Integrated Resource Plan

Appendix 3A-30

2013 Resource Options Report Update

Lower Mainland / Vancouver Island
Pumped Storage Report
and
North Coast Pumped Storage Report
BC HYDRO
EVALUATION OF PUMPED STORAGE
HYDROELECTRIC POTENTIAL
SCREENING ASSESSMENT REPORT

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November 30, 2010

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BC HYDRO
EVALUATION OF PUMPED STORAGE
HYDROELECTRIC POTENTIAL
SCREENING ASSESSMENT REPORT
(REF. NO. VA103-313/1-1)

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EXECUTIVE SUMMARY

BC Hydro requested the services of Knight Piésold Ltd. (KPL) to conduct a screening assessment of the pumped storage potential in the Lower Mainland and Vancouver Island region of southwest British Columbia.

The focusing question of this study is: “Are there potentially viable greenfield pumped storage hydroelectric sites in the Lower Mainland and Vancouver Island region of southwest British Columbia that are economically viable?”

The answer to this question is YES, there are numerous potential pumped storage sites that meet the basic criteria established for this study. The results of this study are summarized below, with each numbered paragraph below being a summary of the corresponding section of this report:

1. BC Hydro has conducted three previous assessments of pumped storage hydro potential in the Lower Mainland and Vancouver Island dating back to 1977. These studies have included site identification, costing and environmental consideration.

2. Freshwater pumped storage is the most prevalent form of pumped storage that has been developed worldwide to date, with approximately 127,000 MW in operation as of 2009. Only one conventional saltwater pumped storage facility is in operation worldwide (the 30 MW Okinawa Pumped Storage Facility in Japan), and there are no known operating underground pumped storage plants (i.e. with an underground reservoir). Each type of pumped storage facility is subject to permitting, financial and schedule risks, however saltwater and underground pumped storage have additional technical, environmental, permitting and schedule risks due to the lack of worldwide experience.

3. The screening assessment was limited to the area south of latitude 51°N and west of longitude 121°W. The following screening constraints were also applied:
   a. Terrestrial parks were excluded from the assessment, but all other land use types were considered, such as marine parks, private land, and Indian reserves
   b. Known salmon bearing rivers were excluded from the study (Chinook, Sockeye, Chum, Coho, Pink and/or Steelhead); however, salmon bearing lakes were considered in the assessment
   c. Drinking water reservoirs and BC Hydro reservoirs were also considered in the assessment
   d. The capacity threshold for the assessment was limited to 1,000 MW in the Lower Mainland and 500 MW on Vancouver Island
   e. A minimum storage requirement was set at 6,000 MWh for 1,000 MW sites, and 3,000 MWh for 500 MW sites, equivalent to the water required for full plant generation output for 6 hrs; and
f. A loaded capital cost threshold at plant gate (no site access, transmission or interconnection costs were assessed in this study) of $200/kW-yr was set for the assessment, based on a design life of 70 years and a discount rate of 6%.

194 sites in the Lower Mainland and Vancouver were identified using a combination of a GIS-based assessment tool and visual assessment. As anticipated, freshwater pumped storage was generally the most economical form of pumped storage, followed by saltwater and underground pumped storage. Compared to the most attractive freshwater and saltwater alternatives identified in this study, underground pumped storage is not cost competitive in BC. The identified sites fit into the following levelized cost ranges:

- **Freshwater Pumped Storage**
  - 45 projects were identified less than $100 /kW-yr
  - 54 projects were identified between $100 – $125 /kW-yr
  - 9 projects were identified between $125 – $150 /kW-yr
  - 9 projects were identified between $150 – $175 /kW-yr, and
  - 4 projects were identified greater than $175 /kW-yr.

- **Saltwater Pumped Storage**
  - 6 projects were identified less than $100 /kW-yr
  - 31 projects were identified between $100 – $125 /kW-yr
  - 27 projects were identified between $125 – $150 /kW-yr
  - 7 projects were identified between $150 – $175 /kW-yr, and
  - 2 projects were identified greater than $175 /kW-yr.

- **Underground Pumped Storage**
  - A ‘typical’ underground pumped storage project is anticipated to cost in the range of $230/kW-yr.

This study was limited in its scope based on the tight timeline associated with the deliverables, with the entire study being completed in less than 6 weeks. The level of detail and screening criteria used for this assessment can easily be updated, as the key components of the GIS assessment tool have now been developed. If this study is to be expanded upon, the following items are recommended. KPL is aware that some of these items are already underway as a follow-up to this study.

- Estimate the costs of transmission, interconnection and access to each alternative identified above in order to meaningfully be able to compare each identified site
- Conduct a system-wide study of the BC Hydro grid to determine the benefits/impacts of integrating pumped storage
- Determine the ‘ideal’ characteristics of a pumped storage facility, in terms of providing the maximum benefits to the BC Hydro system, improving export opportunities and firming of renewable (especially wind power) sources
- Conduct a screening assessment for the remaining portions of the province, especially where there is a high resource potential of intermittent renewable energy sources such as wind, run-of-river hydro, tidal and/or wave energy, and
- Conduct a more detailed assessment of the most favourable sites identified in this assessment.
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1.1 INTRODUCTION

BC Hydro requested the services of Knight Piésold Ltd. (KPL) to conduct a screening assessment of the pumped storage potential in the Lower Mainland and Vancouver Island region of southwest British Columbia. This report discusses the results of the assessment.

1.2 PREVIOUS STUDIES

BC Hydro has commissioned three screening level studies of pumped storage hydroelectric potential in southwest British Columbia since 1977. A brief discussion of the findings of each study is presented in the following subsections.

1.2.1 Pumped Storage in British Columbia – Preliminary Engineering Assessment, 1977

In December 1977, BC Hydro and Power Authority completed a preliminary assessment of pumped storage hydroelectric potential in the Lower Mainland and Vancouver Island. The study was bound by the following constraints:

1. The lower Mainland area was limited to approximately 150 km from Vancouver
2. Only sites capable of generating 500 MW or higher were considered, and
3. Both lower and upper reservoirs were required to have sufficient storage to operate on a weekly cycle.

The report identified approximately 80 sites that were deemed suitable for pumped storage development. Of these 80 sites, eight sites were selected (four on Vancouver Island and four in the Lower Mainland) based on their ability to generate 500 MW for 10 hours of continuous operation, the conduit length to head ratio and other considerations, such as interfering with park boundaries.

Overall design concepts were prepared on 1:50,000 scale mapping of the eight shortlisted sites. A helicopter reconnaissance and overview geological assessment was conducted for each site in order to identify the top two preferred sites on each of Vancouver Island and the Lower Mainland. The most attractive pumped storage sites were identified to be:

1. Lower Mainland – Stave River – Thomas Lake 1000 MW Development
2. Lower Mainland – Harrison lake – Slollicum Lake 1000 MW Development
3. Vancouver Island – Buttle Lake – Beadnell Lake 1000 MW Development, and
Cost estimates of each development were generated, and ranged from $249 million to $326 million dollars (1977). This corresponds to an approximate development cost ranging from $249/kW to $324/kW.

It was noted in the study that "When it became apparent that there were a large number of good sites, the potential in the more remote areas of the Lower Mainland and north-western part of Vancouver Island was not pursued in detail."

