Forensic Review in Support of Commission of Inquiry Respecting the Muskrat Falls Project

WILLIAMS ENGINEERING CANADA

November 30, 2018

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Project Name
Commission of Inquiry Respecting the Muskrat Falls Project

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Forensic Review

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Muskrat Fall, Newfoundland and Labrador

Prepared For
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Introduction

Williams Engineering Canada Inc. (WEC) was retained by Grant Thornton LLP to provide expertise and support to identify best practices that are relevant to the Muskrat Falls energy project. Specifically, WEC was asked to focus on the following areas:

1) Forecasting and Budgeting
2) Temporary Enclosure
3) Contract Structure
4) Work Package Sizes
5) Project Management Structure
6) Productivity Factors
7) Schedule
8) Risk and Mitigation During Sanctioning and Construction
9) Geotechnical Risk and Mitigation

Documents reviewed by WEC were provided by Grant Thornton LLP. It is understood that due to the vast number of documents related to this project, only select documents were provided to WEC. Consequently, WEC is able to provide a perspective on best practices in these areas and how they were applied to this project based only on the documents provided.

Findings

Forecasting and Budgeting

1. Contingency costs (increases or decreases) and associated potential schedule impacts (delay or acceleration) are included in project planning to account for factors that cannot be anticipated or predicted. Best practice is that if a factor is identified as part of the project planning process, then a cost and schedule impact (if any) is estimated and included in the project plan. Cost and schedule contingency are then also added in addition to the estimate. Documents provided for review indicate that this process was not followed in some circumstances.

2. Monte Carlo simulation was used to estimate the variability of cost and schedule. When using this simulation method, it is best practice to report the variability of the calculated information, at least within a range of P(25) to P(75). Greater variability of P(10) to P(90) is also used depending on the level of confidence in the simulation process.

3. Best practice budget reporting includes contingency costs. It appears from documents reviewed that contingency costs were not included in the reported budget when a mitigation strategy was identified to address the risk. Contingency costs are included in budgets until the scope of work associated with the contingency amount is completed and the risk is eliminated.

4. Budget contingency is attached to specific scopes of work. Contingency for one scope of work should not be used to address a cost increase on a different scope item. It appears that contingency was treated as a single amount to be used as it was needed without consideration to the remaining budget risk for the remaining scope.

5. Budget and schedule allowances are included in project plans for scopes of work that have been identified as part of the project planning process, but a detailed scope of this work is not clear. Allowances are incorporated into the project contingency. It appears that allowances and risk factors were not included in the budget and schedule process.

6. It is best practice to update a project schedule and budget immediately as information is collected regarding all project milestones as well as site conditions and quantified construction progress. This enables analysis and prediction of future outcomes while there is time to assess and take corrective action if required.

7. Construction progress reports should forecast final construction cost and completion date based on current productivity and work completed.

Temporary Enclosure

8. The strategy to enclose the main dam structure to facilitate production was a high risk approach. The enclosure:
    1) Provided a controlled environment to mitigate winter construction risk;
    2) Provided a method to move concrete and other materials around and over the dam structure.

    Without the enclosure, there was no weather protection and no system to move materials efficiently.

9. The enclosure strategy is not uncommon in cold climates. Attempting to enclose an area as large as the dam structure combined with an overhead crane, material movement system is not common and warranted detailed scrutiny.

10. It is not known if detailed production capacity rates were calculated for the ICS system by either the contractor or the project design team. For high risk methodologies, best practice is to validate performance assumptions before implementation.

11. The proposed enclosure was only suitable for scope contained inside the enclosure. The structural steel towers could not be erected while the enclosure was in place.

12. Integrating the temporary enclosure with the design requirements for the structure would require significant effort by all project stakeholders. Addressing these issues earlier in the schedule could have mitigated schedule delays by not delaying the procurement process.

Contract Structure

13. When dealing with large projects, different contractors delivering different, small scopes of work under different contracts does not mitigate schedule or cost risk for the project. Each contractor insists on initial site conditions outlined in a contract being met before work begins, and this same contractor is not motivated to complete their scope on schedule to facilitate further work as required for the overall project.

14. Not retaining one general contractor to oversee and control all scopes of work and being responsible contractually for overall project performance results in a high risk construction plan. To be successful under these conditions requires exceptional control over activities on site, as well as strong contracts with incentives and penalties within each contract to align each contractor's behaviour with overall project objectives.

15. Risk-sharing opportunities in construction contracts are limited because contractors cannot operate without recovering costs at a minimum.

Work Package Sizes

16. Best practice on large projects in remote locations is to provide large work packages in order to limit risks associated with delays in contract completion, particularly scope on the critical path.

17. Work packages on the project critical path merit special attention because they represent the highest risk to the project.

18. Larger work package sizes attract large-scale contractors and the expertise to complete complex projects.

Project Management Structure

19. Changing project management strategies after a project begins is not best practice.

20. Changing project managers results in a loss of "project memory" due to changes in staff and loss of document knowledge. Retaining and controlling documentation does not necessarily result in retention of the knowledge contained in the documents. Simply changing roles within a team can also lead to loss of memory because priorities and focus change, particularly when teams are not located in the same office or don't see each other as part of day-to-day operations.

Productivity Factors

21. At the tender stage, the productivity rate calculated by Astaldi was reasonable assuming other risks were mitigated appropriately, such as geotechnical conditions, labour scheduling and schedule delays.

22. The impact of cold weather was not considered adequately. Winter construction without heated enclosures is not productive. The onset of winter in the north can delay construction by an entire year if weather-sensitive work is not completed when planned.

23. It is not clear what concrete placement productivity could have been achieved if the temporary enclosure was successfully implemented. The complexity of the dam and spillway construction warranted special studies to plan and confirm realistic production rates during the planning stages of the project and with bid submissions. These efforts would also benefit site leaders because methods and procedures would be more clearly defined in advance, and targeted training could have been provided to all workers.

24. At the task level, best practice is to coordinate labour schedules with task work plans so task productivity is not interrupted by labour transitions, breaks, or overtime costs.

25. Significant changes combined with multiple schedule delays can magnify the impact of individual factors on productivity factors. Productivity reductions can be magnified by 30-60% depending on the severity and number of the changes and delays. A combination of factors resulted in the planned productivity rates not being achieved.

Schedule:

26. During the DG3 project review stage, it was estimated that first power might not be achieved until March 2019. Until schedule risk was overcome because of construction progress, best practice would require March 2019 to be the reported end date. Plans to accelerate and complete sooner would accompany the schedule plan.

27. The impact of weather was not considered holistically when the project schedule was developed. Civil construction is commonly assumed to stop during winter months. Attempting to continue outdoor construction through the winter season is typically uneconomic when time is typically better spent planning and optimizing processes for the following summer construction season.

28. The impact of remote construction in cold climates was not considered. Not completing a scope of work such as access roads, excavation, and delivery of materials to site before the onset of winter typically results in work being delayed by entire seasons, not just the delay in completing a previous milestone. The logistics plan for the entire project can be disrupted resulting in reduced overall productivity.

Risk and Mitigation During Sanctioning and Construction:

29. Risks can be mitigated during the design phase and during the construction phase. Risks are mitigated during the design phase by clarifying the scope of work and construction documents to address the risk. In this situation, contingency must still be carried to account for unforeseen risks that may occur during construction.

30. For risks that are not addressed through the design process, best practice is to carry an allowance (cost and schedule) to address this potential outcome. A contingency must also be carried to account for unforeseen risks in addition to the allowance risk.

31. Nalcor risk mitigation plans developed during planning and sanctioning phases of the project do not appear to have materialized during construction. It is not clear what processes were put in place to ensure these plans were implemented on site or in contract documents.

