions between OPG/OR and contractor for detail review of the contract's terms and conditions, scope of work, schedule, and construction execution shortly after signing the contract. This process took about four months to complete for the present project. Changes in construction execution had been identified,

resulting in some cost savings and schedule improvements. As requested in the contract, [redacted] prepared the "Construction Execution Plan" based on the results of these discussions.

- Between signing the construction contract on August 24, 2016 and start of the site mobilization in early January 2016, the following meetings were held:
  - Sept. 18: Attended by OPG/[redacted] and [redacted] at Niagara Falls,
  - Oct. 7: Attended by OPG/[redacted] and [redacted] at St. Catharines,
  - Nov.3: Attended by OPG/[redacted] [redacted] and all [redacted] subcontractors at Niagara Falls,
  - Nov. 12: Attended by OPG/[redacted] and [redacted] at St. Catharines,
  - Nov. 20: Attended by OPG/[redacted] [redacted] and [redacted] at [redacted] offices in King City, Ontario,
  - Dec. 8: Attended by OPG/[redacted] [redacted] and all [redacted] subcontractors at Niagara Falls.

Lessons Learned:

- The project schedule should include scope clarification and construction execution meetings between the contract signing and contractor's site mobilization. Having a period of time between the contract signing and site mobilization will allow all parties to work together to refine the construction approach and optimize the work methods.
- If the contractor is going to hire subcontractors for significant portion of the work, it would be advisable to invite the major subcontractors to these meetings have them hear the project objectives, scope of work and schedule directly from the OPG/[redacted] project team.
- The result of these meetings should be documented by the contractor before the site mobilization. For this project this document was called the "Construction Execution Plan" (CEP).

3.2 Construction execution plan

Experience:

- Objective and content:

  [redacted] was requested in the contract to prepare the CEP to document how they intend to execute the construction and to ensure that they fully understand the project requirements. The CEP included the following subjects:
  - Organization chart,
  - Schedule,
  - Work sequence,
  - Project Site Specific Safety Plan,
  - Environmental Management Plan,
  - Permits and approvals,
  - Quality control program,
  - Trades training plan,
  - Subcontractor management plan,
  - Change management plan,
  - Site security, site maintenance and traffic plan.

- Benefits:

  Although [redacted] had the flexibility to deviate from CEP depending on changes in site conditions, it was a road map for all parties involved in the construction to see the big picture and to clarify their roles in the construction. Initially, [redacted] had concerns about providing a CEP in case OPG would hold them to the work sequence provided in the CEP. [redacted] was assured that it would not be the case.

During preparation of the CEP, [redacted] had identified significant work improvement potentials: The width of the grout access platform could be reduced from 10m to 8m, while still allowing enough access for construction vehicle traffic. This change not only resulted in reduction of the cost of the access platform construction, it also made possible to proceed with the grout work and liner installation simultaneously which saved significant time in the overall construction schedule.

Lessons Learned:

- The CEP was successfully used in this project and it is highly recommended for future OPG projects.

4. CONSTRUCTION MANAGEMENT

4.1 Owner Only Contract Execution

Experience:

- Implementation of Owner Only approach:

  OPG's Owner Only contract execution worked very well for this project. The contractor [redacted] was well aware of its responsibilities as the constructor as defined in the OHSA.

- Memorandum of Understanding and Construction Island:

  A master copy of the Memorandum of Understanding (MOU) was prepared by OPG for signatures by the OPG project manager, PGS FLM and [redacted] project manager prior to the construction commencement. MOU included the definition and maps of the construction island (CI), communication protocol for emergency and non-emergency situations, and information on hazardous energies, site access, security and other site conditions. The CI boundary was determined based on the contractor's needs and it was agreed by both parties. MOU was updated and signed whenever the construction island has changed. Depending on the locations of the construction activities, multiple CIs had been assigned. In each case, OPG's "Control of Hazardous Energies Walkdown Sheet" was signed by PGS FLM and [redacted] project manager or their delegates. Safety tags, locks and signs were placed before transferring the CI to [redacted]

Lessons Learned:

- For construction sites adjacent to the OPG assets, OPG should prepare the MOU and determine the CI boundaries in close cooperation with the contractor.
- OPG should ensure all corporate security requirements are met when establishing CI boundaries, including security clearances for the contractor workers.

4.2 Communications between OPG/OR and Contractor

Experience:

- Weekly site meetings and issue tracking

  The construction progress and outstanding issues were reviewed at the face-to-face weekly meetings among the project managers and technical staff of OPG, [redacted] and [redacted] [redacted] issued the minutes of the weekly meetings and maintained the lists of the outstanding issues and actions. Separate meetings were held for detailed discussions of more important issues.

- Resolving issues:

  [redacted] full-time presence at the site was very beneficial in quickly addressing the design and QC/QA issues encountered. [redacted] was appreciative of the quick responses and cooperation provided by OPG

and [redacted] in resolving the technical issues. [redacted] previous experience with [redacted] and [redacted] also assisted with the work execution.

Lessons Learned:

- Prompt responses to new construction issues is essential for the project success. OPG's and OR's (e.g., the project manager's, design experts' and QA specialists') full-time presence at the site is highly recommended especially for large projects.
- Weekly progress meetings should be held at the site and attended by the project managers. The minutes of the meetings should be prepared by the OR.

4.3 [redacted] construction management

Experience:

- [redacted] construction team:

  [redacted] assigned an experienced construction team to the project. The construction superintendent played a major role in work planning, innovative solutions and work execution.

- Management of subcontractors:

  [redacted] had limited experience in major dewatering, grouting and liner installation work. Sharing OPG's reservoir dewatering experience with [redacted] helped in planning the dewatering activities. [redacted] has also hired [redacted] and [redacted] and some of the [redacted] staff had been involved in the 2011 dewatering. [redacted] selection of [redacted] and [redacted] from the lists of prequalified grouting and liner companies also helped to ensure the quality of work. It appeared that [redacted] maintained good relationships with all its subcontracts except for some commercial challenges with the liner supplier, [redacted]

- Availability of skilled workers:

  At beginning of the grouting work, [redacted] had difficulty in skilled labour from the union hall. [redacted] and [redacted] meetings with the union rep on the work requirements resolved this issue.

Lessons Learned:

- The contractor should be made aware of the details of the major studies that had been carried out by OPG in the past for more effective construction planning.
- Prequalification of subcontractors specialized on major activities is very important to ensure quality work.
- Experience and leadership skills of the contractor's site superintendent is very important for successful construction execution.
- Where EPSCA labour is needed on a project, OPG and the contractor should inform the EPSCA union halls in advance of the skill sets required for the construction so that the appropriate workers can be sent to the site.

4.4 Safety and Security

Experience:

- [redacted] overall safety performance:

  [redacted] did not have any lost time or serious injuries during this project. [redacted] overall safety performance was satisfactory considering the challenging site conditions encountered within the Reservoir and at the Queenston Seep. [redacted] indicated that they held safety meetings daily, weekly and

as-required basis. In addition, [redacted] produced a site-orientation video for safety training for all its employees on their first day at the site.

- [redacted]

- [redacted]

- MOL visit for site conditions:

  [redacted] invited MOL to visit Queenston Seep to ensure that the work conditions had satisfied the H&S regulations. MOL confirmed that the Project Notice issued for the reservoir work would be applicable for the Queenston Seep as well and a new Project Notice was not required. [redacted] implemented MOL's recommendations for certification of the rock climbing equipment.

- Security clearance:

  At the beginning of the construction, OPG did not require security clearance for workers working inside the reservoir because there they did not have any contact with the OPG equipment. Near the end of the work, the rules had changed and all new workers were required to have their security clearances from OPG. This change didn't have much impact on the work progress.