1.2.2 Resource Smart - Pumped Storage in British Columbia, 1993

In March 1993, the Hydroelectric Engineering Division of BC Hydro re-evaluated the economics associated with the pumped storage alternatives that were identified in the 1977 study. The main objectives of the study were to:

1. Update the costs of the 1977 study
2. Obtain equipment costs from manufactures
3. Determine any significant change to pumped storage technology and costs, and
4. Conduct environmental assessments of the four sites identified in the 1977 study.

The results of the study indicated the following main findings:

1. Development costs had increased from a range of $249/kW - $324/kW to a range of $635/kW - $773/kW.
2. The updated costs were similar to inflated 1977 costs.
3. Sites located in areas where increased peak capacity is required, would be most beneficial.
4. Advances in technology between 1977 and 1993 increased single unit capacities to approximately 300-330 MW. For single-stage reversible pump turbines, the maximum allowable head increased from 600 m in 1977 to approximately 900 m in 1993.
5. Pumped storage could be incorporated into existing BC Hydro facilities, such as Ash River, Wahleach, Bridge River and Cheakamus.
6. Peak vs. off-peak energy pricing should be included in future analyses.

1.2.3 Vancouver Island Green Energy Study – Review of Pumped Storage and Tidal Barrage Energy Generation, 2001

In September 2001, Klohn Crippen Consultants Ltd. completed a review of the pumped storage sites identified in the 1977 study. The purpose of the assessment was to identify the most cost effective development that would add a combined capacity of 200 MW to Vancouver Island. Sites in the Lower Mainland were not considered in the study.

Potential pumped storage sites identified in the 1977 study that were situated in parks were not considered in the assessment. An initial screening was completed, resulting in the selection of the seven most attractive sites for development. From these seven alternatives, the two best sites were chosen for a more detailed assessment and costing. The redevelopment of the Strathcona generating site was also considered in the detailed assessment and costing. The results of the study indicate the following main findings:

1. Shawnigan Site – 200 MW – Development cost of $1200/kW
2. Comox Site – 200 MW – Development cost of $1270 /kW, and 

Environmental considerations were also described for each development alternative listed above.
SECTION 2.0 - TECHNOLOGY REVIEW

2.1 BACKGROUND

The concept of pumped storage is the generation of electricity by capturing the energy of water being transferred from a higher elevation upper reservoir, through turbine/generator units, into a lower elevation reservoir. The system is then reversed and the water from the lower reservoir is pumped back to the upper reservoir. Though the system is a net consumer of energy, it can be advantageous to developers/utilities by:

- Providing additional capacity during high-load hours when the cost of energy is greatest
- Increasing profitability by using low-value base load energy to pump water to the upper reservoir during low-load hours
- Providing grid stability by reducing the generation differential between high-load and low-load periods,
- Relieving constrained transmission components
- Providing voltage regulation, especially at the end of long transmission systems (i.e. the Peace River to Lower Mainland transmission network)
- Providing storage for intermittent renewable energy sources that cannot be dispatched on demand
- Providing backup capacity in the event of a planned or unplanned outage of another significant generation source connected to the grid, and/or
- Providing capacity for export.

The following subsections discuss some of the types of pumped storage, including their general concepts, development status and development risks. Comments on the state of pump-turbine technology are discussed as well as closed vs. open systems.

2.2 FRESHWATER PUMPED STORAGE

2.2.1 General Concept

Freshwater pumped storage simply refers to a pumped storage hydroelectric project where the upper and lower reservoirs impound only fresh water. Nearly all pumped storage development to date worldwide has primarily consisted of freshwater pumped storage.

2.2.2 Worldwide Development Status

Freshwater pumped storage is by far the most prevalent form of pumped storage that has been developed to date worldwide. Construction of freshwater pumped storage dates back to the early 1900s, when the first pumped storage plants came into operation in Italy and Switzerland. Since then, pumped storage development has increased with rising energy demand, and the increased need for peaking capacity.

The last thirty years has seen the largest growth of pumped storage development. Table 2.1 shows a list of operating projects greater than 1,000 MW in capacity that are known to be operating to date.
As of 2009, it was estimated that more than 127,000 MW of pumped storage capacity was operating worldwide, with some experts predicting future growth to be up to 60 percent over the next four years.

2.2.3 Development Risks

There are very few technical risks unique to freshwater pumped storage development that cannot be addressed through diligent planning and design. Freshwater pumped storage is a proven technology with projects operating worldwide, and as such, the predominant risks in development are similar to those of conventional hydropower development, or any large infrastructure project. Some of these risks include:
- Permitting risks – Social acceptance and environmental impact
- Geotechnical risks
- Financial risks, and
- Schedule risks.

2.3 SALTWATER PUMPED STORAGE

2.3.1 General Concept

The concept of saltwater pumped storage is the same to that of freshwater pumped storage, with the exception that seawater is exchanged between the ocean and an upper reservoir instead of freshwater. The advantage of saltwater pumped storage over freshwater pumped storage is that construction of only one reservoir is needed. This allows for potential development of sites closer to load centres, where freshwater pumped storage may not be feasible due to unsuitable terrain or other constraints.

2.3.2 Worldwide Development Status

Only one “conventional” saltwater pumped storage plant exists worldwide: the Okinawa Pumped Storage Plant on the coast of Japan. The 30 MW plant was constructed as a demonstration project and consists of a lined upper reservoir that transfers water via a tunnel and fibre-reinforced plastic penstock through an underground powerhouse to the Pacific Ocean. The project, which commenced operation in 1999, has a net head of approximately 136 m, and consists of a single 30 MW reversible pump-turbine.

2.3.3 Development Risks

Due to the unique high corrosion environment of saltwater pumped storage projects, as well as the lack of worldwide experience in saltwater pumped storage, there are higher development risks than conventional freshwater pumped storage. Some of these risks include:
- Corrosion protection of components exposed to sea water that are susceptible to rust
- Potential saltwater contamination of groundwater
• Prevention of marine growth in project waterways
• Potential requirement to line upper reservoir and install costly drainage collection system to prevent saltwater seepage into groundwater
• Potentially longer permitting timeline
• Higher operating costs, and
• Higher equipment costs.

Initial feedback from some pump/turbine manufacturers indicates that corrosion protection of high head projects (gross head > 400 m) represents a much higher risk than low head projects (gross head < 400 m) due to the current technology of corrosion resistant austenitic stainless steel having a lower strength than traditional martensitic stainless steel. Further, these manufacturers believe that currently available coatings (including ceramic coatings traditionally used for abrasion protection) are not suitable for use in saltwater pump-turbines due to their brittle nature as well as low resistance to cavitation.

2.4 UNDERGROUND PUMPED STORAGE

2.4.1 General Concept

The concept of underground pumped storage is the same as conventional pumped storage, with the exception that one or both of the reservoirs are located underground in either natural or man-made caverns.

The concept of underground pumped storage has advanced in recent decades as the number of viable surface configurations have been reduced with development, as well as the increased environmental and social sensitivity associated with the disturbance caused by the construction of a conventional pumped storage scheme above ground.

2.4.2 Worldwide Development Status

To date there are no known operating “Underground Pumped Storage” projects (i.e. with the lower reservoir located underground). Concepts for such developments have been presented in both Canada and the USA, but none have proceeded to the construction phase to date.

Studies to date have considered the use of abandoned mines for reservoir storage, and others have considered excavation of a cavity large enough to meet reservoir requirements. In order to make the alternative more cost effective, abandoned mines or natural cavities could be used to meet the reservoir requirements.