32. At DG3, the unmitigated risk date of full power was predicted to be March 2019. Using Monte Carlo simulation, the unmitigated risk P(75) date of full power was predicted to be September 2019.

33. At DG3, the construction cost estimate was based on the traditional workplan estimate, with the contingency calculated as the difference between the workplan cost and the Monte Carlo P(50) cost value.

Geotechnical Risk and Mitigation:

34. Insufficient geotechnical investigation was completed during the planning and sanctioning phases of this project in order to reasonably quantify the foundation risks already identified at this point in the project. It appears that the risk of schedule delay and cost increase associated with these risks were not incorporated into the overall schedule and budget.

35. Insufficient geotechnical investigation work was completed during the feasibility phase of this project in order to quantify risks that were identified at this point in the project. It appears that the risk of schedule delay and cost increase associated with these risks were not incorporated into the overall schedule and budget.

36. It appears that schedule and cost risks due to uncertain geotechnical conditions at the powerhouse location were not considered in the project planning and detailed scheduling of work. Delays due to dewatering and foundation treatment delayed subsequent phases of work including the start of powerhouse construction.

37. For transmission line projects, best practice is to attend and complete a minimum of one borehole per tower location. Insufficient geotechnical information was available to mitigate risk when the transmission line tower construction package was tendered.

1.0 Introduction

Williams Engineering Canada Inc. (WEC) was retained by Grant Thornton LLP to provide expertise and support to identify best practices that are relevant to the Muskrat Falls energy project. This scope is part of a much larger forensic review of the Muskrat Falls project being lead by Grant Thornton LLP. This overall forensic review is undertaken in support of the Commission of Inquiry Respecting the Muskrat Falls Project underway in Newfoundland and Labrador.

Specifically, WEC was asked to focus on the following areas of the project:

1) Forecasting and Budgeting
2) Temporary Enclosure
3) Contract Structure
4) Work Package Sizes
5) Project Management Structure
6) Productivity Factors
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Documents reviewed by WEC were provided by Grant Thornton LLP. It is understood that due to the vast number of documents related to this project, only select documents were provided to WEC. Consequently, WEC is able to provide a perspective on best practices in these areas and how they were applied to this project based only on the documents provided.

2.0 Forecast / Budgeting

2.1 Introduction

Planning and delivering a construction project are complex processes requiring many skillsets and processes to be applied in a particular manner and time in a project. Initially, a project is more of an idea than a defined outcome. An idea is then developed further and becomes a documented, tangible and physical asset. Not only do the details of the asset need to be defined, but the process of how an asset is to be built must also be defined. Experts with experience in defining and delivering a project are required to deliver a construction project for an owner. Initially, very little detail is known, so experts begin the process of determining the most efficient and effective approach. For large projects, this process can take years, and even then, not all details for a project will be resolved before construction begins.

Budgets and schedules are developed based on increasing levels of detail that are defined as the planning and documentation for a project are developed.

Scope definition and documentation of the scope provides the greatest level of detail with which to build detailed budgets and schedules required to complete the project. Initially, scopes of work lack detail but are recognized as necessary to complete the project. In this situation, best practice is to assign an allowance in the budget and schedule for this scope of work. Because the scope is not clearly defined, a contingency is estimated for factors that have not yet been identified, and this contingency is added to the allowance.

When construction sequences are complex and involve variables like site conditions that are not fully understood, the precise scope of work required to complete some tasks is not known and might not be required, depending on undefined conditions that will be more clearly defined in the future. In this case, these factors and the associated scopes of work are considered risks to the budget and schedule of a project. Some risks are intuitively less likely to materialize than other risks, but it is in the best interests of a construction project to identify all project risks regardless of how likely they are to occur and diligently work towards defining and mitigating these risks as quickly as possible. Addressing these risks as quickly as possible will lead to a more certain project outcome and mitigate the implications of dealing with the risks later in the project when the impacts on cost and schedule can be more severe. It is best practice to include the potential cost and schedule impacts of these risks in the overall project cost and schedule reporting.

2.2 Monte Carlo Simulation

Historically, the ability to forecast the most likely final project cost and completion date has largely been based on experience with previous similar projects. For large and complex projects with unique challenges, previous project experience may not be sufficient. The Monte Carlo simulation method of determining probable outcomes has been adapted to apply to construction projects and, at the time of Muskrat Falls, represented best practice and state of the art in assessing multi-variable, cost and schedule outcomes for large construction projects.

As with any analysis tool, however, the quality of the information generated by the tool is directly proportional to the accuracy and detail of the data put into the tool. The number and type of risks on a large project can be very significant and therefore requires a defined process to ensure all risks are accounted for. For each risk, a potential scope and impact must be defined in terms of probability, cost, and confidence of occurrence. The impact of these risks on other parts of the project – either other risks or defined scopes of work – must also be considered and incorporated into the risk assessment. This process must then be quantified and the relationships between factors must also be defined using numerical techniques and contains its own level of uncertainty because it is not possible to define the exact nature of each risk because of its own uncertainty. Assessing the likelihood of an outcome is part of the uncertainty that a Monte Carlo simulation addresses by consolidating the individual risk components into an overall risk assessment. Defining the accurate input for a simulation requires collaboration between experts in the field of construction as well as experts in how to use the Monte Carlo method.

With each risk defined as clearly as possible, as well as the dependency between risks and project scope defined in terms of cost and sequence, then Monte Carlo simulations can estimate the likely range of project cost and confidence range of that estimate. It is important to recognize that Monte Carlo calculates the probability that a project cost will either be over or under a particular value, and not an expected project cost. Similarly, Monte Carlo calculates the probability that a project end date will be before or after a particular date. Hence, the confidence range (expressed as probability of achieving an outcome) of this outcome must also be reported to put the result into context. Without knowing the confidence range, a reported outcome is meaningless.

2.3 NAL001838 Project Controls Plan

The Project Controls Plan describes the various classes of estimates, their likely accuracy and the contingency that should be applied to an estimate along with a process for evaluating costs and schedule throughout the project. The plan also includes Performance Factors, including Labour Productivity and Seasonal Impacts, which should be included in the Capital Cost Base Estimate.

Cost estimating was to be done based on P(10)-P(90) ranges. The actual reporting for this project was based on the traditional approach of reporting a single P(50) number. The reporting did not attempt to use the probability approach which describes risks and ranges of costs. The intention was to set the baseline budget at the P(90) number, and also to include a contingency but not strategic risks like cost escalation risk.

A Cost Estimate Maturity Model was to be used as the design and planning progressed. As the level of detail increased, the implication of this model is that the accuracy of the cost and schedule estimate increases. This holds true only if the scope is fully defined and all risks are accounted for as part of the forecasting process. At the early stages of the project, a Class 5 estimate is developed based on "Benchmarking, Factoring, and Allowances." At the Class 4 estimate stage of the model, factors and allowances are transferred to the contingency and project scope is determined based on 1-10% complete engineering design. At this critical stage in the project, the model used for this project changes specific risks and allowances to a general contingency amount that is linked to basic engineering concepts rather than the factors not fully understood or accounted for on the engineering drawings. Effectively, this step in the plan appears to reduce project scope and relies on the contingency to include costs for specific risks and allowances rather than simply a percentage of scope defined on a set of incomplete drawings.