Lessons Learned:

- It is recommended that the site orientation trainings by the contractor should include a site-specific safety video as well for large projects.
- Pre-screening of workers by the unions should be a standard practice prior to their employment at the site.
- The contractors should have up-to-date safety policies posted at the site visible by all workers.
- The safety training should include materials to prevent workplace violence and harassment.
- MOL representative should be invited to the site to clarify whether another project notice is required if the work is expanded beyond the original construction island or whenever the contractor feels that the changing site conditions justify an H&S inspection by MOL.
- Security clearance requirements should be included in the RFP documents and clearly communicated with the RFP proponents. The contractor's construction management team should be reminded of this requirement at the project kick-off meeting as well.

4.5 Environmental Management

- Beyond the turbidity monitoring of water discharged from the reservoir and the grout release at the Queenston Seep issues described previously, only minor environmental issues had been experienced such as small fuel or oil leaks from the construction vehicles. These issues were quickly handled by the contractor. OPG's and Golder's environmental staff were available to provide assistance to [redacted] whenever needed.

- The Environmental Management Plan (EMP) describes management of the potential environmental issues that can be encountered during the construction. It was the contractor's responsibility to prepare the EMP. [redacted] had drafted an EMP for construction based on the 2011 dewatering and geotechnical experience. This document was shared with [redacted] during the construction planning stage and it was well appreciated by the contractor.

  Lessons Learned:

- The project team should include experienced environmental representatives from OPG, the OR and the contractor to resolve potential issues in cooperation.
- An environmental summary report should be prepared by the OR at the end of the definition phase to identify the environmental issues encountered by then. This would help the contractor prepare the construction EMP.

5. MAJOR CONSTRUCTION ACTIVITIES

5.1 Reservoir dewatering

Experience

- Benefit from 2011 dewatering experience:

  OPG and [redacted] dewatering experience gained during the Comprehensive Geotechnical Investigation (CGI) in 2011 and sharing this information with [redacted] was instrumental in planning and successful completion of dewatering in 2016. [redacted] also subcontracted most of the dewatering work to [redacted] that installed and operated the dewatering pumps and piping in 2011. Finally, [redacted] subcontractor for fish rescue operation was [redacted] and some of [redacted] staff were also involved in the 2011 dewatering as former employees of [redacted]

- Fish rescue:

  The 2016 dewatering started on April 1 and completed by April 25. The reservoir elevation was kept at 600ft for the first five days as requested by [redacted] for electrofishing. The electrofishing at this level was not successful as much as [redacted] hoped for due to the significant water depth (about 10-15ft). As the water elevation dropped, the electrofishing efficiency increased.

- Turbidity monitoring:

  The MOECC imposed limits on the turbidity of the water discharged from the reservoir for the 2011 dewatering and the same limits were applied to the 2016 dewatering as well. The turbidity measurements were required at six locations during the active dewatering (i.e., pumping from the reservoir) and whenever high winds and rain increased the turbidity in the water. The measured turbidity levels were less than the limits except for one incident: On April 19, 2016, an excavator working on a road construction in the immediate vicinity of the PGS intake caused disturbance of the bottom material and resulted in increased turbidity levels. The headgates were quickly closed to prevent further discharge of the turbid water. MOECC was immediately informed of the incident. There was no significant impact on the work progress.

Lessons Learned:

- Benefitting from experience gained in similar projects is very important for success of any new project.
- The fish rescue work in the future should start at reservoir elevations lower than 600ft (e.g., 595ft) to increase the efficiency of electrofishing.

- Training on potential environmental risks should also be provided by the contractor to the workers especially to the heavy equipment operators.
- Establishing good communications with the regulatory agencies early in the project and maintaining these relationships throughout the construction is very important to prevent or reduce potential work interruptions when any safety or environmental incidences occur.
- The roadways to designated pumping locations were left in place should the reservoir need to be dewatered again.

5.2 Sediment removal

Experience:

- The volume of the sediment at the bottom of the reservoir was higher than originally estimated. Sediment removal became a major concern because of the large volume and its high water content. Fortunately, the warm summer helped to quickly dry the sediment. However, assessment of the sediment volume based on the surveys conducted by [redacted] was a subject of dispute between OPG/[redacted] and [redacted] although most of the surveys had been carried out in presence of a [redacted] QA staff.

Lessons Learned:

- If complete dewatering of the reservoir is required in the future, the schedule should be similar to the 2016 experience to benefit from the warmer weather in summer months.
- An independent third party should survey the materials that are high cost items (such as the sediment volume) to prevent any conflict between the parties.
- Sediment covering the reservoir floor rapidly dewaters once exposed to an ambient environment in summer.
- It should be expected that removal of some reservoir floor materials will occur during sediment stripping.
- The sediment volume should be considered a transient number that varies with the material moisture content.

5.3 Miscellaneous road construction

Experience:

- The Niagara Tunnel Boring Machine (NTBM) granular material stored at the south side of SAB2 Canal has been used extensively for maintenance of the existing roads inside the reservoir and construction of the new access roads and a ramp outside the reservoir, resulting in significant cost savings for the project.

Lessons Learned:

- The material stockpiles left at the site from the previous projects can be very useful for future project.
- The TBM material has high fines content and is subject to sloughing if placed on steep slopes.

5.4 Liner installation

Experience:

- The liner installation was completed ahead of the schedule as a result of the favourable weather conditions and a good team work among the [redacted] installation crews, [redacted] experienced QA staff and [redacted] site management.

- At the post-construction review meeting, [redacted]. The original GCL supplier informed [redacted] prior to GCL delivery that they could no longer supply the material from their U.S. plants. [redacted] found a new GCL supplier from the U.S.in rush that satisfied the GCL criteria set in the technical specifications and the material was delivered to the site on time. [redacted] technical expertise and cooperation played a crucial role in resolving the issue quickly.
- The liner subgrade was rockier than expected in some areas. OPG/[redacted] and [redacted] agreed to use the liner key trench spoil on the subgrade to save cost and time instead of supplying new material.

Lessons Learned:

- OPG should consider prequalifying the HDPE and GCL suppliers separately and order the material in advance of construction to ensure the liner quality and timely delivery.
- For future projects involving major liner work, the project management must ensure that the Owner's Engineer has extensive design and installation experience on this subject.
- The reservoir floor is typically a silty sand material and is trafficable by heavy equipment soon after removal of the overlying sediment.
- Future liner installations should give consideration to the venting of potential biogas generated under the liner. Also, venting of pore air from the reservoir floor materials should be considered.

5.5 Grout trial

Experience:

- The grout trial gave an opportunity to [redacted] and [redacted] to be familiarized with the actual bedrock conditions, test the grouting equipment, observe grouting at the overburden-bedrock interface and make proper adjustments to the grouting process before commencement of the production grouting program. The grout trial results revealed that grouting of the overburden/bedrock contact was not required, resulting in cost savings.
- Cost increases and schedule delays were incurred as a result of the grout release from the North trial area to the Queenston Seep on April 28, 2016. The early identification of the subsurface connection issue prevented potentially longer delays during the production grouting.
- To prevent new grout releases, production grouting procedures were significantly modified which resulted in additional costs. However, no grout release was observed at the Queenston Seep during the production grouting program.

Lessons Learned:

- Grout trial program should be included in the scope of work when the project includes extensive production grouting to identify any major issues early and refine the production grouting procedures accordingly.
- Projects involving major geotechnical work, especially grouting in highly fractured bedrock formations should have higher cost and schedule contingencies.