Though conceptually feasible, the increased cost and higher technical risk of underground pumped storage development is much higher than other more economical energy alternatives. Prohibitive costs and underground geotechnical risks are the primary detractors from advancing underground pumped storage beyond feasibility study and into construction and operation.
2.4.3 Development Risks

Sources of technical risk for underground pumped storage development include:

- Higher volume and cost of excavation of underground reservoirs.
- Longer (more expensive) access tunnels and shafts.
- Longer (more expensive) and more complex ventilation requirements.
- Higher geotechnical risks, including:
  - Structural adequacy of the rock mass
  - Permeability of the rock mass
  - Mineral content and contamination of the water supply, and
  - Groundwater contamination.
- Disposal of large amount of excavated material (large spoil areas required).

2.5 PUMPED STORAGE IN BRITISH COLUMBIA

To date, there are no operating pump-storage generation stations in the province of British Columbia, or are there any under construction. Recently, some private companies have applied for water licenses in support of future pumped storage developments.

2.6 DEVELOPMENT SCHEDULE

Conceptual development schedules were prepared for each pumped storage type, and are shown on Figure 2.1. It should be noted that the development schedule for each particular pumped-storage alternative can be expected to vary significantly. The schedules shown on Figure 2.1 aim to show the differences in development timelines between the different pumped-storage types, and are not applicable to any particular site.

Some of the key differences in development schedules between the three pumped storage types are:

- Saltwater pumped storage may have longer lead time on equipment and materials due to anti-corrosion requirements, permitting period extended since no projects have been completed to date in Canada or the USA; and
- Underground pumped storage has a longer timeline due to increased geotechnical investigations, longer construction timeline, potential challenges in permitting, and longer technical studies due to lack of worldwide experience (i.e. no reference projects built to date, and therefore likely extended due diligence requirements by financiers).

2.7 CLOSED VERSUS OPEN SYSTEMS

A “closed” pumped storage project refers to a design where the water used for generation and pumping is in a hydraulically closed loop. There are no (or minimal) inflows or discharges from either the upper or lower reservoir beyond seepage, evaporation, sublimation and direct rainfall.

An “open” pumped storage project refers to a design where a portion of the water used in generation or pumping comes from either natural runoff, or sources beyond the storage of the upper and lower reservoirs. Some of the following scenarios can be considered “open” systems:
• A pumped-storage plant that is integrated into an existing traditional hydroelectric plant
• A pumped-storage plant where either reservoir receives a significant portion of inflow from natural basin runoff, and
• A pumped-storage plant where either reservoir draws from or discharges to a natural lake or an existing river system.

Some “open” pumped storage projects can be converted to “closed” systems by constructing diversions around both the upper and lower reservoirs, similar to those used in tailings ponds in the mining industry. This hydraulically isolates each reservoir, and thus “closes” the system by eliminating external inflows.
SECTION 3.0 - SCREENING ASSESSMENT

3.1 SCREENING CONSTRAINTS

3.1.1 Spatial Limitations

The study area was limited to the Lower Mainland and Vancouver Island, defined as the area south of latitude 51°N and west of longitude 121°W. Within this study area, the following spatial limitations apply:

- Terrestrial parks and reserve areas will be EXCLUDED from the study area
- Marine parks will be INCLUDED in the study area
- Private land will be INCLUDED in the study area, and
- Indian Reserves will be INCLUDED in the study area.

A summary of the study area is shown on Figure 3.1.

3.1.2 Limitations on Generation Capacity

The original project terms of reference called for the identification of projects capable of generating a peak capacity of at least 100 MW. Due to the suspected large number of potential sites, this generating capacity threshold was increased to 1,000 MW for the Lower Mainland, and 500 MW for Vancouver Island, with the idea that should inadequate sites be found, the generation capacity threshold criteria would be lowered.

3.1.3 Minimum Storage Requirements

The minimum storage requirements for each pumped-storage facility was set at 6,000 MWh (the amount of water required for 6 hours of generation at 1000 MW capacity) for the Lower Mainland, and 3,000 MWh (the equivalent storage of 6 hours of generation at 500 MW capacity) for the 500 MW sites on Vancouver Island. The volume of water required to store this amount of energy varies by project, depending on the available head.

3.1.4 Environmental Limitations

Salmon bearing rivers were excluded from the study. The Fish Information Summary System (FISS) from the BC Ministry of Environment was used as the basis for known fish distribution data. Rivers with historical observances of Chinook, Sockeye, Chum, Coho, Pink and/or Steelhead were not considered in the screening assessment.

It should be noted that lakes and rivers with historical observations of Kokanee Salmon were not excluded from the study area, as several existing BC Hydro reservoirs contain this salmon species. Historical observances of any other fish species other than those listed above were ignored in the assessment.
Existing lakes with historical observances of Salmon were included in the assessment. However, these lakes were labelled as being salmon bearing in the assessment results. A summary of the fish distribution data for the salmon species mentioned above are shown on Figure 3.2.

For the saltwater pumped storage screening assessment this constraint was ignored.

3.1.5 Technical Constraints

As per the terms of reference, projects with a maximum real levelized cost greater than $200/kW-year were to be excluded from the assessment. Since a cost estimate could not be completed until a potential site had been identified, additional constraints were necessary to eliminate unattractive sites prior to completing project capital cost estimates.

In order to determine the real levelized cost ($/kW-year), the following was assumed:
- Design Life = 70 years, and
- Discount Rate = 6%.

Freshwater Lake-to-Lake Sites

The abundance of small lakes in combination with the steep topography, give south-western British Columbia a high potential for freshwater pumped-storage development. Due to this large potential, sites with the most attractive characteristics were targeted. These characteristics included:
- Existing lakes within a 5 km horizontal distance that could be used as an upper and lower reservoir respectively (i.e. waterway length is limited to approximately 5 km or less). In some instances, lakes with horizontal distances greater than 5 km were considered.
- Existing lakes with the capability of storing 6,000 MWh (or 3,000 MWh for the 500 MW sites on Vancouver Island) by constructing a maximum dam height of 20 m. In some instances, maximum dam heights exceeding 20 m were considered. Since no bathymetry data was obtained for the lakes in the study area, the depth-area-capacity curve for each lake could not be determined. As such, all storage was assumed to be constructed above the natural lake water level, with the following exceptions:
  o For BC Hydro reservoirs, lake drawdown was accepted, since existing operations draw down most reservoirs
  o For drinking water reservoirs, lake drawdown was accepted, since existing operations draw down most reservoirs, and
  o For large existing lakes, where the draw down would be minimal, draw down was accepted.

Freshwater “Crow’s Nest” Sites

As historical developments have shown, existing lakes or reservoirs are not a pre-requisite for a successful pumped-storage development. Some reservoirs are created through the construction of a dam in an incised valley, or even by constructing perimeter dams on flat ground or around
natural depressions (i.e. “Crow’s nest” sites). Since the combinations of dam locations and geometries are limitless, it was necessary to apply some screening constraints.

The same constraints were used for the identification of freshwater “Crow’s nest” sites, including the 5 km maximum waterway length, the ability to store either 6,000 MWh (1000 MW sites) or 3,000 MWh (500 MW sites) by constructing a maximum embankment height of 20 m. In some instances, these constraints were exceeded. The same drawdown constraints were also applied.