Following the initial creation of the contingency amount at the Class 4 estimate stage, the Class 3, 2, and 1 Estimates become inherently flawed as the level of detail defined by the engineering design documents is perceived to be more complete. The level of completeness is justified by the bottom-up approach for development of the workplan and scope definition. However, a bottom-up approach to estimating does not effectively identify project risks. The top-down approach used for the Class 5 estimate includes risks and allowances that are not part of a detailed work plan. Therefore, to accurately estimate an overall project budget and schedule, the bottom-up and top-down approaches must be combined. The Muskrat Falls cost estimate maturity model appears to only consider the bottom-up approach. As the documentation is considered more accurate, it appears that the contingency is reduced without consideration to how the contingency was originally calculated for the Class 4 estimate.

The adopted maturity model indicates that the level of completeness required for the DG3 sanctioning milestone is a Class 3 estimate based on 10-25% engineering completed, requiring a 10-15% contingency. At the DG3 milestone for the Muskrat Falls project, a contingency of 7% was used, which corresponds to a level of 80-100% engineering design completeness and does not align with expectations of the Nalcor controls plan.

Uncertainty of estimated information is defined in the controls plan based on a traditional percentage range approach. This range definition is not directly applicable to a Monte Carlo probabilistic approach where uncertainty is defined using a probability distribution of all input parameters. It is unclear how a probability distribution was assigned to each project variable.

In addition, the relationship between factors should be considered. For example, secondary impacts like impact of productivity factors on schedule and schedule-related costs should be added together to account for the cascading impact of one variable on many other variables. A schedule delay at the end of a summer construction season could lead to a "step delay" of many months due to the impact of cold weather on productivity. Each factor cannot be considered in isolation.

Knowing the scope and relationship between project factors, it is possible to forecast the final cost of construction. The final forecast cost must be correlated to the scope completed and the costs to accomplish the earned progress. The control plan implies that the total project cost would not change as changes occur during the project. Contingency and escalation allowances are tied to specific scopes of work so the rate at which the contingency and escalation allowances are consumed cannot exceed the rate of project progress. The final forecast cost is not a fixed value based on budget.

Similarly, the final forecast completion date must also be updated based on productivity and remaining scope to completion. If progress is slower than estimated, schedules must be extended. Only if methods to accelerate productivity are implemented and are successful, can a forecasted schedule be shortened. The forecast completion date is tied to construction progress rather than a static target completion date.

The project controls plan contains only basic information describing a general framework for how change management is to be handled. The change management process is described as time-sensitive with a priority to identify the potential impacts of the issue. The initial step is to create a Deviation Alert Notice (DAN) to start the evaluation process. The information required for a DAN is not clearly described in the plan, but should include an estimate of cost and schedule impact in order to highlight the potential significance and importance of the DAN. As the change process progresses, the estimate of cost and schedule impact is refined. Given the importance of change management, it would be expected that a detailed process, outlining detailed procedures and information that must be provided, is created as part of the project planning process.

2.4 NAL0019570 Decision Gate 3 Basis of Estimate

The Basis of Estimate document outlines how the budget estimate was determined. It should be highlighted that the estimate is assembled based on the assumption that the project would be performed under an Engineer, Procure, Construct, and Manage (EPCM) contract on behalf of the Owner. This form of contract was not used by Nalcor to deliver this project.

For DG3, the cost estimate is determined using scope of work descriptions and drawings available at the time. This is known as a bottom-up estimate strategy. Benchmarks and similar projects were only used when the bottom-up method wasn't possible.

Using only the bottom-up method introduces many concerns:

- When it's not an actual construction contractor, the risk of getting it wrong isn't the same. Without "skin in the game", unit price estimating risks missing the less tangible things.

- Cost consultants & quantity surveyors do good work but 99%+ of their work can be checked, even very informally, against the actual costs of previous similar work. Even when we look at a cost estimate for a Northern building or site project that, on its face is created with the bottom-up method, in reality a review of project-specific risks must be considered before assuming that this project is similar to the projects used as a comparison.

- A conservative, careful cost estimate would use both unit pricing and benchmarking. This is standard for projects of all sizes.

- The inherent risk in a bottom-up estimate is that risks and lump-sum allowances are forgotten. To ensure all risks are accounted for, each risk and allowance must be included in the defined project scope. Without a formal tracking process, an estimating process becomes distracted with the details of a particular scope activity that is clearly defined rather than ensuring that the overall project risks and circumstances are considered.

- Changing from a top-down to a bottom-up estimating process, requires a careful tracking process of risks identified from early stages of a project to ensure all risks are incorporated into the detailed estimates generated later when more project documentation has been generated. A strong project "memory" is required, so changes in personnel and project delivery methodology do not inadvertently introduce more risk to the project.

2.5 Monthly Progress Reports

Monthly project progress reports as well as construction progress reports were delivered. The format of the construction reports is not consistent throughout the project. Deviation Alert Notices (DAN) are sorted according to potential cost, but most DAN's were recorded as "To Be Determined", which is contrary to the intended purpose of using a DAN process and prevents forecasting of costs in any meaningful way.

Construction Progress Reporting continues until mid-2016, when the budget and schedule are re-baselined, after which a comparison of progress against planned progress is more difficult to determine. Graphs showing Cumulative Progress Planned, Cumulative Progress Actual, and Cumulative Progress Forecast clearly showed that the project was not progressing as planned. The forecast lines from month to month indicated that production would need to accelerate to rates not achieved up to that point if the current end date was to be achieved. Similarly, cost forecasts were calibrated to achieve the budgeted project cost rather than reflect the cost at completion based on the actual productivity rates.

Cumulative progress reporting for cost and productivity should have been used to forecast future performance based on current performance and costs. If this had been done, significant delays and cost overruns would have been forecasted, starting in the fall of 2014.

Re-baselining of costs and schedule information periodically effectively erases historic performance from the project and construction reports. This makes overall project performance as a function of time very difficult.

Contingency drawdown does not seem to change significantly from month to month. It appears that contingency is not adjusted to reflect reduced progress for costs incurred, and DAN information was not used to update the necessary contingency allowance. It is not clear how contingency measurement was used through the course of the project.

3.0 Temporary Enclosure

3.1 NAL0436468 Recommendation for Award Summary Report

Of the bidders for the powerhouse work, Astaldi ($1.26B) proposed the heated shelter solution, their competitor Salini JV ($1.25B) either stopped work during the winter or severely curtailed the amount of work. It would be very unusual for any remote and northern project to not incur some sort of winter shutdown, so focused scrutiny of a strategy proposed to avoid a shutdown is warranted.

The use of temporary enclosures, like the integrated cover system (ICS) Astaldi proposed, to protect the work and workers from the weather conditions is common in cold-weather climates for projects of all sizes. Strategies for enclosure of work vary depending on the type, size, complexity, and repetition of work. An enclosed workspace using a temporary metal building is very standard on a large construction site. Putting the ICS on top of a massive concrete structure that is being built under and around the ICS is not standard.

From the report, Astaldi was also relying on this cover building to move concrete over the entire dam structure. Using the temporary building to support a grid of cranes to move buckets of concrete from concrete trucks to the placement location is also not standard. The proposed system appears to be very congested - moving concrete by bucket to concrete pumps. The pumps are supported on the dam structure, with the ICS extending down through the dam structure to the bottom of the excavation, with independent foundation below the dam. There is no detail provided regarding how the dam structure would be built up and around the ICS during the sequence of construction. A significant amount of coordination with the design team would be required to accommodate the ICS and integrate it into the overall dam structure design. The process of completing this coordination would not be simple or straight-forward and would require a considerable amount of time that should have been built into the construction schedule.

Without the ICS, Astaldi did not appear to have an alternate plan to deliver the required production rate in order to achieve the overall schedule. Should the ICS not work, Astaldi would need to react quickly to find/buy/transport/erect/operate traditional construction cranes and determine how to meet productivity targets with limited crane placement capacity. Without developing an alternate system quickly, significant delays and increased costs would result.