5.6 Production grouting

Experience:

- Exploration drilling was carried out to verify the accuracy of the dyke alignment shown in the original as-built drawings from 1950s. The results revealed that the dyke alignment was generally consistent with the as-built drawings except for the area around Ch. 28+00 where the grout curtain alignment had to be modified.
- In total, 706 holes were drilled, water tested and grouted. Production drilling decisions for each hole were made by the [redacted] and [redacted] representatives together located in [redacted] grouting control centre at the site.
- Most of the production grouting was completed with two grout plants as planned originally. However, a third grout plant had to be added in late September 2016 to make up for the delay caused by the grout release issue at the Queenston Seep. The production grouting program was completed on December 14, about a month after the original schedule. It appeared that [redacted] and [redacted] were conservative in their estimates for the completion date to avoid the liquidated damages included in the contract.
- In addition to [redacted] the cost increases in the production grouting was reviewed by OPG's PMO Estimating Services and found reasonable based on the average unit prices in the industry.

Lessons Learned:

- Grouting work is subject to significant uncertainties even in areas where geotechnical investigations were conducted previously. Therefore, imposing liquidated damages in the contract may not be enforceable and it would make the contractor and its grouting subcontractor more conservative in their cost and schedule forecasting.

5.7 Grout release at Queenston Seep

- During the 2011 CGI, it was determined that there was no connection between the reservoir water (above ground) and the Queenston Seep on the Niagara River bank where an endangered salamander species habitat is located. However, we could not foresee that the groundwater system could carry the grout (mainly the bentonite component of the grout mixture) to the bottom of the Niagara River bank at a distance of 700m. The grout release was observed on April 28, 2016 during grouting at the North Trial area near Weir No. 2.
- Initially [redacted] had reservations to participate in dealing with this urgent environmental issue due to potential legal liabilities and temporary lack of OPG's construction insurance. OPG expressed its disappointment to [redacted] with the contractor's reluctance to participate. [redacted] decided to participate only after OPG clarified that resolving this issue was ultimately OPG's responsibility as far as the regulatory agencies are concerned.
- OPG had not shared the 2011 Queenston Seep/salamander investigation with [redacted] during the construction planning meetings because it was thought as a non-issue.
- It was beneficial to have involvement of MNRF and MOECC from the start of the project (i.e., the definition phase). Also informing the regulators immediately following the grout release ensured their cooperation and quick response.
- The remedial measures at the Queenston Seep (i.e., a diversion and water supply system) were designed by OPG/[redacted] and constructed by [redacted] [redacted] was also responsible for operation and maintenance of the system. [redacted] provided the usual QA services during the construction and operation.

Lessons Learned

- Effective communication with the regulatory agencies from the onset of the project and informing them immediately after any environmental incident is key to assure their cooperation. As in any large

organizations, the staffing changes in the agencies are also common and that is another reason for the need of continuous communication with the agencies.

- Groundwater flows and potential connections to any habitats of endangered species should be investigated during the project definition phase. Special attention should be paid to the steep banks of lakes and rivers for habitats.
- OPG should share all available information with the contractor on environmental issues encountered in the past, such as the salamander habitat investigations in 2011 in the present project.
- All parties need to understand the importance of effective communication and willingness to cooperate in case of unexpected events.

APPENDIX B: CHRONOLOGICAL LIST OF EXECUTION PHASE ACTIVITIES

DATE	ACTIVITY
Nov.2014 – Feb. 2015	Prequalification of Contractors and Subcontractors • A public ad was published on November 4 for prequalification of (general) contractors. The closing date for responses was Dec. 5, 2014. • Grouting companies and liner companies (supplier/installer) were prequalified based on invitation. • Following companies were prequalified to participate in RFP: o Contractors: [redacted] o Grouting Companies: [redacted] o Liner companies: [redacted] • Results were announced in February 2015.
Mar.-June, 2015	RFP for Contractors • RFP was issued on March 16 to [redacted] and [redacted] The RFP was closed on May 12. [redacted] and [redacted] decided not to participate in the RFP process. • Contractors were requested to select a subcontractor from each list of the prequalified grouting and liner companies to participate in RFP. • [redacted] was selected as the successful proponent in June.
June-Aug., 2015	Fund Release for Execution Phase and Contract Sign • This was the first project which had gone through the Gate Review Board (GRB) process of Hydro-Thermal Operations. • Project introduction meeting was held with GRB on May 29, 2015. • Business Case Summary (BCS), Board Memo, Project Execution Plan (PEP), Project Definition Readiness Index (PDRI) report, Risk register and [redacted] RFP response were submitted to GRB on July 6 for review. A second meeting was held with GRB on July 13 to discuss GRB's comments and questions. GRB issued its concurrence report to SVP of Hydro-Thermal Operations on July 21. • Following a review by ELT, recommendation by SVP, approval by the President, a review and recommendation by the Board Risk Oversight Committee (ROC) of the BCS and Board Memo, the OPG Board approved the fund release for the project Execution Phase on August 21, 2015. • The Construction Services Agreement ("Contract") dated August 24, 2015 was signed OPG VP-Supply Services and [redacted] CEO.
Sep. 18, 2015	Project Kickoff Meeting • A project kickoff meeting was held at SAB1 Boardroom. OPG, [redacted] and [redacted] staff attended the meeting. • At the meeting, importance of H&S for OPG was emphasized, key sections of the CSA were reviewed and OPG's expectations from the Construction Execution Plan (CEP) were explained to [redacted]
Sep. 24, 2015	Outage Planning • An outage planning meeting for the construction was held at PGS with Ray Dejonge PGS, FLM) and his supervisors. The 2011 outage and dewatering activities were also reviewed.

Sep. 28 and Oct. 8, 2015	Archeological Assessment • Stage 2 Archeological assessment was completed by a crew of [redacted] licensed archeologists in the southwest corner of the reservoir (outside the dyke). No archeologically valuable artifacts were found.
Oct. 7, 2015	Scope Review • A scope review meeting was held between OPG and [redacted] at [redacted] offices in St. Catherines.
Oct. 28, 2015	Quarterly Update for Niagara Operations Management • A quarterly project update was provided to the Niagara Operations management at SAB1 boardroom.
Oct. 30, 2015	Scope Review • A scope review meeting was held between OPG and [redacted] at [redacted] offices in Mississauga.
Nov. 3, 2015	CEP Review • A project execution review meeting was held at SAB Auditorium with OPG, [redacted] [redacted] and [redacted] subcontractors to discuss the preliminary construction schedule, [redacted] construction approach and the CEP to be prepared by [redacted]
Nov. 6, 2015	Public Relations - Construction Notification • Niagara Operations-Corporate Relations Officer (Steve Repergel) has notified via emails the key local stakeholders (including Mayors of Niagara Falls and Niagara-on-the-Lake (NOTL), Councils, NPC, Niagara Bridges, Niagara Helicopters, etc.) and Hydro One to inform them about the upcoming construction activities and schedule.
Nov. 12, 2015	CEP Review • A meeting was held at [redacted] offices in St. Catherines, including OPG and [redacted] representatives to discuss the project schedule and work sequence in detail.
Nov. 13, 2015	Archeological Assessment • [redacted] intended to bring the grouting water from NPPC fire hydrant near the floral clock. [redacted] archeologist inspected the OPG property east of the reservoir (outside the fence line) where the water line would be installed. • It was concluded that the area had been extensively disturbed in the past and no further archeological investigation is required in this area.
Nov. 13, 2015	Stone Stockpiles • [redacted] representatives, accompanied by OPG and [redacted] staff visited the Niagara Tunnel Boring Machine (NTBM) stockpiles. Material samples were taken by [redacted] for lab tests to further assess usability of the piles during construction.
Nov. 19, 2015	Hydro One Work around PGS • A meeting was held between OPG and Hydro One representatives for information exchange on PGS project and Hydro One's tower and transmission line maintenance work and to coordinate activities in the common areas.
Nov. 20, 2015	Scope Review for Grouting • A meeting was held at [redacted] offices in King City, Ontario to discuss the grouting specs and work execution. Attendees visited [redacted] equipment yard after the meeting.