**Saltwater Pumped Storage Sites**

The same constraints for the freshwater “Crow’s nest” sites were applied to the screening assessment of saltwater pumped storage sites. Additionally, freshwater lakes were not considered as upstream reservoirs, due to the high environmental impact of pumping saltwater into a freshwater ecosystem. In some instances, upstream reservoirs were proposed in areas that contained either wetland or small ponds. Since it is difficult to determine at what size threshold this may not be permissible, a certain amount of judgement was required to satisfy this constraint.

**Underground Pumped-Storage Sites**

Due to the potentially smaller surface footprint of an underground pumped storage project, potential sites could potentially be located anywhere (though proximity to load centres, geological conditions and available spoil areas may drive site selection). To make the sites economically competitive however, they would potentially need to utilize existing underground caverns (such as those in abandoned underground mines) to save the costly expense of excavating a large cavern. Site identification was therefore limited to searches of active and abandoned underground mines in the study area.

3.1.6 Other Limitations and Constraints

- Existing BC Hydro reservoirs were INCLUDED in the study area, and
- Drinking water reservoirs were INCLUDED in the study area.

The potential impact of a potential pumped storage project on existing BC Hydro reservoirs and drinking water reservoirs was considered beyond the scope of this study.

3.2 SCREENING ASSESSMENT RESULTS

3.2.1 Freshwater Site Identification

Freshwater pumped-storage sites were identified using a combination of an automated GIS search, and a visual assessment. For the automated GIS search, KPL developed a pumped-storage assessment tool, which identified existing lakes that could be developed into pumped storage projects while meeting the constraints listed in Section 3.1. These constraints could be varied in order to identify projects of different characteristics. The tool analyzes a pair of existing
lakes by extracting their elevation, area and proximity. It then calculated whether their head differential and surface area were sufficient to meet the characteristics of the constraints mentioned in Section 3.1.

As mentioned in Section 3.1, sites were also identified by visual assessment of the areas in the vicinity of the largest existing lakes and BC Hydro reservoirs. The visual assessment was conducted by examining digital TRIM and NTS mapping for incised valleys or plateaus surrounding largest freshwater lakes in the study area. Sites were flagged and then characterised in the same manner as the sites identified using the automated GIS search (discussed in Section 3.2.4). A summary of the results are shown in Table 3.1. Similarly, the identified sites can be seen on Figure 3.3.

The sites listed in the above tables are considered the most attractive sites in the study area, and range in gross head from 42 m to 1590 m. Many of the identified sites in the Lower Mainland area are clustered around existing lakes and BC Hydro reservoirs, as the larger lower reservoir in many cases eliminated the need for construction of a lower impoundment, thus making the projects more economically viable. Further, the large lower reservoir provides adequate storage for projects of ranging gross head.

3.2.2 Saltwater Site Identification

Saltwater pumped-storage sites were identified through a visual assessment of the coastline for high-elevation depressions, incised valleys and/or plateaus. Utilizing existing lakes as upper reservoirs was not deemed suitable for site identification, since the environmental impacts of pumping saltwater into an existing freshwater lake were deemed too great.

The potential saltwater sites identified ranges in gross head from 180 m to 1670 m. The majority of the saltwater pumped storage sites are located in the Lower Mainland, since coastal Vancouver Island contains numerous coastal parks on the west coast, and lacks steep topography near the coastline on a large portion of the east coast.

The identified saltwater pumped storage sites are shown in Table 3.2 and Figure 3.4.

3.2.3 Underground Site Identification

Table 3.3 shows a list of current and historical underground mines in the project area. These sites are shown on Figure 3.5. The assessment of the feasibility of underground pumped storage at these active/abandoned underground mines is considered beyond the scope of this assessment.

In order to determine the cost competitiveness of a greenfield underground pumped storage project, KPL completed a cost estimate of a “generic” underground pumped storage plant with the following characteristics:

- The upper reservoir would consist of an existing lake with adequate storage (6,000 MWh), therefore eliminating the requirement to construct a reservoir.
- New underground lower reservoir (no existing underground cavern or abandoned underground mine considered) corresponding to a volume of 6,000 MWh of storage, and
- Gross head = 750 m. This gross head was selected because it is approximately equal to the highest achievable gross head of single-stage reversible pump turbines.

The estimated cost of such a “generic” development, which was considered to have very favourable characteristics, was approximately 230 $/kW-yr. Compared to the most attractive freshwater and saltwater alternatives identified in this study, underground pumped storage is not cost competitive in BC.

3.2.4 Site Characterisation and Costing

Each site was characterised in order to determine the project properties, which were then used as the basis of the cost estimate for each alternative. The main parameters of the characterisation include overall project parameters (gross head, design flow, capacity) reservoir parameters (required storage volume, reservoir area, embankment height and length, embankment volume), and waterway parameters (length, diameter, lining requirements). A summary of the parameters for each site is shown in Tables 3.1 and 3.2.

Cost estimates were prepared for each identified pumped storage alternative by developing a cost template of unit rates for project components. The unit rates used in the costing were based on experience from other recent projects, as well as budget quote information from pump/turbine suppliers. All costs are in 2010 dollars. The capital cost estimates do not include transmission, interconnection or access to the site. BC Hydro indicated to KPL that these costs would be determined by others, and should not be considered in this assessment.

The costs for each site are presented as loaded capital costs (based on the schedules presented in Figure 2.1, a discount rate of 6%, and a cost distribution as presented in Table 3.4). Cost per MW installed, cost per MWh stored, and levelized capital cost ($/kW-yr) were also determined. The costs for each site are summarized in Tables 3.1 and 3.2. As indicated, costs range from $77/kW-yr ($1.3 billion loaded capital cost) to $213/kW-yr ($3.3 billion loaded capital cost) for 1000 MW facilities. This is in the range of $1,300 to $3,300 per kW installed. A breakdown of the cost ranges is shown below:

- Freshwater Pumped Storage
  - 45 projects were identified less than $100 /kW-yr
  - 54 projects were identified between $100 – $125 /kW-yr
  - 9 projects were identified between $125 – $150 /kW-yr
  - 9 projects were identified between $150 – $175 /kW-yr, and
  - 4 projects were identified greater than $175 /kW-yr.

- Saltwater Pumped Storage
  - 6 projects were identified less than $100 /kW-yr
  - 31 projects were identified between $100 – $125 /kW-yr
  - 27 projects were identified between $125 – $150 /kW-yr
  - 7 projects were identified between $150 – $175 /kW-yr, and
2 projects were identified greater than $175/kW-yr.

- Underground Pumped Storage
  - A favourable pumped storage project is anticipated to cost in the range of $230/kW-yr.

As mentioned previously, the costs above do not include transmission, interconnection or access to the site. As such, it would not be prudent to compare the above sites purely on a cost basis until these additional costs have been determined. Ultimately, the cost of transmission, interconnection and access will favour those sites closer to the load centres or major transmission lines in the Lower Mainland and Vancouver Island.

The cost breakdown varied by each project, but is summarized below as average percentages of the total estimated capital cost.

- Freshwater pumped storage
  - 17% - Mob, Demob, Insurance, Bonds, Overhead, Contractor's Profits
  - 6% - Permitting and Design
  - 24% - Generation equipment and switchyard (this ranged from 14%-30%, depending on the project)
  - 31% - Construction costs (this ranged from 25%-41%, depending on the project), and
  - 22% - Contingency.

- Saltwater Sites:
  - 17% - Mob, Demob, Insurance, Bonds, Overhead, Contractor's Profits
  - 6% - Permitting and Design
  - 27% - Generation equipment and switchyard (this ranged from 15%-32%, depending on the project)
  - 28% - Construction costs (this ranged from 23%-40%, depending on the project), and
  - 22% - Contingency.