The ICS solution is innovative but very high risk and is critical to the Astaldi bid. Subsequent to the tender process, Astaldi would need to confirm that their system, as planned, had the capability of placing the required volume of concrete and could meet project objectives. All parties – Astaldi, Nalcor, and SNC Lavalin Inc (SLI) would need to accept that the ICS could achieve production targets. Astaldi site meeting minutes appear to highlight the level of coordination and execution planning that continued though the fall of 2014. No approvals or acceptance to proceed with this strategy should have been given until the ICS could be justified as viable and accepted by all parties. Means and methods for construction are the responsibility of the contractor. Simply stating an intention to enclose the construction area does not alleviate the contractor of their responsibilities to coordinate their efforts with the design team and objectives of the project. The contractor is responsible to ensure their methods of construction meet the requirements of the project – scope, schedule and technical requirements. The risk for means and methods remains with the contractor.

4.0 Contract Structure

At DG3 budget estimate stage in May 2013, it appears that the project was planned assuming that an EPCM contract format would be followed. Instead, Nalcor provided the project management function for the project, starting as tendering and construction began.

When dealing with large projects, different contractors delivering different, small scopes of work under different contracts does not mitigate schedule or cost risk for the project. Each contractor insists on initial site conditions outlined in a contract being met before work begins, and this same contractor is not motivated to complete their scope on schedule to facilitate further work as required for the overall project.

Not retaining one general contractor to oversee and control all scopes of work and being responsible contractually for overall project performance results in a high risk construction plan. To be successful under these conditions requires exceptional control over activities on site, as well as strong contracts with incentives and penalties within each contract to align each contractor's behaviour with overall project objectives.

Risk for assumed performance metrics is difficult to delegate except when a scope of work is well understood and common on typical construction projects. When unique conditions exist, contractors will be reluctant to accept risk without more significant compensation which will inflate pricing. A risk sharing arrangement can motivate both parties to ensure efficient project execution, however, contractors cannot operate without covering costs at a minimum, which limits the opportunity to share risk and minimize costs for all parties.

5.0 Work Package Sizes

Work package size is made small on some projects to encourage more bidders or to suit the locally available supply chain capabilities. The location of Muskrat Falls is such that small bidders are unlikely to work on the project in any event. Larger packages are needed to attract the large-scale contractors to site.

Best practice on large projects in remote locations is to provide large work packages. Advantages to this approach are:

1) attract skilled and experienced bidders;

2) allow bidders to determine best approach to complete the work;
3) allow bidders to optimize workflow and maintain a consistent labour force; and
4) reduce risks of one scope of work impacting another and providing incentive to the contractor to mitigate cost and schedule risks within a larger scope of work.

Work packages on the project critical path merit special attention because they represent the highest risk to the project. Limiting risk to within one contract requires initial conditions and final completion conditions to be met on schedule. If scope that defines the critical path is divided into different contracts, then special efforts should be made to monitor progress and ensure site conditions defined within a contract are achieved from one contract to the next.

The work packages used at Muskrat Falls are logical for an EPCM contract format. It appears that scope was broken into work packages based on typical contractor expertise. This format works when one general contractor is responsible for the overall performance of the project and is therefore motivated to ensure the individual work packages are coordinated and scheduled to optimize productivity and project efficiency. In the case of Muskrat Falls, a contractor with this responsibility was not assigned, and an overall EPCM contract format was not used, thus individual contractors were not motivated to collaborate.

Without a general contractor for the overall project, scope could have been divided according to critical path scope or geographic boundaries. For example, the powerhouse construction scope could have been tendered to include excavation and site preparation so that the risk of schedule delays would be transferred to the contractor.

6.0 Project Management Structure

An EPCM format for a large project is common and provides the Owner with a single line of accountability for overall project performance. A traditional design-bid-build format can be advantageous over EPCM when a project scope is well defined with few risks and interest from contractors is strong.

Once a contract format is selected, planning and project organization processes are set in motion that align with the contract methodology. Therefore, changing project management strategies after a project begins is not best practice. Changing project managers results in a loss of “project memory” due to changes is staff and loss of document knowledge. Sub-contracts and the arrangement of scopes of work may not be optimal for the new project management format, which requires time and effort to review and modify, if necessary. When time and resources are limited, this re-organization time is better spent refining the project itself rather than potentially causing confusion while a project structure is changed.

Retaining and controlling documentation does not necessarily result in retention of the knowledge contained in the documents. Turnover of personnel requires exceptional effort to familiarize new individuals with the available documents and knowledge contained within them.

Converting the project management contract from an EPCM format to an integrated management team appears to be an attractive option because combining the best parts of different organizations can result in a more capable team. In these circumstances, however, it is critical to define lines of accountability and authority. Without this organizational clarity, conflict can occur, and decision-making abilities can be undermined.

When the performance of a project manager is not optimal, the entire project can suffer. An alternate approach by Nalcor starting in 2010 or as late as 2012 would have been to replace SLI with a new construction manager. Until 2012, site work was minimal and would have given Nalcor an opportunity to onboard a new team. Making this change after 2012 would have been inadvisable.

Managing construction projects requires a strong on-site team capable of motivating and organizing disparate teams of people and trades who wouldn't normally collaborate effectively, nor work towards a common objective. Administration and monitoring functions can operate remotely, but productivity is very dependent on strong, consistent and constant leadership in the field.

7.0 Productivity Factors

Productivity factors are a commonly used tool to estimate the resources required to complete a scope of work. Contractors and estimators create productivity factors based on past project experience, and some benchmarking factors are published to aid all stakeholders understand the level of effort required to complete a task and the factors involved in understanding the relative effort to complete the same scope of work under different conditions. For unique projects, care must be taken to ensure productivity estimates reflect a practical and viable method for completing a task. This generally requires the expertise of experienced estimators with a proven track record of successfully estimating comparable (in size and complexity) projects.

7.1 NAL0019570 - Decision Gate 3 Basis of Estimate

Decision Gate 3 Basis of Estimate assumes the following work schedule and costs:

- Labour rotation to be 20 working days /8 days off;
- 30% of labour on night shift;
- Key trade rates: $60 to $70 per hour;
- One trip for every 210 mhrs worked (So, working 10.5 hrs days);
- 4 hours of work is for travel; and
- All in wage rate $70/hr.

Regarding productivity, the Basis of Estimate makes the following assumptions:

- Concrete works 5.97 mhrs/m3;
- Performance basis using a 60 to 80% of normal productivity to account for remoteness; climate, pace of work , crew sizes, multiple shifts and long work weeks;
- Mech productivity 1.13 and 1.55 plus 6% congestion;
- Productivity factor 1.44 plus 6% congestion; and
- Productivity at 70% 1.43 based on 20 days working 8 days off.

7.2 Literature Review (see Appendix A)

In the referenced documents there are several references to differing productivity numbers. The following is to ensure a common discussion of productivity:

- **PF1**: In some, productivity is shown as a performance based number of 60% of 80% of normal productivity. In general, this number was meant to cover for: remoteness, climate, pace of work, crew sizes, multiple shifts and long work weeks. The number is also shown in the form 1.25 to 1.66 meaning that the work will take 25% to 66% longer on this site than when estimated using a standard estimating tool. This productivity factor was applied directly to the man-hours for the estimated task.
- **PF2**: In other places it shows an additional productivity factor of 6% due to congestion. That is, congestion will increase man-hours on site by 6%. This productivity factor was applied directly to the man-hours for the estimated task.
- **PF3**: For travel to and from the site, a man-hour allowance of 2 hours per trip was allowed. This amount was carried in a separate account and was not part of the productivity calculation.
- **PF4**: In other places, productivity is shown as 1.2. This number was meant to cover for labour shortages.