Nov. 27, 2015	CEP Submission • [redacted] submitted the draft CEP for OPG's review.
Dec. 2, 2015	Notice of Project (NOP) • [redacted] submitted its Notice of Project to MOL. The construction start date was shown as Jan. 18, 2016.
Dec. 7, 2015	MOU-Revision 0 for Mobilization • An internal (OPG) meeting was held with Niagara Operations and Corporate Safety staff to discuss the MOU format and contents.
Dec. 8, 2015	CEP Review • A meeting was held at SAB Auditorium with OPG, [redacted] [redacted] and [redacted] subcontractors' staff to discuss the draft CEP submitted by [redacted] and the dewatering and construction approaches planned by [redacted]
Dec. 11, 2015	Static Head Test Terms of Reference (TOR) • The TOR was issued for the pre-construction Static Head Test to be carried out on January 20-22, 2016. [redacted] was not involved in the test.
Dec. 14, 2015	Public Relations-Stakeholders Meeting • A presentation was made at the "2015 Niagara Operations Dam & Public Safety Program Stakeholders Meeting" at SAB Auditorium on the project scope and schedule.
Dec. 14, 2015	[redacted] Mobilization • [redacted] delivered two office trailers to the site for storage. They were placed over the existing concrete pads south of the Niagara Tunnel outlet. The trailers will be operational after the construction islands are assigned to [redacted] for mobilization.
Dec. 15, 2015	Presentation to Niagara Operations Services • A project presentation was made to the staff of Niagara Operations Services group at the Stanley Ave. offices.
Dec. 17, 2015	Static Head Test Preparation • A meeting was held between OPG and [redacted] representatives at [redacted] offices in Mississauga to discuss the resource requirements and instrumentation for the pre-construction static head test. • OPG has measured the flows through eight horizontal pipes around the reservoir. The reservoir HWL was about 623.5ft. The flows were almost the same or less than what were measured during the 2012 Static Head Test (HWL=627ft).
Dec. 18, 2015	CEP-Safety Plan • OPG and [redacted] staff met at SAB1 boardroom to discuss OPG's comments on the Project Specific Site Safety Plan (PSSSP) that is included in [redacted] CEP. PSSSP includes the Emergency Response Plan as well.
Dec. 24, 2015	Technical Specs for Construction • [redacted] issued the final versions of the technical specifications for construction.

Dec. 31, 2015	Static Head Test Preparation • [redacted] inspected all eight vibrating wire piezometers installed inside the reservoir during the 2011 dewatering. Piezometer connection lines were originally brought to the dyke crest for easy access. • Four of eight piezometers were found still functioning and they will be equipped with data loggers for the upcoming static head test scheduled for on Jan. 20-22.
Dec. 31, 2015	Construction Drawings • [redacted] issued the final versions of the construction drawings.
Jan. 4, 2016	Archeological Assessment • [redacted] issued the final Stage 2 Archeological Assessment Report.
Jan. 6, 2016	Public Relations - Construction Notification Niagara Operations-Corporate Relations Officer hand-delivered letters to about 120 PGS neighbours (residences and businesses) to inform them of the upcoming construction activities.
Jan. 6 & 15, 2016	EPSCA Assignment for Mobilization • [redacted] held its EPSCA markup meeting at its St. Catherines offices on Jan. 6 with union representatives for the mobilization activities and stone crushing. • [redacted] issued the final assignments on Jan. 15.
Jan. 8, 2016	CEP-Environmental Management Plan OPG, [redacted] and [redacted] staff met at Kipling to provide OPG's comments on the Project Specific Site Environmental Management Plan (PSSEMP) that was included in [redacted] CEP.
Jan. 11, 2016	MOU-Revision 0 for Mobilization • Following the internal reviews and discussions with [redacted] the Memorandum of Understanding (MOU)-Revision 0 for construction islands associated with mobilization was issued on Jan. 11 for signatures. • The MOU was signed by OPG (Ray Dejonge and Clara Greco) on Jan. 11 and by [redacted] on Jan. 12.
Jan. 11, 2016	Technical specs and drawings for construction • Technical specs and drawings stamped by [redacted] as "Issued for Construction" were sent to [redacted]
Jan. 11 & 18, 2016	[redacted] mobilization • [redacted] initiated the Ontario 1 Call on Jan. 11 for the locates of the underground services for the construction islands for mobilization. • [redacted] placed the construction islands signs on Jan. 18 and started to bring equipment for stone crushing.

Jan. 11-14 & 15, 2016	Pre-Construction Static Head Test • Instrumentation preparation (Jan. 11-14): o Installation of data loggers in the piezometer wells around the reservoir and vibrating–wire piezometers have been completed by OPG-PES and [redacted] technicians. o Four water-level data loggers were installed underwater at four locations within the reservoir to assess any potential wind effect on the reservoir water levels. o Two meetings were held between OPG and [redacted] to review the instrumentation progress. • Static Head Test and reservoir dewatering planning (Jan. 15): o An internal meeting was held with the PGS and Outage Management staff (Ray Dejonge, Gilles Numainville, David Malone and Fernando Gonzalez) to review the scope and schedule of the upcoming Static Head Test (Jan. 20-22) in the reservoir and the reservoir dewatering activities to start on April 1.
Jan. 18, 2016	CEP-Safety Plan • [redacted] issued a revised version of the Project Specific Site Safety Plan for OPG's review.
Jan. 19, 21 & 27, 2016	Additional costs and savings • Meetings between OPG/[redacted] and [redacted] on cost increases and cost savings due to changes in [redacted] execution approach: o A teleconference was held on Jan. 19 between OPG/[redacted] staff to discuss the potential cost increases and savings with a net saving for OPG. o A meeting was held at [redacted] offices in St. Catherines on Jan. 21 to discuss the subject further. o A meeting was held at SAB1 GS on Jan. 27 to provide OPG/[redacted] comments to [redacted] on assumptions made by [redacted]
Jan. 20-22, 2016	Pre-Construction Static Head Test The pre-construction reservoir Static Head Test was carried out between Jan. 20, 8:00 and Jan. 22, 5am. The weather conditions were favourable for the winter, with low winds and light snow only for about 2 hours.
Jan. 26, 2016	Stone Crushing • [redacted] and its subcontractor, [redacted] started with stone crushing on Jan. 26.
Feb. 1, 2016	Terminal Points and LOTO Procedure • An internal meeting was held with the PGS and outage management staff to determine the terminal points and the lockout-tagout (LOTO) procedure for the reservoir dewatering process.
Feb. 2, 2016	Project Update for Niagara Operations Management • 2016-Q1 project update meeting was held with Niagara Operations managers in SAB Boardroom.