Operation and maintenance costs were also estimated for each site. These costs were described as a percentage of the total estimated capital cost (2010 dollars) as follows:

- Freshwater pumped storage sites, 1000 MW – 1.0%
- Freshwater pumped storage sites, 500 MW – 1.5%, and
- Saltwater pumped storage sites, 1000 MW – 2.0 %.

### 3.3 PHOTOS AND SCHEMATICS OF TYPICAL PUMP STORAGE PROJECTS

Attached with this report are several schematics and photos of ‘typical’ developments as well as photos from recent KPL experience. A description of the photos/schematics and the applicability to this study are below.

Photo 1 is a schematic of a typical pumped storage scheme. The schematic could apply to both freshwater and saltwater pumped storage projects.

Photo 2 is a schematic of single-stage and multistage pump turbines. The single-stage pump turbine is applicable to the sites identified in this study that have a gross head approximately less than or equal to 750 m. The multistage pump turbine is applicable to sites with a gross head greater than 750 m.
Photo 3 is a schematic of a powerhouse where the pelton turbine is combined with a submersible pump. They are connected such that the two can be run simultaneously in order to be dispatched nearly instantaneously, such as for spinning reserve. Though not applicable to any particular project identified in this study, pumped storage facilities can be designed with this concept.

Photo 4 is a rendition of a three dimensional computer model of the underground works of a pumped-storage powerhouse. The schematic includes the powerhouse cavern, inlet valve hall, waterway tunnels, transformer gallery, surge chambers (pump mode) and access tunnels. This schematic is applicable to all sites identified in this study.

Photos 5 and 6 are applicable to all saltwater pumped storage projects. Photo 5 is an artistic rendition of the Spirit of Ireland Project, which KPL has been recently involved. Photo 6 is a photo of a physical model of the Okinawa Pumped Storage Plant in Japan. The cutaway shows the reservoir, tunnel, underground powerhouse and access shaft.

Photos 7 – 10 are from the Ingula Pumped Storage Scheme in South Africa, which KPL has been a part of the design team. The photos show the upper dam, intake tower, underground works and outlet structure during construction. This 1,334 MW project is similar in scale to a potential 1000 MW development in south western BC.

Photos 11 – 14 show different “Crow’s Nest” reservoirs from various projects around the world (USA, Japan and Czech Republic). These are applicable to the “Crow’s Nest” reservoirs that have been identified in this study.
SECTION 4.0 - CONCLUSIONS AND RECOMMENDATIONS

South-western British Columbia has a high technical potential for freshwater and saltwater pumped storage development, due to the steep topography and existence of hundreds of large natural lakes and man-made reservoirs. The vast coastline also yields a high potential for numerous saltwater pumped storage sites, especially near the Lower Mainland.

Approximately 194 sites were identified in the Lower Mainland and Vancouver Island, ranging from 500 MW to 1,000 MW in installed capacity as shown on Figure 3.6. Each site has the capability of storing the equivalent of 6 hrs at full output (3,000 MWh for a 500 MW site, and 6,000 MWh for a 1,000 MW site). Cost estimates were prepared for sites (at the plant gate, not including transmission, interconnection or access to the site), which ranged from $77/kW-year to $213/kW-yr. Within that range, projects were divided into the following levelized capital cost brackets:

Freshwater Pumped Storage
- 45 projects were identified less than $100 /kW-yr
- 54 projects were identified between $100 – $125 /kW-yr
- 9 projects were identified between $125 – $150 /kW-yr
- 9 projects were identified between $150 – $175 /kW-yr, and
- 4 projects were identified greater than $175 /kW-yr.

Saltwater Pumped Storage
- 6 projects were identified less than $100 /kW-yr
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- 27 projects were identified between $125 – $150 /kW-yr
- 7 projects were identified between $150 – $175 /kW-yr, and
- 2 projects were identified greater than $175 /kW-yr.

Underground Pumped Storage
- A ‘typical’ underground pumped storage project is anticipated to cost in the range of $230/kW-yr.

Should BC Hydro wish to pursue further pumped storage potential in BC, KPL recommends the items below. KPL is aware that some of these items are already underway as a follow-up to this study.
- Estimate the costs of transmission, interconnection and access to each alternative identified above in order to meaningfully be able to compare each identified site
- Conduct a system-wide study to determine the benefits/impacts of integrating pumped storage into the BC Hydro grid
- Determine the ‘ideal’ characteristics of a pumped storage facility, in terms of providing the maximum benefits to the BC Hydro system, improving export opportunities and firming of renewable (especially wind power)
- Conduct a screening assessment for the remaining portions of the province, especially where there is a high resource potential of intermittent renewable energy sources such as wind, run-of-river hydro, solar, tidal and/or wave energy, and
- Conduct a more detailed assessment of the most favourable sites identified in this assessment.
SECTION 5.0 - REFERENCES


SECTION 6.0 - CERTIFICATION

This report was prepared, reviewed and approved by the undersigned.

Prepared:  
Tom Furst, P.Eng.  
Project Engineer

Reviewed:  
Sam Mottram, P.Eng.  
Specialist Hydropower Engineer

Approved:  
Jeremy Haile, P.Eng.  
President

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### TABLE 2.1

**BC HYDRO**

**EVALUATION OF PUMPED STORAGE HYDROELECTRIC POTENTIAL**

**SUMMARY OF FRESHWATER PUMPED STORAGE SITES > 1000 MW WORLDWIDE**

<table>
<thead>
<tr>
<th>ID</th>
<th>Station</th>
<th>Country</th>
<th>Location</th>
<th>Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tumut-3</td>
<td>Australia</td>
<td>50°23'12&quot; S 151°51'26&quot; E</td>
<td>1,500</td>
</tr>
<tr>
<td>2</td>
<td>Cooil Hydroelectric Power Station</td>
<td>Belgium</td>
<td>50°23'12&quot; S 151°51'26&quot; E</td>
<td>1,500</td>
</tr>
<tr>
<td>3</td>
<td>Sir Adam Beck Hydroelectric Power Station</td>
<td>Canada</td>
<td>43°08'51&quot; N 79°04'43&quot; W</td>
<td>1,600</td>
</tr>
<tr>
<td>4</td>
<td>Ballantr Hydroelectric Station</td>
<td>China</td>
<td></td>
<td>1,224</td>
</tr>
<tr>
<td>5</td>
<td>Banquai Pumpeed Hydroelectric Station</td>
<td>China</td>
<td></td>
<td>1,200</td>
</tr>
<tr>
<td>6</td>
<td>Guangdong Pumpeed Storage Power Station</td>
<td>China</td>
<td>23°45'52&quot; N 113°57'12&quot; E</td>
<td>2,400</td>
</tr>
<tr>
<td>7</td>
<td>Heimfang Pumpeed Storage Power Station</td>
<td>China</td>
<td></td>
<td>1,200</td>
</tr>
<tr>
<td>8</td>
<td>Huoshui Pumpeed Storage Power Station</td>
<td>China</td>
<td></td>
<td>1,000</td>
</tr>
<tr>
<td>9</td>
<td>Liyang Hydroelectric Power Station</td>
<td>China</td>
<td></td>
<td>1,000</td>
</tr>
<tr>
<td>10</td>
<td>Bailianhe Hydroelectric Station</td>
<td>China</td>
<td></td>
<td>1,224</td>
</tr>
<tr>
<td>11</td>
<td>Guangdong Pumpeed Storage Power Station</td>
<td>China</td>
<td>23°45'52&quot; N 113°57'12&quot; E</td>
<td>2,400</td>
</tr>
<tr>
<td>12</td>
<td>Heimfang Pumpeed Storage Power Station</td>
<td>China</td>
<td></td>
<td>1,200</td>
</tr>
<tr>
<td>13</td>
<td>Jiuhai Pumpeed Storage Power Station</td>
<td>China</td>
<td></td>
<td>1,000</td>
</tr>
<tr>
<td>14</td>
<td>Bailianhe Hydroelectric Station</td>
<td>China</td>
<td></td>
<td>1,224</td>
</tr>
<tr>
<td>15</td>
<td>Guangdong Pumpeed Storage Power Station</td>
<td>China</td>
<td>23°45'52&quot; N 113°57'12&quot; E</td>
<td>2,400</td>
</tr>
<tr>
<td>16</td>
<td>Heimfang Pumpeed Storage Power Station</td>
<td>China</td>
<td></td>
<td>1,200</td>
</tr>
<tr>
<td>17</td>
<td>Jiuhai Pumpeed Storage Power Station</td>
<td>China</td>
<td></td>
<td>1,000</td>
</tr>
<tr>
<td>18</td>
<td>Grand Maison Dam</td>
<td>France</td>
<td>50°23'12&quot; S 151°51'26&quot; E</td>
<td>1,500</td>
</tr>
<tr>
<td>19</td>
<td>Cooil Hydroelectric Power Station</td>
<td>Belgium</td>
<td>50°23'12&quot; S 151°51'26&quot; E</td>
<td>1,500</td>
</tr>
<tr>
<td>20</td>
<td>Sir Adam Beck Hydroelectric Power Station</td>
<td>Canada</td>
<td>43°08'51&quot; N 79°04'43&quot; W</td>
<td>1,600</td>
</tr>
</tbody>
</table>