- **PF5**: Finally, in the Ibbs report, the report talks about Productivity Factors of the form 0.30. This productivity factor is a comparison of the productivity that Astaldi achieved in comparison to the Astaldi bid, which carried within it other productivity factors.

The SLI productivity estimate for the civil works was: PF1=1.31 plus PF2=1.06 plus PF4=1.2. Pre-employment training is undertaken prior to mobilization and at the cost of the Union, so no cost is carried for this item. Therefore, total productivity factor for civil works is 1.67 or 0.6 which is a productivity in the range of 5.8 man-hours/m3.

An independent way to arrive at a productivity factor would be as follows:

- Work: 20 days on /8 days off; 7 day week 10 hours/day. Week 1 productivity factor is 1.15, week 2 is 1.23. Average productivity factor is 1.19. Assume resets during days off.
- Assume two shifts daily. Productivity of second shift is reduced by some percentage. Assume average reduction 5%.
- Safety program: Assume 15-minute lunchbox session daily. Average Productivity factor 1.03.
- Congestion: 2 to 14% depending upon extent. Assume 6% for congestion.
- Cold weather introduces a reduction in efficiency in the range of 24%. Assuming 50% cold weather would result in a 1.12 productivity factor.
- Bad weather, rain or wind would shut down production several days a year. It was noted that there might be 10 snow events a year, so perhaps 10 days a year would be shutdown due to weather events. That would be a 3% loss or a 1.03 productivity factor.

Totaling the above factors results in 1.19x1.05x1.06x1.12x1.03=1.44 total productivity factor.

Regarding Labour Shortage Productivity PF4.

- RS Means 2016 suggests that the cost allowance of 11% of total cost for Heavy Industrial projects for shortage of skills. If this is applied to labour only, the 11% cost allowance would (original estimate $292M labour, $837M total project cost) would yield a 32% markup for labour. This would be required to match an extremely tight labour market.
- Craft staffing difficulty runs from 0 to 3 with 0 meaning no difficulty and 3 meaning very severe difficulty. For the Muskrat Falls project craft recruiting is blamed for project delay and therefore a 3 can be selected resulting in a 11% to 33% increase in total project costs. For $837M total estimated project cost, the equation resolves to an overrun of $92M to 276M or 31% to 95% of original labour costs. Average cost increase would be about 63% for total labour.

- It is concluded that an allowance of 32% to 63% should have been taken to account for labour shortages. This averages to 48% or PF4=1.48.
- A factor of PF4=1.48 should be added to the above to account for labour shortages, resulting in a labour factor of about 2.13, which is approximately equal to what Astaldi used.

The Astaldi estimate for labour was significantly higher than the SLI estimate. (7 mhrs/m3 versus 5 mhrs/m3) which would imply an overall productivity factor of about 2.34 as the basis for their estimate.

Astaldi was not able to achieve the productivity factor of 2.34. Ibbs determined that they had a Productivity Ratio of 0.3 as compared to their bid. This is an overall productivity factor of 7.8 prior to 2015. The productivity factor is partially caused by winter construction efforts. Given the conditions at Muskrat Falls, Ibbs suggested a best productivity factor of about 3.20 could be achieved in the summer.

This level of productivity appears to be significantly worse than what would normally be predicted. Other factors that might affect productivity that have not been considered are:

- Training of staff to achieve higher production rates;
- Higher time lost coming to and from camps on travel days;
- Movement to and from lunch rooms, coffee rooms and washroom facilities;
- Poor staff motivation;
- Overtime spent between shifts;
- Poor leadership of the teams; and
- Engineering Changes.

The lack of skill, experience and competency is recognized as the main labour-related factor that contribute to the loss of efficiency in projects encountering craft labour shortages. This is already considered in the PF4 factor. The severity of labour shortage on the project could have been impacted by the change in construction process resulting from seasonal construction. Rather than a consistent number of workers over a period of approximately three years, the number of workers required by Astaldi ranged from more than 1000 in the summer to less than 100 in the winter. The summer construction number was much higher than anticipated which would cause the craft labour shortage to be even more extreme.

The Estimate for the Powerhouse and Spillway work package was prepared when engineering was 40% complete. Productivity rates were calculated assuming normal circumstances, with 20% contingency built into the base estimate for climate-related productivity issues. Actual productivity factors used were: PF1=1.31 plus PF2=1.06 plus PF4=1.2 plus PF-3 for travel to and from site. This productivity factor adjustment is reasonable.

The 1.2 factor used appears to be in a reasonable range of labour shortage productivity factors. However, Karimi, in a study done in 2017, has shown that labour shortages, if severe can affect total project cost in the range of 33% which would result in a 1.94 labour productivity factor and a 39% increase in the expected schedule under worst case conditions. A 1.94 productivity factor would bring the total of productivity factors to 2.79 which is approaching what Astaldi was achieving on site.

In cold weather, most civil work stops. Work outside with wet materials when temperatures are below freezing is very difficult. In addition, labour productivity reduces by:

Temperature (deg C)	Gross Skills	Fine Skills
4	0%	15%
-2	0%	20%
-7	0%	35%
-13	5%	50%
-18	10%	60%
-23	20%	80%
-28	25%	95%
-34	35%	100%

Muskrat Falls average temperatures are shown below:

	Average High Temperature (deg C)	Average Low Temperature (deg C)
July	21	10
Aug	20	10
Sep	14	5
Oct	7	-1
Nov	0	-8
Dec	-8	-17
Jan	-12	-22
Feb	-10	-21
Mar	-4	-15
Apr	3	-7
May	11	0
Jun	17	6

A productivity estimate should contain the expected productivity factors. The contingency should contain contingency for when productivity factors are worse than expected. In general, however, civil construction during winter months is not desirable and it is more typical to accelerate construction during the summer season to compensate for little or no production during cold weather. The report by Ibbs (DISCL-NAL-182546, Exhibit B-3 dated 11 Sept 2015) indicates that reasonable productivity rates at Muskrat Falls cannot be achieved during cold weather.

In addition to individual factors affecting productivity, the Ibbs Consulting Group document "Change and the Loss of Productivity in Construction: A Field Guide" (see Appendix A) indicates that the impact of changes during construction can be magnified when multiple changes occur. The impact of multiple changes is a function of: percent change to the original contract, and schedule delays, with multiple schedule delays having an even greater impact. With the significant and multiple delays seen on the Muskrat Falls project, productivity could be decreased by between 30-60%. This magnifying factor is a factor that accounts for the cascading impacts of one factor on another and is likely a contributing factor to the difference between the best-case productivity achieved on site, and the estimated productivity forecast during the project sanctioning phase.

8.0 Schedule

Construction is a complex and highly variable process. However, a construction schedule can predict a reasonable and achievable outcome when the scope of work is well defined and the risks that can impact the scope and duration of activities are well documented and integrated into the project workplan. Changes to schedule during the course of construction can significantly impact costs and productivity since the schedule is critical in defining when resources are required – both material and labour.

The critical path of a project should be analyzed in detail because this path will define when a project is completed. Risks of task delays and acceleration must be considered, and iterations of possible schedule outcomes should be completed, to determine the sensitivity of the critical path to different variables. The relationship between different tasks regarding the necessary order of completion must also be analyzed. It is possible that activities may fall off or become critical path items depending on the duration of other, related activities.