Feb. 4, 8, 9 & 10, 2016	Fire Hydrant Installation for Grout Water Supply • Feb. 4: A small construction island has been agreed and signed off by signatories of the existing MOU (i.e., Ray Dejonge, Clara Greco and Bill Snow) to be effective on Feb. 8-11. Because of the short construction duration, there was no need for MOU revision. Instead an email with the attached sketch of the CI was forwarded by Mahir Aydin to the MOU signatories for their approvals. • Feb. 8: A walkdown was completed by OPG (M. Aydin) and [redacted] ([redacted] [redacted] to identify potential hazards and the walkdown sheet was signed before turning over the CI to [redacted] The signage and snow fence were placed on the same day to delineate the construction island boundaries. • Feb. 9: Fire hydrant was installed. • Feb. 10: Pressure testing was completed and CI was returned to OPG.
Feb. 8, 2016	Change Management & Invoicing Processes • A meeting was held between OPG/[redacted] and [redacted] representatives at [redacted] offices at St. Catherines to discuss the change management process, invoicing and progress reporting.
Feb. 9, 2016	Terminal Points and LOTO Procedure • An internal meeting was held with the PGS, outage management and Corporate Safety representatives to finalize the discussions on the terminal points and the lockout-tagout (LOTO) procedure for the reservoir dewatering process.
Feb. 10 & 16, 2016	Construction Islands • Feb. 10: A meeting was held between the representatives of OPG and [redacted] to discuss the boundaries of the future construction islands and timing. • Feb. 16: OPG and [redacted] representatives toured around the PGS to finalize the construction island boundaries.
Feb. 17, 19, 2016	Additional Costs and Savings • Feb. 17: [redacted] forwarded to OPG the updated information on additional costs and savings due to the changes in the work execution plan. • Feb. 19: OPG/[redacted] and [redacted] representatives met at [redacted] offices in St. Catherines for clarification of the new assumptions made by [redacted] in updating the additional costs and savings.
Feb. 18, 2016	Dam Safety Panel Teleconference • A teleconference meeting was held to update the Panel members (Kaare Hoeg, Joe Ehasz and Kerry Rowe) and OPG Dam Safety staff on the project progress.
Feb. 19, 2016	Survey of Trial Grouting Areas • [redacted] surveyed the trial grouting areas, accompanied by OPG/[redacted] representatives. Based on the site observations, some changes were made in the trial grouting locations.
Feb. 19, 2016	Hydro One work around PGS • A meeting was held at SAB1 Boardroom among Hydro One, OPG and their contractors ([redacted] [redacted] and [redacted] for information exchange on their current projects around PGS.

Feb. 23 & Mar. 4, 2016	<u>EPSCA Assignment for Construction</u> • [redacted] held its EPSCA markup meeting on Feb. 23 with the union representatives at its St. Catherines offices. • [redacted] issued the final assignments on March 4, 2016.
Feb. 22, 23 & Mar. 4, 2016	<u>Additional Costs and Savings</u> • Feb. 22: [redacted] submitted an updated table to summarize the additional costs and savings due to the changes in [redacted] work execution plan. • Feb. 23: A teleconference was held between OPG/[redacted] and [redacted] reps to further discuss the updated table. • March 4: [redacted] submitted a new table for OPG's review, showing slightly higher savings for OPG.
Feb. 23 & Mar. 2, 2016	<u>Stone Crushing</u> • The stone crushing was completed on Feb. 23. • Demobilization of most of the crushing equipment was completed and the subcontractor ([redacted] left the site on March 2.
Mar. 3, 2016	<u>MOU-Revision 1 for Construction Islands inside and outside of Reservoir</u> • Following the internal reviews and discussions between OPG and [redacted] the MOU-Revision 1 was issued on March 2 for signatures for the construction islands associated with different phases of construction, including for reservoir dewatering, construction inside the reservoir, storage yard and Niagara Tunnel boring machine (TBM) material stockpile. • The MOU was signed by OPG and [redacted] signatories by Mar. 3.
Mar. 4, 2016	<u>Site Safety Training by [redacted] to OPG/[redacted] Security Staff</u> • [redacted] provided safety orientation to 8 Cantec staff at [redacted] St. Catherines offices to allow them to enter [redacted] construction islands unaccompanied.

Mar. 7, 2016	<u>Terminal Points, LOTO Procedure and Trashracks</u>
	• A meeting was held between OPG and [redacted] reps to discuss the following:
	  o Terminal points and LOTO procedure during dewatering,
	  o Modifications of the old trashracks (not belonging to PGS) stored at the site to be placed in front of PG1-A headgate for the reservoir dewatering.

Mar. 8, 2016	<u>Fire Hydrant Connection to PGS for Grouting</u> • [redacted] has completed installation of a 2"-PVC line below the ground from the new fire hydrant. Later, it was extended to Ch. 47+00 for the trail grouting.
Mar. 9 & 11, 2016	<u>Turbidity Measurements and [redacted] Environmental Management Plan (EMP)</u> • Mar. 9: Representatives of OPG, [redacted] [redacted] and [redacted] toured the proposed locations of sediment sampling during the reservoir dewatering to review the site conditions and to practice the sediment sampling process at one of the locations. Following the tour, parties met at SAB1 to discuss OPG's comments on the latest version of [redacted] EMP. • March 11: [redacted] issued the revised EMP based on comments provided by OPG/[redacted]

Mar. 10 & 11, 2016	<u>OPG-Hydro One Information Exchange</u> • Mar. 10: OPG, Hydro One and their contractors ([redacted] and [redacted] met at SAB1 to provide updates on their projects south of the reservoir. An inspector from MOL's St. Catherines office attended the meeting as well. He was invited by OPG to be briefed on the upcoming construction activities. • MOL inspector issued a "Detailed Narrative" to summarize his observations, which included some suggestions to improve the control of the truck traffic at the site. No MOL orders have been issued.
Mar. 10, 2016	<u>Site Safety Training by [redacted]</u> • [redacted] started the site safety training for the OPG and [redacted] staff for unaccompanied access to the CIs.
Mar. 11, 2016	<u>Additional Costs and Savings</u> • An agreement was reached between OPG and [redacted] to share the cost savings associated with the improvements made in the work execution plan.
Mar 15 & 18, 2016	<u>New road through Hydro One's Transmission Right-of-way and MOU-Revision 2</u> • March 15: A walkdown was completed by OPG (M. Aydin) and [redacted] ([redacted] to identify potential hazards within the construction island of the new road to be constructed by [redacted] under the transmission lines. The purpose of the new road is avoid driving over the challenging access road between Ch. 200+00 and Ch. 215+00 south of the reservoir. The walkdown form was signed before turning over the CI to [redacted] • Mar. 15: MOU-Revision 2 was issued for signatures to include the construction island for the new road. The MOU was signed by OPG and [redacted] signatories by March 18. • Mar. 18: [redacted] completed the construction of the new road. NTBM material was used for construction.
Mar. 17, 28, 30 & 31, 2016	<u>HDPE Price Escalation and GCL Supply</u> • March 17: A teleconference was held with [redacted] and its liner subcontractor ([redacted] to discuss the supply source, specifications, QC/QA and production schedule for GCL. The GCL manufacturer (CETCO) would ship some samples to be tested at the site within the following two weeks. • March 28: OPG and [redacted] staff met at [redacted] offices to prepare responses to [redacted] RFI-013 (GCL QA) and RFI-016 (HDPE-resin price escalation). • March 30: A teleconference was held with [redacted] and [redacted] for the HDPE price escalation formula and impact of the upcoming increase in resin price. Following the teleconference, [redacted] decided to order the resin material. • March 31: Discussion on GCL supply and schedule continued between OPG/[redacted] and [redacted] after the weekly progress review meeting on March 31.
Mar. 23 & 25, Apr. 3, 2016	<u>Turbidity Sampling</u> • March 23: [redacted] safety plan for turbidity sampling was reviewed at a site meeting as requested with Ray Dejonge (PGS FLM). • March 25: [redacted] revised the safety plan and reissued it for OPG's review on March 25. • April 3: A test run for turbidity sampling was conducted at SAB1 Canal control structure by [redacted] in presence of OPG/[redacted] representatives.
Mar. 29, 2016	<u>Trial Grouting</u> • Trial grouting started at both Ch. 37+00 and Ch.48+00 locations. • Minimum 10 primary and 8 secondary holes were to be drilled and grouted.

Mar. 30, 2016	Earned Value System • OPG/[redacted] and [redacted] reps met at [redacted] trailer to discuss EVS proposed by [redacted] P. Merry ([redacted] explained the details of the proposed system on an excel file and parties agreed on the proposal.
Mar. 30, 2016	MOU-Revision 3 • MOU Revision 3 was issued on March 30 to include the turbidity sampling locations. It was signed by MOU signatories by April 1.