**Projects Under Construction**

<table>
<thead>
<tr>
<th>ID</th>
<th>Station</th>
<th>Country</th>
<th>Location</th>
<th>Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Okinawa Seawater Pumped Storage Power Station</td>
<td>Japan</td>
<td>35°07'33&quot; N 137°49'38&quot; E</td>
<td>1,125</td>
</tr>
<tr>
<td>2</td>
<td>Tumut-3</td>
<td>Australia</td>
<td>50°23'12&quot; S 151°51'26&quot; E</td>
<td>1,500</td>
</tr>
<tr>
<td>3</td>
<td>Cooil Hydroelectric Power Station</td>
<td>Belgium</td>
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<tr>
<td>4</td>
<td>Sir Adam Beck Hydroelectric Power Station</td>
<td>Canada</td>
<td>43°08'51&quot; N 79°04'43&quot; W</td>
<td>1,600</td>
</tr>
<tr>
<td>5</td>
<td>Ballantr Hydroelectric Station</td>
<td>China</td>
<td></td>
<td>1,224</td>
</tr>
<tr>
<td>6</td>
<td>Banquai Pumpeed Hydroelectric Station</td>
<td>China</td>
<td></td>
<td>1,200</td>
</tr>
<tr>
<td>7</td>
<td>Guangdong Pumpeed Storage Power Station</td>
<td>China</td>
<td>23°45'52&quot; N 113°57'12&quot; E</td>
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</tr>
<tr>
<td>8</td>
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<td></td>
<td>1,200</td>
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<tr>
<td>9</td>
<td>Jiuhai Pumpeed Storage Power Station</td>
<td>China</td>
<td></td>
<td>1,000</td>
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<tr>
<td>10</td>
<td>Bailianhe Hydroelectric Station</td>
<td>China</td>
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<td>1,224</td>
</tr>
<tr>
<td>11</td>
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<td>China</td>
<td>23°45'52&quot; N 113°57'12&quot; E</td>
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<td>12</td>
<td>Heimfang Pumpeed Storage Power Station</td>
<td>China</td>
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<td>13</td>
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<td>China</td>
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<td>1,000</td>
</tr>
<tr>
<td>14</td>
<td>Bailianhe Hydroelectric Station</td>
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<td>1,224</td>
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<tr>
<td>15</td>
<td>Guangdong Pumpeed Storage Power Station</td>
<td>China</td>
<td>23°45'52&quot; N 113°57'12&quot; E</td>
<td>2,400</td>
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<tr>
<td>16</td>
<td>Heimfang Pumpeed Storage Power Station</td>
<td>China</td>
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<td>1,200</td>
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<tr>
<td>17</td>
<td>Jiuhai Pumpeed Storage Power Station</td>
<td>China</td>
<td></td>
<td>1,000</td>
</tr>
</tbody>
</table>
TABLE 3.1

BC HYDRO
EVALUATION OF PUMPED STORAGE HYDROELECTRIC POTENTIAL

SUMMARY OF FRESHWATER PUMPED STORAGE SITES

<table>
<thead>
<tr>
<th>Site</th>
<th>Source</th>
<th>Salt/Fresh</th>
<th>Pure</th>
<th>Mixed</th>
<th>Type</th>
<th>Pump/Turbine</th>
<th>Water Release</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slippery</td>
<td>Clowhom</td>
<td>N50 44 35.5</td>
<td>W123 28 15.5</td>
<td>49.74318</td>
<td>123.47097</td>
<td>LM</td>
<td>Fresh</td>
<td>Mixed</td>
</tr>
<tr>
<td>Potato</td>
<td>Un-named</td>
<td>N50 09 05.5</td>
<td>W123 41 17.9</td>
<td>50.15154</td>
<td>123.68829</td>
<td>LM</td>
<td>Fresh</td>
<td>Mixed</td>
</tr>
</tbody>
</table>
# TABLE 3.2

**BC HYDRO**

**EVALUATION OF PUMPED STORAGE HYDROELECTRIC POTENTIAL**

**SUMMARY OF SALTWATER PUMPED STORAGE SITES**

| Name         | Latitude | Longitude | Latitude | Longitude | Capacity | Location | Salt/Fresh | Type | Upper Reservoir | 1000 LM Salt Pure Lake | 350 880 2500 3 3,145,643 6,000 2700 880 33% 146 102 Multi-Stage 8.6 6 9 2,935,913,377 3,336,495,784 3,336,496 556,083 204 58,718,268 385 5 5 5 10.4 168 | Foster |
|-------------|----------|-----------|-----------|-----------|----------|----------|------------|------|-----------------|------------------------|-------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Mouat       | N 49° 39' 29.1"  W 124° 18' 56.8" | 49.65809 | 124.31578 | 1000 LM Salt Pure Man Made | 50 440 1400 15 | 6,291,287 | 6,000 1500 440 29% 291 204 Single-Stage 8.6 6 9 1,647,817,409 1,872,649,200 1,872,649 312,108 114 32,956,348 55 5 5 5 4.4 74 | Mouat |
| Hkusam Mountain South | N 50° 21' 40.3"  W 125° 44' 34.5" | 50.3612 | 125.74293 | 1000 VI Salt Pure Man Made | 113 550 3770 6 | 5,033,029 | 6,000 4000 550 14% 233 163 Single-Stage 8.6 6 9 1,966,247,230 2,234,526,278 2,234,526 372,421 136 39,324,945 124.3 5 5 5 6 145 | Hkusam Mountain South |
| Tsakonu     | N 50° 38' 19.3"  W 126° 10' 06.9" | 50.6387 | 126.1686 | 1000 LM Salt Pure Lake | 30 520 300 20 | 5,323,396 | 6,000 1600 520 33% 246 173 Single-Stage 8.6 6 9 1,463,796,031 1,663,519,546 1,663,520 277,253 102 29,275,921 33 5 5 5 5.2 53 | Tsakonu |