To mitigate schedule risk, it is important to consider initial conditions for each task and not just the task itself. These risks are often overlooked because they are not always easy to identify. When a bottom-up construction workplan is created, it is not always possible to link external risk to a particular task. Placing concrete has many inherent risks. However, significant risk to the start of concrete placement is ensuring that the base preparation is sound and completed before concrete placement begins. Best practice is to allow for schedule impact due to imperfect site conditions. The magnitude of the allowance is determined based on the amount of information available and the degree of certainty regarding existing conditions. Specific workplans and resources are typically assigned to ensure delays to the start of work are mitigated. Schedule contingencies for this type of delay are not removed from the schedule until milestones are achieved.

It appears that the project schedule was not updated to reflect schedule slippage of activities on the critical path. When this occurs, contractor delay claims result because resources that are mobilized to meet a contract milestone rest idle rather than being deployed productively. Site excavation and access clearing are typical examples of this risk. Seasonal construction restrictions due to cold weather limitations can magnify the impact of delays if work from one season is not completed on schedule and then must be delayed into a future construction season.

8.1 NAL0019445 Integrated Project Schedule

The overall project schedule is defined by, and can be controlled using, the Integrated Project Schedule (IPS). The basis of this document appears sound, however several items are noteworthy:

1) The IPS is defined as a static document that is not regularly updated with actual schedule and site progress information. The link to actual performance is monitored by a manual process and the reporting of this comparison is not addressed in the IPS document.
2) The decision to update the IPS is at the discretion of the Project Director. The IPS document does not define a process that would control when the IPS is updated and re-baselined. Consequently, there is no predictability around when the overall project schedule will be updated.

The only guidance regarding when the IPS is to be updated is "when accumulated changes/delays have had a significant impact on the target milestones." Best practice is to re-baseline the schedule regularly and frequently with best available information at the time. Regular and predictable updates, even when no changes have occurred, provide invaluable feedback to the project team to communicate both positive and negative developments. This prevents assumptions that are made when no information is made available.

Best-practice is to update cost and schedule on an ongoing basis. Monthly is a reasonable reporting frequency. Schedule and cost contingency are assigned to each scope of work and are not released until the scope of work is completed. If one scope consumes more than the contingency allowed, then the forecasted project cost increases immediately. Impact of schedule on contingency is to be considered. Impact of schedule on strategic reserve is also to be considered – financing costs, delayed revenue, etc. Updating the IPS would facilitate an overall adjustment of tendering and resource deployment to minimize non-productive activities. If new factors impacting cost and schedule are identified as a result of site activities, then budgets as well as the IPS should be recalculated to include this new information.

8.2 NAL0436468 Recommendation for Award Summary Report

The Recommendation for Award Summary report outlines the process and activities leading up to the recommendation to award the CH0007 contract to Astaldi. The original schedule dates indicate that the Astaldi contract was to be awarded in July 2013, but award was delayed until late in 2013. This resulted in delayed mobilization and lost opportunity to prepare the site before the onset of winter.

The causes of the late tender award appear to be related to:

- large number of addendums;
- many requests for information; and
- fundamental commercial terms that would impact cost and schedule risks for the project.

Concerns identified regarding the qualifications of Astaldi to complete this project are:

- subtrades not qualified to complete the work, and
- concerns with how the Integrated Cover Structure (ICS) would function.

It appears that the bid review team made inquiries regarding these concerns, but it is not clear to what level of detail these concerns were addressed.

The schedule indicates that the site was to be prepared and ready for Astaldi in November 2013. Excavation details were not completed until spring of 2014 resulting in delay to the start of concrete work as well as temporary enclosure planning. Hence, final bedrock elevations would not have been available for Astaldi to begin their work even if their contract had been awarded much earlier in 2012.

Had the site excavation been completed earlier and the Astaldi contract been awarded earlier in the year, significant coordination work was required to incorporate the ICS into the powerhouse design as well as confirm operational procedures for the material handling systems inside the ICS. It is not clear if these scopes of work were accounted for in Astaldi's schedule.

Considerable time and effort were spent to make the ICS strategy successful. During this time, work proceeded but it is not clear if a plan had been developed to ensure productivity rates were achieved during this temporary condition. When the decision to abandon the ICS was made, it appears that the alternate strategy was not able to achieve the necessary production rates. Not successfully using the ICS resulted in many cascading schedule impacts during the project which were considered during the planning stages of the project but not expected to occur due to anticipated mitigation strategies.

Only the Astaldi bid claimed to be able to place concrete during the winter. Astaldi would rely on the temporary structure enclosure to achieve this. Regardless of the ICS, SLI did not believe that the required concrete placement schedule was achievable and anticipated including a contingency to address this risk.

9.0 Risk and Mitigation During Sanctioning and Construction

During early phases of a project, a list of project risks is typically developed. The process of developing this list began before the DG2 milestone. Potential cost and schedule implications are estimated for each risk and then added to the forecasts. Risk mitigation plans are then developed in order to mitigate the likelihood of these risks occurring. Until plans are implemented, these plans are not realized. Best practice is the schedule and cost implications associated with these risks are not removed from the project until the risk is eliminated.

Budget and schedule allowances are made to account for scopes of work that will be required but the details of the scope are not yet defined. These scopes of work are considered project risks that can be investigated further to more accurately determine their impact on cost and schedule. These allowances are reported as part of the project budget and overall schedule until the scope of work is clearly defined, at which time the scope is included in the budget while removing the allowance.

At the DG3 stage, some risks may have been investigated further and additional project requirements added into the construction documents. In this situation, the risk has been removed and an allowance for this risk is no longer required, however a contingency is still required for this scope of work to account for unknown risks.

Risks that have not been investigated and addressed by that point in the design process, are still considered risks that cannot be removed from the budget. Mitigation plans for these risks have not been realized so contingencies associated with these risks cannot be removed from the budget.

The project contingency was exhausted during the first year of the project, when only limited effort was forecasted. Based on this, the contingency should have been re-calibrated immediately.

9.1 NAL0020663 DG2 Project Risk Analysis

The reporting of risk and probable project outcomes as part of DG2 is based on the P(50) outcome, meaning that the likely outcome of the forecast will be less than the reported value 50% of the time. The Monte Carlo simulation method is compared against the cost and schedule calculated using the traditional method of building a schedule and budget by building a bottom-up workplan approach. The difference in calculated values using the different approaches is assumed to be an appropriate contingency to carry for the project.

Using the P(50) to compare with the traditional approach is an arbitrary comparison with little or no basis for equivalency except that the two approaches are an attempt to predict the most likely outcome. Instead, a predictive range of outcomes should be reported. Using a probability approach, the predictive range in the DG2 analysis is defined as the range in which 50% of the probable outcomes are calculated, and is defined as outcomes between P(25) and P(75). Using this approach, the impact of risk is included in the reported outcomes. The DG2 approach discounts the impact of risks by reporting the value calculated using the traditional workplan and reporting a contingency by comparing the workplan outcome to the P(50) value.

The Monte Carlo technique predicted the range of project cost to be much higher than the traditional workplan approach. The Monte Carlo technique predicted the project duration to be between 9 and 16 months longer than the schedule calculated using a traditional workplan approach.

9.2 NAL0020664 DG3 Project Cost and Schedule Risk Analysis Report

The basis for the DG3 estimates for project duration and cost was the same as for the DG2 estimates. During the time between DG2 and DG3, the estimated project cost increased by over $1B. This significant increase should have triggered a re-assessment of the assumed workplans for the project. The increase in base estimate reflects additional information being available to calculate a more accurate work plan for known risks.

Project duration is estimated to be approximately the same as at DG2. Using Monte Carlo simulation, the unmitigated project P(50) Full Power date is predicted to be March 2019, and a P(75) Full Power date of September 2019.