Apr. 1 to 18, 2016	<u>Dewatering Process</u> Reservoir dewatering was carried out in five ranges of reservoir elevations: 1. Reservoir elevation: 600 ft (April1-4): • Apr. 1: The new construction island (including the entire reservoir but excluding the headworks) was transferred to [redacted] on April 1, 11am after OPG and [redacted] representatives placed their tags and locks on AC breakers of all headgates of PG2 to 6 and on swing arms of stoplogs in front of PG1. The "Control of Hazardous Energies Walkdown Sheet" (OPG-Form-0173) was also signed by Ray Dejonge (OPG) and [redacted] before the CI transfer. The water level was 599.5 ft on April1, 7am. Fish rescue activities started on the same day. 2. Reservoir elevation: 597 ft (April 5-6): • Apr. 4: [redacted] requested to lower the reservoir elevation to 597 ft due to low numbers of fish caught. Both headgates of PG6 were opened after removing the locks on the PG6 headgates, starting 5pm. PG6 was put on speed-no-load without generation (PMC was not able to generate power using PG6 due to the short notice). The reservoir water level was lowered to 597 ft after about 3 hrs of draining. Both headgates were closed by Niagara Operators from the control centre around 8pm. • Apr. 5: OPG and [redacted] placed their locks again on both headgates around 7am. • Apr. 6: Locks on PG6 headgates were removed from both headgates of PG6 around 5pm to prime the unit. PG6 was operated 3 hrs at about 5MW to lower the reservoir elevation to 594 ft by 8pm. Then the headgates were remotely closed by the Niagara Operators. 3. Reservoir elevation: 594 ft (April 7-11): • Apr. 7: Locks were placed again on both headgates of PG6 about 7am. • Apr. 8: The trashracks frame was placed by [redacted] in front of PG6-B headgate using a mobile crane. • Apr. 11: Locks were removed from both headgates of PG6 at 5pm and both gates were raised to drain the reservoir through the unit at speed-no-load down to 590 with runner blade angle of 5-deg. No power was generated due to the concern of sediment entry into the unit cooling system. Since the PGS reservoir gauge operates only above 592 ft, Ray Lajambe (Niagara Operations) stayed at the site while reservoir is lowered from 594 ft to 590 ft. As soon as the water surface touched the top of the sill at the water elevation of 589.7ft, the headgates were closed by the Niagara Operators which was achieved shortly after the midnight (12:15am, Apr. 12). 4. Reservoir elevation: 590 ft (April 12-14): • Apr. 12: Locks were placed again on both headgates of PG6. • April 14: [redacted] dewatering subcontractor ([redacted] started pumping water from the North Pool to the South Pool using a similar pumping system as in the 2011 dewatering. 5. Reservoir below 590 ft (Apr 15 and on): • April 15: Starting at 8am, the following activities were carried out: o OPG and [redacted] placed their locks on PG6 unit breaker in its open position o [redacted] placed a lock over the lifting cable of the trashracks frame in front of PG6-B headgate. o Locks were removed from PG6-B headgate and the gate was lifted by 1 ft. o Blades of PG6 runner was opened by 5-deg to drain the reservoir. A walkdown sheet was signed off by Ray Dejonge (OPG) and [redacted] to list the devices and their positions (i.e., headgates, stoplogs, trashracks and unit breaker) and terminal points which will be maintained until the end of construction. • April 18: Elevation in the reservoir dropped to 585.3 ft. At this level, flow depth in each of three notches of the sill is only 0.1m.
Apr. 1-15, 2016	<u>Fish Rescue and Relocation</u> • About 630 fish were rescued from the reservoir between April 1 and 15. The native fish (rainbow trout, yellow perch, northern pike, bass, red horse sucker, drum fish, etc.) were returned to Niagara River at Queenston dock. Non-native fish such as carp were taken out of site for euthanization.

Apr. 11 & 15, 2016	Construction Island for Installation of 3-in line for Grouting Water • [redacted] plans to install a 3-inclh water line connecting to the fire hydrant on the east of the reservoir (outside of OPG's fence line). This will be in addition to the 2-inch line installed previously to supply water for grouting. Because of the short work duration, there was no need for revision of the current MOU. Instead, the construction island schematics was issued on April 11 to three signatories of MOU for their approvals. • The work was completed on April 15.
Apr. 29, 2016	Fish Rescue and Relocation • Fish rescue has been completed. Approximately 3,000 fish have been rescued and relocated. From then on only fish salvage activities were carried out in shallow waters.
May 6, 2016	Dewatering Process • Dewatering of the North Pool has been completed using 4 pumps of 12". A small pump (about 8") would be installed to maintain the drained of the area for rain events. • Dewatering of the South Pool is largely completed using 4 pumps of 12'. The remaining water would be drained with an 8" pump.
Apr. 28 to June 17, 2016	Grout Release at Queenston Seep • April 28: The trial grouting operation was stopped following a report of grout leak at the Queenston Seep on Apr 28. • May 9: A meeting was held with representatives of MNRF and MOECC at the site to discuss the impact of the incident and the plans for the short-term remediation, long term monitoring (including habitat enhancement), further dye testing (to determine the source of the leak), and changes in production grouting procedures (to prevent similar incidents in the future). • May 19-20: Grout release was removed from lower part of Queenston Seep in cooperation with MNRF ("Preliminary Remediation work"). • May 24: Approval was received from MNRF to proceed with dye test at four holes of the North and South trial areas. • May 26-30: Dye tests have been completed. • June 2-3: Excavation of North trial area was carried out. • June 3: A meeting was held with representatives of MNRF, MOECC and NPC at Niagara Operations Auditorium to discuss the results of the dye tracer test, revised grouting plan and mitigation plan describing the mitigation measures to be carried out during the production grouting. • June 6-8: Excavation of South trial area was carried out. • June 7: [redacted] issued a technical memorandum entitled "Dye Tracer Test Results". • June 7: The following three documents were emailed to MNRF, MOECC and NPC for their reviews and comments: o Dye tracer test results, o Revised production grouting plan, o Mitigation plan. • June 10: Ontario Dusky Salamander Recovery and Implementation Team met and provided advice on grout cleanup, monitoring and compensation activities. • June 14: The grouting activities were officially registered with MNRF under the endangered Species Act. This is one of the requirements to proceed with the production grouting. The following documents were included in the registrations: o [redacted] technical memorandum to OPG entitled" "SAB PGS Reservoir Refurbishment Project-Revised Production Grouting Plan", o "Endangered Species Act Mitigation Plan". The registration was confirmed by MNRF on June 15. • June 16: Filtration socks and straw bales were installed at Queenston Seep.