**Integrated Resource Plan Appendix 3A-30**

**August 2013**

---

**Integrated Resource Plan Appendix 36-26**

**2013 Resource Options Report Update Appendix 9-A**

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**Boundary Conditions**

- **Regional Waterway**
- **Integrated Resource Plan Appendix 3A-30**
- **Canal / Integrated Resource Plan Appendix 3A-30**
- **Type**
- **Upper Reservoir**
- **Cost**
- **Year**
- **Requirement**
- **Storage**
- **Other**
- **2D Waterway**
TABLE 3.3

BC HYDRO

EVALUATION OF PUMPED STORAGE HYDROELECTRIC POTENTIAL

UNDERGROUND MINES IN THE PROJECT AREA

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Type of Operation</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myra Falls Operations¹</td>
<td>Operating Underground Mine</td>
<td>Copper, Gold, Silver, Zinc</td>
</tr>
<tr>
<td>Quinsam Mine²</td>
<td>Operating Underground Mine</td>
<td>Coal</td>
</tr>
<tr>
<td>Britannia Mine²</td>
<td>Historic Underground Mine</td>
<td>Copper</td>
</tr>
<tr>
<td>Pioneer Mine²</td>
<td>Historic Underground Mine</td>
<td>Gold</td>
</tr>
<tr>
<td>Bralorne Mine²</td>
<td>Historic Underground Mine</td>
<td>Gold</td>
</tr>
<tr>
<td>Minto Mine²</td>
<td>Historic Underground Mine</td>
<td>Gold</td>
</tr>
</tbody>
</table>

NOTES:


Integrated Resource Plan Appendix 3A-30
2013 Resource Options Report Update Appendix 9-A
### TABLE 3.4

**BC HYDRO**

EVALUATION OF PUMPED STORAGE HYDROELECTRIC POTENTIAL

DEVELOPMENT COST DISTRIBUTION BY PUMPED STORAGE TYPE

<table>
<thead>
<tr>
<th>Year</th>
<th>Freshwater</th>
<th>Saltwater</th>
<th>Underground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Year 2</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Year 3</td>
<td>5%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Year 4</td>
<td>10%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>Year 5</td>
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3. PROJECTION: BC ENVIRONMENT ALBERS
4. THE FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:5,500,000 FOR SCALABLE PRINTING. ACTUAL SCALE MOTORING MAPS & INTERPRETATION APPRAISER SETTINGS.

STUDY AREA

EVALUATION OF PUMPED STORAGE HYDROELECTRIC POTENTIAL

BC HYDRO

MAPPING SOLUTIONS

Fig. 3.1
NOTES
1. COLOURIZE GRID IS IN METRES
2. PROJECTION IS ENVIRONMENTAL
3. THIS FIGURE IS PRODUCED AT A SCALING SCALE OF 1:1,800,000

BC HYDRO
EVALUATION OF PUMPED STORAGE
HYDROELECTRIC POTENTIAL
SALMON BEARING LAKES AND RIVERS
IN THE PROJECT AREA

Legend:
- Study Area Boundary
- River
- Lake
- Glacier

Scale:
- 1:1,800,000

Drawn:
Knight Piésold Consulting

Rev Date of Description Design Check Approval
2013 Resource Options Report Update Appendix 9-A

Integrated Resource Plan Appendix 3A-30
August 2013
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PHOTO 1 – Schematic of Pumped Storage Scheme.

PHOTO 3 – Schematic of Pelton Unit Combined with Multistage Pump.

PHOTO 4 – Schematic of 3D Model of Underground Powerhouse.
PHOTO 5 – Spirit of Ireland Project – Artistic Rendition of Saltwater Pumped Storage Scheme.

PHOTO 6 – Okinawa Saltwater Pumped Storage Plant – Cutaway Model of Plant.
EVALUATION OF PUMPED STORAGE HYDROELECTRIC POTENTIAL

PHOTO 7 – Ingula Pumped Storage Scheme – CFRD Dam.

PHOTO 8 – Ingula Pumped Storage Scheme – Intake Tower Under Construction.

PHOTO 11 – Example of “Crow’s Nest” Upper Reservoir – Taum Sauk Facility, USA.

PHOTO 12 – Example of “Crow’s Nest” Upper Reservoir – Seneca Facility, USA.
PHOTO 13 – Example of "Crow’s Nest" Upper Reservoir – Dlouhé Stráně Facility, Czech Republic.

PHOTO 14 – Aerial View of Okinawa Saltwater Pumped Storage Plant, Japan.
BC HYDRO
EVALUATION OF PUMPED STORAGE HYDROELECTRIC
POTENTIAL IN THE NORTH COAST REGION OF BRITISH COLUMBIA

SCREENING ASSESSMENT

PREPARED FOR:
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## BC HYDRO

**EVALUATION OF PUMPED STORAGE HYDROELECTRIC POTENTIAL IN THE NORTH COAST REGION OF BRITISH COLUMBIA**

**SCREENING ASSESSMENT**

(REF. NO. VA103-313/2-1)

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**Knight Piésold Ltd.**

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750 West Pender Street  
Vancouver, British Columbia Canada V6C 2T8  
Telephone: (604) 685-0343  
Facsimile: (604) 683-0147  
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EXECUTIVE SUMMARY

BC Hydro engaged Knight Piésold Ltd. (KPL) to conduct a screening assessment of the pumped storage potential in the North Coast Region of British Columbia. The purpose of this assessment was to determine whether there are potentially viable greenfield pumped storage hydroelectric sites in the North Coast Region of British Columbia. This report illustrates that there are a number of potentially viable sites, all of which are freshwater.

The assessment was limited to an area within 50 km of BC Hydro’s two main transmission lines within the North Coast Region (2L101 and 2L99). Within the area surrounding 2L99, sites of up to 1000 MW capacity were assessed, while sites were limited to 500 MW in the region near 2L101. In addition, potential pumped storage sites were assessed along a likely transmission corridor from the West Coast of Banks Island to Douglas Channel, given the high potential for wind resources in the area.

Potential basins were identified using a combination of existing lakes and/or man-made reservoirs. Using these potential candidate basins, an in-house GIS screening tool identified sites that could provide storage for 16 or 48 hours of continuous generation with a minimum dam embankment construction volume. In addition, potential saltwater sites were identified. The 120 potential sites identified using Knight Piésold’s in-house GIS screening tool were then ranked using a cost estimation spreadsheet in order of levelised capital cost ($/kW-year).

From the list of possible sites, a total of 33 were identified as having the potential to provide 16 hrs of continuous generation at either 500 MW or 1000 MW capacity below a threshold of $200/kW-yr. In addition, 29 sites were identified as having the ability to provide 48 hrs of continuous generation below a threshold of $500/kW-yr. The 25 best sites had estimated costs ranging from $83/kW-yr to $140/kW-yr for 16 hours of continuous generation, and $181/kW-yr to $430/kW-yr for 48 hours of continuous generation. While a number of potential saltwater sites were identified, it appears that development of freshwater pumped storage sites would be more cost effective. The saltwater pumped storage sites identified ranged in cost between $267 – 490/kW-yr. In addition, the development of freshwater pumped storage sites will likely have a reduced environmental impact in comparison to saltwater pumped storage.