The fundamental difference between the workplan budget and schedule development compared to the Monte Carlo results is that risk variables were not included in the traditional workplan when mitigation strategies were identified during the planning process.

The contingency identified at DG3 to account for unforeseen risks and conditions was consumed very quickly during the construction phase of the project. Carrying a contingency of 7% aligns with an assumed design and documentation completion of 80-100%. This does not align with the Project Controls Plan required allocation of 10-15%, and the assumed proxy of a 15% difference between the calculated workplan cost compared to the P(50) value using the Monte Carlo technique. However, the calculated contingency is consistent with the difference between the traditional workplan cost and the P(50) value of cost. This is justified because of the increasing level of detail and confidence in the defined scope for the project.

The conclusions made in the DG3 risk report appear to be reasonable, except that the impact of the identified risks is significantly underestimated compared to the project outcomes to date. It should be noted that the anticipated concrete placement duration ranged from 810 days to 1300 days, with a target duration of 900 days. This schedule range reflects the general sentiment that the concrete placement target schedule was very aggressive and unlikely to be achieved, and the significant potential schedule delay predicted by the Monte Carlo simulation. It appears that the corresponding cost impact of this extended concrete placement duration was not considered.

In order to assess the impact of project risks, the scope of each risk needs to be defined and added to the budget and schedule in the same way as documented project scope line items. Ranges of cost and duration are then assigned and input into the Monte Carlo simulation. By doing this, the impact of each risk can be studied.

It cannot be forgotten that a contingency in cost and schedule is added in addition to the probable range of outcomes in order to account for risks that have not been identified. The DG3 risk analysis did not consider contingency to be in addition to the probable project outcome values.

10.0 Geotechnical Risk and Mitigation

The final feasibility study for Muskrat Falls was authorized in 1998. The following review of this study illustrates how the information could have been applied to the planning and construction of the dam project.

10.1 Muskrat Falls Hydroelectric Development – Volume 1 – Engineering Report

Executive Summary

Subsection 1.2.1 “General” introduces the principle elements, one of which involves the stabilization works for the North Spur, which connects the rock knoll to the north bank of the original river valley. The Spur soils consist of a complex interbedded sequence of relatively low permeability silty sands, sands, and sensitive marine clays.

Subsection 1.2.6 “North Spur” states that the crest width of the Spur varies from about 1000m at the north end to about 70m at the south end, where it has been narrowed by erosion and landslide activity. Significant stabilization methods have been incorporated including lines of pumped wells to lower groundwater table, upstream rock erosion protection due to the excessive river water velocity, provision of drainage trenches, downstream rock toe erosion protection & relief drains, and localized unloading of high over-steepened slopes along the downstream side of the Spur.

Subsection 1.2.6 goes on to state that in 1982, another line of pumped wells was installed to prevent ongoing sliding that could have breached the Spur.

Subsection 1.8 "Project Master Schedule" states that the river closure and diversion works would be achieved by the end of July of Year 2. There is a narrow annual construction window, and only a practical 7-month work period per year. The potential delay identified in the report is not included in this schedule. The consequences of a delay are not discussed.

Subsection 1.10.1 goes on to state that further investigations and studies are suggested to be completed three years before the project starts, chief amongst them geotechnical field investigations to confirm quality & quantity of acceptable borrow materials. This work normally forms the basis of "very early" consideration in order to properly scope the cost and availability of materials to ensure they meet contract specifications.

Pages 8 and 12 of the Executive Summary were not included for review.

1.0 Introduction and Background

The "Final Feasibility Study" of the project was authorized in 1998 and meant to be the last extensive study prior to the final design and implementation. Newfoundland and Labrador Hydro (NLH) retained SNC-AGRA Joint Venture in partnership with SGE Group Inc., Newfoundland Design Associates Limited and Quadratec Inc. for the Study Report. The services were to include coordination with Acres International Ltd.

An extensive terms-of-reference was set out which included: energy & capacity optimization, verification of geodetic elevations, bathymetric contours of the riverbed, further geotechnical investigations to confirm in-situ foundation conditions, detailed mapping, project logistics, capital cost estimates to more-or-less 10% accuracy, and an optimum project schedule.

The 230 kV AC transmission lines from the Muskrat Falls switchyard to the HVDC converter station near Gull Island were not included in the Study scope, however, additions were made to the telecommunications scope (microwave link and the Fibre Optic line).

Subsection 2.4 "Project Background" involved studies and reports dating back to April 1965 stemming from initial work done by Acres Canadian Bechtel. The preliminary assessment was based solely on information from existing maps and aerial photographs – no on-the-ground field reconnaissance was carried out.

Subsection 2.4 goes on to state that in May 1965 further field reconnaissance at the North Spur was conducted which entailed shallow test pits, shallow test trenches, and two boreholes (no specific location nor depth data have been made available). During the data interpretation, questions were raised regarding seepage and stability in the North Spur, connecting the rock knoll to the north bank.

Another geotechnical review was conducted, ten years later in 1975, suggesting changes to the 1965 layouts and recommending more detailed field investigations. In 1977 field work was conducted to study the landslide areas in the near-vicinity of the North Spur. In the Spring of 1979, Acres completed yet another study which set out the specifications for a detailed exploration program at the North Spur. Later in 1979, SNC-Lavalin Newfoundland Ltd. was appointed as engineering advisor and instructed to initiate a further detailed field investigation for a new development at Muskrat Falls, wherein was stated the site was technically feasible.

The 1979 Study also included the proposed stabilization requirements for the North Spur.

In 1980, SNC completed a supplemental study which focused primarily on the optimal Variants (alternative project layouts), which recommended a 4-Unit Powerhouse rather than the original three units. None of the foregoing documents were available for review.

6.0 Alternative Project Layouts

Subsection 6.1 "General" introduces 11 Variants (different project configuration layouts) for the proposed development. The Variants are further subdivided into River Schemes (7), Tunnel Schemes (3), and one Right Bank Scheme. Only Variants 5, 7, 10, and 11 were selected for more detailed quantitative analysis.

Subsection 6.5 "Comparison of Alternatives" goes into more depth regarding the relative advantages and disadvantages, including assessed associated risks, estimated costs, and ease-of-constructability issues. Variant 7 was selected as the optimal scheme as it was determined to be the least expensive, with the least risk and the simplest diversion and construction sequence.

Section 6.5 identifies schedule risk due to uncertain geotechnical conditions:

1) Coffer dam construction delays due to seepage control, dewatering delays; and
2) Powerhouse, spillway and dam delays due to rockslope support, seepage, foundation treatment.

The estimated construction duration and potential delay due to geotechnical risks for Variant 7 is: 56 months with a potential 6-month delay risk due to foundation preparation (totaling 5 years and 2 months). Best practice is to include potential delay. In this case, the risk is identified as a "normal" procedure for foundation treatment. The implications of a normal construction process are that the likelihood of occurrence is significant, so a contingency in cost and schedule is required.

The Master Schedule was developed assuming a January release. This timing is selected to prevent conflict with spring flooding issues. This timing is also critical to avoid being impacted by winter construction in the first year. A January project release facilitates planning time for the contractors, mobilization time in winter months, so construction can then begin in the spring of year one. The impact of winter construction is not considered in subsequent construction years.

8.0 River Diversion

Subsection 8.2.3 "Geological and Geotechnical Design Considerations" states that the bedrock is comprised of Precambrian granite gneiss with bands of amphibolite gneiss and pegmalite stringers. A juxtaposed statement then follows "rock quality is generally good to excellent but zones of poor quality, fractured rock occur locally due to shear zones and minor faults which… will necessitate treatment with rock support." The text goes on to state that geological mapping shows some minor faults, and one major fault associated with an aplite dyke.