	• June 16: [redacted] sent an email to MNRF, MOECC and NPC to report that the filtrations socks and straw bales were installed at Queenston Seep and data loggers for PH meter, water level and temperature were also installed at Smeaton Cove, Queenston Seep and locust Cove. [redacted] also informed the agencies that the grouting will start at Ch. 70+00 and proceed up to Ch. 55+00 (progressing from west to east) on June 17. The water supply and diversion systems need to be in place before grouting beyond Ch. 55+00. • June 17: Grouting started on Ch. 70+00 and interface grouting was completed in 10 holes without any issues.
May 27, 2016	<u>Debris removal in Front of Intake</u> • Debris in front of the intake has been removed by [redacted] using two skid-steer loaders and a crane. The work was included in [redacted] scope before signing the contract.
June 3, 2016	<u>Public relations - Media Event</u> • A media event was held SAB PGS to emphasize PGS as the major energy storage in Ontario and introduce the project to the media. It was attended by local and provincial media, local, provincial and federal politicians, OPG SVP Mike Martelli and [redacted] President [redacted]
June 8, 2016	<u>Preparation for Liner Installation</u> • A meeting was held between OPG, [redacted] and [redacted] including [redacted] liner expert, [redacted] to inspect the excavation of the key trench and dyke clay tongue.
June 6-23, 2016	<u>Production Grouting</u> • June 6: [redacted] issued an RFI (GOL-005) to [redacted] to request a proposal, cost estimate and schedule to develop a series of low mobility grout (LMG) mixtures as part of the revised production grouting procedures. • June 14: [redacted] issued a Field Communication (GOL-007, "Updated Grout Curtain Alignment") to [redacted] to describe the required changes to the grout curtain alignment between Ch. 28+00 to Ch. 30+00) as a result of the exploration drilling. • June 16: LMG tests have been successfully completed and [redacted] requested [redacted] proceed with the purchase of 10 pails of Celbex 653 material to be used in LMG mixtures. • June 16: [redacted] issued a Field Communication (GOL-008) to [redacted] to provide the details of the revised production grouting procedures and to ask [redacted] to start with the production grouting from Ch. 70+00 up to Ch. 55+00 before implementing the mitigation measures i.e., water supply and diversion system. • June 17: Contact grouting commenced around Ch.70+00. • June 23; Bedrock grouting commenced around Ch.70+00.
June 16, 2016	<u>Environmental Spill (non-reportable)</u> • A hydraulic line from one of [redacted] drill rigs developed a pin-sized hole and sprayed a mist of hydraulic oil onto the slope of the drill access platform. It was estimated that 1-2L of hydraulic oil was spilled. • [redacted] immediately shut down the drill and called [redacted] Within minutes of the spill, an excavator crawled over to the bottom of the drill access platform and removed all oil-sprayed stone. • The stone was loaded into a rock truck and dumped in the contaminated material containment pit beside the old crushed concrete pile. • It was a non-reportable spill due to the small size and no spill into the water.

June 21 & 22, 2016	Pumped Storage Users Committee (PSUC) Meeting • June 21: A project overview presentation was made to the members of North American Pumped storage User Committee at a meeting held at Hilton Hotels and Suites - Niagara Fallsview. • June 22: The members of PSUC and their spouses visited the site.
June 22, 2016	Queenston Seep - Scaling and Brush Removal • [redacted] initiated the scaling and brush removal at the top of the seep.
June 24, 2016	Meeting with MOECC • A meeting was held with Lisa Benvenuti of MOECC to discuss the permit requirements for water take and discharge.
June 24, 2016	MOL visit • MOL's inspector (Jay Thornton) and the area manager visited the Queenston Seep as invited by [redacted] to assess if a separate Notice of Project (NOP) is required for Queenston Seep. • MOL issued its report on the same day (June 24) indicating that it is up to [redacted] whether to issue a separate NOP. [redacted] decided not to have a separate NOP for the Queenston Seep. • The area manager indicated that [redacted] equipment must be CSA certified.
June 28-30, 2016	Queenston Seep - Salamander Survey • Remediation of Areas 4 and 5 were carried out by [redacted] staff with assistance by [redacted] and cooperation with a representative of MNRF. No Dusky salamanders were found in Area 5, while 5 of them were found in Area 4. One dusky salamander was destroyed by accident by the [redacted] staff.
July 8 & 25, 2016	Liner Installation Stoppage due to Weather • July 8: Liner installation stopped in the south liner area due to high winds. • July 25: Liner installation stopped in the northeast liner area due to heavy rain.
July 11, 2016	Dam Safety Panel Meeting and Site Visit • A project review meeting was held with the Dam Safety Panel members, followed by a visit to the construction site.
July 14-15, 2016	Queenston Seep - Oil Sheen • July 14: A film on water surface upstream of straw bales was observed late afternoon on June 14. [redacted] was instructed on July 14, 4pm (Thursday) to stop the production grouting until further notice. MOECC, MNRF and NPC were informed of the incident. Drilling, MPSP installation, and water pressure testing continued in the meantime • July 15: MOECC representative (Lisa Benvenuti) visited the site. It was concluded that the film was of probably organic origin, not related to grouting (this was later confirmed by the lab test results of the water sample taken from the site on July 9). [redacted] was instructed to resume the production grouting on July 18 (Monday).
[redacted]	[redacted]

Aug. 8, 2016	MOU Revision 4 • Revision 4 of the MOU was issued to include the construction islands for implementation of the remedial measures at the Queenston Seep and Installation of the power supply cable for pump operation.
Aug. 12, 2016	MOU Revision 5 • Revision 5 of the MOU was issued for connection of the power cable to the welding receptacle on the north wall of SAB1 GS.
Aug 22, 2016	Queenston Seep • Aug 22: The 600V power supply was connected to the new 7.5 hp pumps and started pumping 2 lit/s. The diesel gen was no longer needed. • Aug 22: Lisa Benvenuti of MOECC visited the site to review the diversion and water supply systems and was impressed with the setup. • Major silt was discharged into the settling tank after the heavy and quick rain during the last weekend (Aug. 20-21).
Oct 11-12, 2016	Diver Inspection of Tailrace Gains of Unit 5 • PGS management decided to close Gate 6B which was in open about 2ft from since dewatering. It was temporarily closed to allow the divers to cleanup the tailrace gains of Unit 5. • The gate was closed on Oct. 11 and reopened on Oct. 12. • [redacted] was informed of the change.
Oct 13, 20 & 21, 2016	Production Grouting • Oct.13: Zone 1 grouting was completed. Grout Plant1 was relocated between Zones 2 and 3 to serve both zones. • Oct. 20: [redacted] reported that grouting to be completed by Jan 12, [redacted] to demobilize by Jan 26 and [redacted] demobilize by Feb 22. • Oct. 21: 424 holes (approx. 59% of total of 722 holes) have been grouted.
Oct 18, 2016	Pre-construction Static Head Test Report • [redacted] has issued the final report for the pre-construction SHT.
[redacted]	[redacted]
Oct. 24, 2016	Toe Berm • The toe berm construction between Ch. 53+55 and Ch. 59+80 had been completed except for the top layer which will be supplied from the external ramp (at Ch. 70+00) when it is removed in November.

Nov. 3, 2016	Liner Repair • Two liner areas at Ch. 27+00 and 47+00 were damaged (small dents and wrinkles) due to heavy equipment traffic and relatively thin sand layer cover. They were repaired by [redacted] with QA provided by [redacted]
Nov. 10, 2016	Turbidity Monitoring • [redacted] resumed the turbidity monitoring as the water is being discharged from the reservoir into the PGS intake due to the recent rain events.
Nov. 10, 14-16, 2016	Production Grouting • Nov. 10: [redacted] started working from 5am to increase the work hours. • Nov. 10: [redacted] confirmed that the production grouting could be completed by Jan. 12 as reported previously. • Nov. 14: 601 holes (approx. 83% of the total 722 holes) have been grouted. • Nov. 15: The winterization (insulation and heating) system of the grouting equipment was installed on November 15, ready for operation when needed. • Nov. 16: Due to the reduced area of grouting, only one grout plant was operated.
Nov. 14, 2016	MOU Revision 6 Revision 6 of the MOU was issued to reflect the following changes: • Appointment of Dave Thom as the new FLM for PGS, replacing Ray Dejonge. • Closing of Headgate 6B and opening of Headgate 3B for the rest of reservoir dewatering on Nov. 9. [redacted] decided not to relocate the trashracks from Gate 6B to Gate 3B.
Nov. 16, 2016	Access Platform • Access platform in grout Zone 1 (between Ch. 55+00 and 70+00) has been removed.
Nov. 16, 2016	Sediment Blanket in Central Area of Reservoir • Placement of sediment blankets and regrading in the central area of the reservoir bottom (i.e., around old Smeaton Creek) had been completed.
Nov. 16 & 17, 2016	Queenstown Seep • No grout release had been observed since April. • The seep flow has been averaging around 0.7-0.8 l/s and it is unaffected by the grouting process. • Nov. 16: [redacted] issued the final version of the Operation and Maintenance Manual for the diversion system as agreed with [redacted] • Nov. 17: [redacted] subcontractor, [redacted] was at the site on November 17 for inspection and maintenance of the diversion system and upgrading the power supply of the video camera used for continuous observation of the system. [redacted] [redacted] will also participate in inspection to ensure no damage to the salamander habitat.
Nov. 17, 2016	Tree Removal • Tree removal from the upstream slope of the dyke has been completed.

EX. L-H-STAFF-01 ATTACHMENT 1 IS CONFIDENTIAL IN ITS ENTIRETY

SUMMARY OF ADJUSTMENTS FOR THE 2016 TAXATION YEAR

OPG | Electrifying life

Impacts of the Market Renewal Program Clearance of Deferral & Variance Accounts

November 2023

Overview

OPG is planning to file an application with the OEB in Q4 2023. The application will address the impacts of the IESO's Market Renewal Program and clearance of deferral and variance account balances.

The following two slides highlight key issues anticipated during the application process.

The remaining slides are from a deck that will be presented to stakeholders in advance of filing the application.

Application Summary and Timing

Deferral & Variance Account Clearance

Impact of the IESO's Market Renewal Program

Application Summary and Timing

EB-2020-0290 Settlement Agreement

- "OPG shall file an application with the OEB regarding any changes to the Hydroelectric Incentive Mechanism and other impacts arising from the MRP with sufficient time for the OEB to adjudicate the application prior to the scheduled implementation of the MRP."

- "in conjunction with [the MRP] application, or separately during the IR term, OPG may also file an application to clear deferral and variance accounts."

Application Summary and Timing

In the application, OPG is requesting:

01 Approval for recovery of audited December 31, 2022 balances of regulated hydroelectric and nuclear deferral and variance accounts.

02 Approval of the Surplus Baseload Generation Variance Account spill calculation methodology.

03 Approval of a revised Hydroelectric Incentive Mechanism ("HIM") methodology and HIM adjustment for spill.

02

Deferral & Variance Account Clearance

Balances & Recovery Periods

- OPG proposes to recover December 31, 2022 D&V account balances for most accounts (less amounts previously approved for recovery through payment riders established in EB-2020-0290)
- Hydroelectric D&V account balances of ~$250M and nuclear D&V account balances of ~$220M
- OPG proposes to clear the recoverable amounts over a 30-month period from July 1, 2024 to December 31, 2026
- Riders concluding at the end of 2026 allows for cleaner transition to rates and riders approved in OPG's next major rate application

02

Hydroelectric D&V Account Balances

Regulated Hydroelectric Deferral and Variance Accounts	Audited 2022 Balance ($M)	EB-2020-0290 Amortization ($M)	2022 Balance Less Approved Amortization ($M)
Water Conditions VA	(172.4)	(72.7)	(99.6)
Ancillary Services Net Revenue VA	(34.2)	(22.2)	(12.1)
Hydroelectric Incentive Mechanism VA	0	0	0
Surplus Baseload Generation VA	402.9	112.2	290.6
Income and Other Taxes VA	(13.3)	(1.8)	(11.5)
Capacity Refurbishment VA	83.0	0	83.0
Niagara Tunnel Project 2008 Disallowance VA	8.0	2.5	5.5
Pension & OPEB Cost VA	2.1	2.1	0
Pension & OPEB Cash VA	(77.0)	(25.7)	(51.3)
Pension & OPEB Cash Vs. Accrual Differential DA	110.4	82.3	28.1
Pension & OPEB Forecast Accrual Vs. Actual Cash – Carrying Costs	(2.0)	(0.1)	(1.9)
Hydroelectric Over/Under Recovery VA	16.1	2.3	13.8
Total	**323.5**	**78.9**	**244.5**

02

Nuclear D&V Account Balances

Nuclear Deferral and Variance Accounts	Audited 2022 Balance ($M)	EB-2020-0290 Amortization ($M)	2022 Balance Less Approved Amortization ($M)
Nuclear Liability DA	188.4	0	188.4
Impact Resulting from Changes in Pickering EOL DAs	(102.4)	(163.9)	61.5
Nuclear Development VA	110.9	2.5	108.4
Ancillary Services Net Revenue VA	(13.6)	(2.4)	(11.3)
Income and Other Taxes VA	(18.8)	(9.7)	(9.1)
Capacity Refurbishment VA	50.7	(76.8)	127.5
Bruce Lease Net Revenues VA	101.3	99.6	1.7
Pension & OPEB Cost VA	(79.6)	42.9	(122.6)
Pension & OPEB Cash VA	(383.4)	(116.1)	(267.3)
Pension & OPEB Cash Vs. Accrual Differential DA	688.3	523.5	164.8
Pension & OPEB Forecast Accrual Vs. Actual Cash – Carrying Costs	(12.3)	(0.4)	(11.9)
Nuclear Over/Under Recovery VA	(74.7)	(16.8)	(58.0)
Fitness for Duty DA	1.6	0	1.6
SR&ED ITC VA	(8.6)	(8.1)	(0.5)
Rate Smoothing DA	568.9	0	568.9
Pickering Closure Costs DA	2.8	0	2.8
Total	**1,019.2**	**274.4**	**744.7**

OPG

03

Impact of the IESO's Market Renewal Program

Market Renewal Program Status and Impacts

- IESO is currently in the implementation phase of its Market Renewal Program ("MRP") with an expected in-service date of May 2025.

Impacts of MRP on OPG's regulated framework are primarily due to:

- Replacing the two-schedule market with a single schedule market ("SSM") and locational marginal price ("LMP").
- Introducing a financially binding day-ahead market ("DAM").

03

Impact of the IESO's Market Renewal Program

Overview of OPG's Effective Payment Amounts

- OPG's base payment amounts for the 2022-2026 period were set in EB-2020-0290 for OPG's regulated hydroelectric and nuclear facilities.
- Certain components of OPG's regulatory framework incorporate features of the current two-schedule market, for example the uniform market price.
- Elements of OPG's payment amounts designed on this basis are incompatible with the market post-MRP implementation and will need to be revised to reflect resultant changes and new drivers.

03

Impact of the IESO's Market Renewal Program

MRP Impacts on OPG Regulated Framework Addressed in this Application

MRP Changes		SBGVA	HIM	MWP/CMSC
Single Schedule Market	Uniform price to Locational Prices	☑	☑	
	Eliminate Unconstrained schedule	☑		☑
	Changes to MWP			☑
DAM & RTM	DAM & RTM Settlement		☑	

03

Impact of the IESO's Market Renewal Program

Surplus Baseload Generation Variance Account (SBGVA)

MRP Impact:

1. The calculation of SBG spill amounts will be affected by transition to a single schedule market with the elimination of the uniform market price used in the current SBG spill determination methodology
2. OPG will no longer have access to an indicator of global SBG conditions.

Proposed Treatment:

Revise the calculation of amounts booked in OPG's SBGVA to record the financial impact of forgone production due to SBG conditions based on LMP.

03

Impact of the IESO's Market Renewal Program

HIM Adjustment for SBG ("Unintended Benefit")

MRP Impact:

In alignment with proposed changes to the HIM and calculation of SBG spill, the formula for unintended benefit will be revised accordingly.

Proposed Unintended Benefit Treatment:

A revised unintended benefit formula that incorporates:

- Settlement on real-time LMP. (Due to the real-time nature of spill);
- daily production averaging;

03

Impact of the IESO's Market Renewal Program

Make Whole Payments

MRP Impact:

MRP will introduce changes to the nature and frequency of MWPs. IESO describes MWPs expected post MRP implementation as small and infrequent.

Proposed Treatment:

OPG proposes to retain any real-time MWPs net of any clawbacks, separate from the regulated payment structure consistent with current treatment.

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