Subsection 8.2.3 continues with a long list of considerations to be taken into account, all of which comprising geotechnical criteria.

9.0 Dams and Spillways

The boreholes provided show a complex upper (near-surface) interbedded mix of fine-to-coarse grained sands, silts, some gravel, and some cobble with relatively minor traces of clay. This is confirmed with five different grain-size distribution (sieve) analyses which show a predominant matrix of gravel-coarse sand-fine sand makeup of in-situ materials. The 1979 investigations are based on only two boreholes.

Throughout Section 9 "Dams and spillways", there are several references to "is expected to" in reference to depth & extent of various soil zones. This is a qualitative assertion based upon presumption and a lack of definitive in-situ investigative or analytical data.

Subsection 9.5.2 "Dyke Design" reaffirms this qualitative approach as stated "will be checked...at the time of construction". Foundation criteria is an essential requirement at the outset and cannot be presumed.

Subsections 9.2.2.3, 9.2.3.1 and 9.2.3.2 refer to occasional faults, open fractures, and sheared rock conditions – all of which require various foundation implementation strategies (grout curtains, controlled blasting, cushion blasting, and line drilling – all over and above pumped wells and other proposed mitigation strategies to limit risk.

The implications of these statements require provisions to be made for schedule delays and cost increases due to additional work that may be required when the foundation bearing surfaces are prepared. Best practice is to investigate this risk in detail in order to anticipate and mitigate the likelihood of unforeseen delays, particularly since this scope of work is on the critical path for the project. Relying on the results of two boreholes in this area is insufficient given the potentially significant impact on schedule and cost. Particularly at the planning and budgeting stage, allowances for this occurring should be made, even if the allowance is a placeholder that highlights the need for further investigated at a future date.

10.0 Reservoir Rim and Spur Stabilization

Subsection 10.1 "Introduction" begins by stating that previous engineering studies have identified landslide activity along the Spur and that it is a significant problem to development of the site. The south end of the spur (narrow end where the Generating station is situated) has been narrowed by landslide activity. In 1982, a network of 22 pump wells was installed on the Spur to lower the groundwater table to prevent continued slope regression due to landslide activity.

Subsection 10.5.1 "Control of Groundwater" states that "the quantity of water which will be pumped will be relatively small due to the generally low permeability of the soils constituting the Spur". Verification of groundwater flows in all parts of the site is critical if impacts of groundwater on construction are to be mitigated.

Section 11.2.3 highlights that foundation treatment may be required before structures are built on top of exposed bedrock due to permeability of the rock or faults and rock seams encountered in the excavation area.

Section 13.2 indicates that the first construction camp would not be operational until the fall of year 1. Construction during the first summer would therefore require transportation from Goose Bay, which could reduce productivity.

Section 14 indicates that further investigations will be required to confirm sources of construction materials. Best practice is to confirm appropriate sources and transportation strategies during design and before tendering.

Section 15 discusses project schedule and acknowledges the need to effectively use the summer construction season during the first year in order to achieve the earliest possible river closure. This section also highlights the need to complete preliminary works quickly, including the north spur stabilization. The report states it is essential that this preliminary work begin immediately in June so the first summer construction season is not missed. Consideration should have also been made to award first contracts earlier in the first year to allow additional mobilization time.

The schedule assumes that detailed geotechnical investigations would occur during year one of construction – during preliminary works. This is reasonable provided cost and schedule contingencies are included to account for additional, anticipated foundation treatment work. Dewatering is identified as a key requirement to enable foundation preparation and concrete placement. The impact of water remaining in the excavation is not discussed but the significance of water in an excavation is general knowledge and a factor in all construction projects. Water in an excavation during winter can result in all activities being halted for an extended period up to and including the remainder of the winter season.

Winter construction and concrete placement during the winter is identified as a project requirement, and it is recognized that productivity will be less than in the summer months.

Subsection 15.3.1 “Type of Contract” outlines the major types of Contract together with the associated risks, however, does not specify what contractual arrangements were made or recommended for tender packages on this project.

17.0 Conclusions and Recommendations

Subsection 17.1.b "Conclusions – Geotechnical" states that "the North Spur is an important feature of the site, provides a natural dam for development of a reservoir on the River." The subsection goes on to state that "stabilization of the North Spur is required to prevent further slope failures along its upstream and downstream sides and prevent the potential loss of this important structure."

Subsection 17.1.b goes on to further state that "erosion by wave action will cause breaching and local bank regression". Then goes on to say that this condition should stabilize after a few years of operation, but does not elaborate further.

Subsection 17.1.g "Conclusions – Scheduling" discusses project start implications of commencing in January vs June. It is highlighted that preliminary works – including site access and clearing needs to begin as early as possible when the ground thaws in the spring. Implied in the text of this discussion is that completing this scope in winter conditions is not possible so if the work is not completed during the first spring/summer construction season then all progress would be delayed until the following spring. This scope is therefore critical to the project proceeding as planned.

Subsection 17.2.2.1.a "Investigations for Final Design" states that the amount of investigation work (survey, geotechnical, bathymetry, groundwater, etc.) completed as of the report submission was enough for the feasibility study. The report also states that moving forward from 1998 (this Feasibility Study), 28 more geotechnical boreholes would be required, all of which should be completed before detailed design is completed. Further in subsection 17.2.3.2, it is reaffirmed that this work should be completed three years before the project begins.

Subsection 17.2.3 highlights that completing the field investigations three years in advance would mitigate risk for many scopes of work that are on the project critical path and provide more cost-certainty for the project. Without completing a detailed geotechnical investigation, a significant contingency in schedule and cost is required to reflect best practice.

Section 16.0 Cost Estimate was not available for review.

Muskrat Falls Hydroelectric Development Volume 2 "1998 Geotechnical Investigations" and Muskrat Falls Hydroelectric Development Volume 3 "Detailed Backup of Capital Cost Estimate" were not available for review.

10.2 Transmission Line Geotechnical Investigations

Geotechnical studies were completed in December 2011 through to April 2012 to refine geotechnical design parameters for the earthworks tender to be issued in 2012. The following documents were reviewed:

NAL0020638 Geotechnical Survey Data Acquisition and Analysis

NAL0426802 Geotechnical Baseline Report ILK-SN-CD-6200-GT-RP-0001-01

The limitations stated in this document indicate that very little field data was available to accurately calculate the foundation design parameters for each transmission tower. In some cases, no data was available at all. In this situation, a conservative approach should be taken that would result in underestimating the actual capacity of the soil at each tower where confidence in the existing soil conditions is low.

On the spreadsheets summarizing the interpreted foundation data, it appears that the majority of towers would be located on bedrock, but many of the site conditions needed to be confirmed. Over-estimating foundation capacity under these conditions would result in construction costs increasing during construction and potential construction delays if the towers provided are not appropriate for their intended location. Issuing tender packages for construction on this basis has a higher level of risk than typical projects of this type.

Best practice is to attend each tower location and complete a minimum of one borehole per tower location. Depending on soil conditions, a site investigation might include an alternate investigation method such as a test pit (digging a hole), confirmation of bedrock conditions, or other appropriate testing techniques.

11.0 Closure

This report has been prepared based upon the information referenced herein. It has been prepared in a manner consistent with good engineering judgement. Should new information come to light, Williams Engineering Canada Inc. requests the opportunity to review this information and our conclusions contained in this report. This report has been prepared for the exclusive use of Grant Thornton LLP, and there are no representations made by Williams Engineering Canada Inc. to any other party. Any use that a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties.

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Appendix A

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