The North Coast Region of British Columbia has a high technical potential for freshwater pumped storage development due to the steep topography and existence of many natural lakes and other suitable basins for constructing pumped storage reservoirs. The development costs appear to be similar to the Lower Mainland and Vancouver Island, but with fewer viable sites, due to the relative lack of existing hydropower reservoirs in the region. Based on the potential for pumped storage in the North Coast, and the projected increase in loads and renewable energy in the region, we recommend further assessment of these sites, commencing with estimation of transmission, access and interconnection costs.
BC HYDRO
EVALUATION OF PUMPED STORAGE HYDROELECTRIC POTENTIAL IN THE
NORTH COAST REGION OF BRITISH COLUMBIA
SCREENING ASSESSMENT
(REF. NO. VA103-313/2-1)

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SECTION 1.0 - INTRODUCTION

1.1 INTRODUCTION

BC Hydro engaged Knight Piésold Ltd. (KPL) to conduct a screening assessment of the pumped storage potential in the North Coast Region of British Columbia. This report discusses the results of the assessment.

1.2 PREVIOUS STUDIES

KPL previously conducted a similar study for the Lower Mainland and Vancouver Island region of southwest British Columbia, in 2010. KPL have adopted a similar methodology in the current report, and have adapted the same screening and assessment tools that were developed for that study.

1.3 BACKGROUND TO PUMPED STORAGE

The concept of pumped storage is the generation of electricity by capturing the energy of water being transferred from a higher elevation upper reservoir, through turbine/generator units, into a lower elevation reservoir. The system is then reversed and the water from the lower reservoir is pumped back to the upper reservoir. Though the system is a net consumer of energy, it can be advantageous to developers/utilities by:

- Providing additional capacity during high-load hours when the cost of energy is greatest
- Increasing profitability by using low-value base load energy to pump water to the upper reservoir during low-load hours
- Providing grid stability by reducing the generation differential between high-load and low-load periods,
- Relieving constrained transmission components
- Providing voltage regulation, especially at the end of long transmission systems (relevant to the North Coast Region of BC)
- Providing storage for intermittent renewable energy sources that cannot be dispatched on demand
- Providing backup capacity in the event of a planned or unplanned outage of another significant generation source connected to the grid, and/or
- Providing capacity for export.

Pumped storage projects can be either freshwater or saltwater. Nearly all pumped storage projects worldwide to date are freshwater pumped storage projects. As of 2009, it was estimated that more than 127,000 MW of pumped storage capacity was operating worldwide.
The concept of saltwater pumped storage is the same as that of freshwater pumped storage, with the exception that seawater is exchanged between the ocean and an upper reservoir instead of a freshwater lower reservoir. The advantage of saltwater pumped storage over freshwater pumped storage is that construction of only one reservoir is needed, which can significantly reduce the capital cost of the development. There is currently only one saltwater pumped storage project operating worldwide. This is located in Okinawa, Japan, and has been operating for more than 10 years. There are also numerous saltwater tidal power projects around the world. However, in BC there are numerous fresh water lakes that could also act as the lower reservoir, without the additional complications of salt water corrosion, marine growth issues and added environmental permitting risk of a saltwater development.
SECTION 2.0 - SCREENING METHODOLOGY

2.1 SPATIAL LIMITATIONS

The study area was limited to the North Coast Region of British Columbia, limited to a 50 km boundary on either side of the 2L99 and 2L101 transmission lines of BC Hydro’s grid. Within the study area, the following spatial limitations apply:

- Terrestrial parks and reserve areas are excluded from the study area
- Marine parks are included in the study area
- Private land is included in the study area, and
- Indian Reserves are included in the study area.

A summary of the study area is shown on Figure 2.1.

In addition, potential pumped storage sites were assessed along a likely transmission corridor from the West Coast of Banks Island to Douglas Channel, given the high potential for wind resources in the area.

2.2 LIMITATIONS ON GENERATION CAPACITY

Only sites that have an installed capacity of 500 MW were considered along the 2L101 corridor. Sites with either 500 MW or 1000 MW of installed capacity were considered along the 2L99 corridor. In instances where the defined study areas along 2L99 and 2L101 intersect, the requirements for 2L99 applied.

It is assumed that the additional sites along potential transmission line routes from Banks Island to Kitimat would follow the same requirements for the 2L99 region.

2.3 MINIMUM STORAGE REQUIREMENTS

Two sets of sites were identified. The first set included sites that have storage for 16 continuous hours of generation. The second set included sites that have storage for 48 hours of continuous generation. These equate to an energy storage of 8,000 MWh and 24,000 MWh for the 500 MW sites, and 16,000 MWh and 48,000 MWh for the 1,000 MW sites respectively. The volume of water required to store this amount of energy varies by project, depending on the available head.

2.4 ENVIRONMENTAL LIMITATIONS

Salmon bearing rivers were excluded from the study. The Fish Information Summary System (FISS) from the BC Ministry of Environment was used as the basis for known fish distribution data. Rivers with historical observances of Chinook, Sockeye, Chum, Coho, Pink and/or Steelhead were not considered in the screening assessment.

Existing lakes with historical observances of Salmon were included in the assessment. Only one salmon bearing lakes was identified as a potential pumped storage site, and this was not one of the more cost effective sites. Another two salmon bearing lakes (Kitsumkalum Lake and Lakelse Lake) were identified in the study area as potentially good pumped storage reservoir locations. However, these were excluded...
as it would be likely that construction of a pumped storage facility at other of these locations would require the creation of a reservoir that would impact salmon habitat on the rivers upstream of the lake. A summary of the fish distribution data for the salmon species mentioned above are shown on Figure 2.2.

2.5 TECHNICAL CONSTRAINTS

For each of the two sets of sites (16 hours storage and 48 hours of storage), a maximum of 25 sites were identified. A preliminary cost estimate for each of the 120 potential sites identified by the screening was undertaken in order to rank the sites in order of levelised capital cost. Only the 25 highest ranked sites for each of the two sets of sites were included in the report. Where a potential site was ranked highly for both 500 MW or 1000 MW capacity, only the lower cost (levelised capital cost) configuration was included in the list of potential sites. In order to determine the real levelised cost ($/kW-year), the following was assumed;

- Design Life = 70 years, and
- Discount Rate = 6%

2.5.1 Freshwater Lake to Lake Sites

The North Coast Region of British Columbia has an abundance of small lakes in combination with the steep topography. Due to this high number of potential sites, lakes with the most attractive characteristics were targeted, and were included in the pool of candidate basins for further assessment. All existing lakes within the study area were screened as follows:

- Lakes > 2 ha were assessed as potential reservoir basins.
- Existing lakes within a 10 km horizontal distance that could be used as an upper and lower reservoir respectively (i.e. waterway length is limited to approximately 10 km or less).
- For existing lakes, all water storage was assumed to be constructed above the natural lake water level.

A total of approximately 100 “existing lake” basins were identified using an automated GIS searching tool.

2.5.2 Man-Made Reservoir Sites

Due to the relatively undisturbed nature of the North Coast Region, there are few existing reservoirs, and large existing lakes are concentrated towards the west coast. For this reason, it was necessary to assess the potential of new man-made reservoirs to serve as potential upper and/or lower reservoirs. A visual assessment was undertaken using TRIM mapping to manually identify potential reservoir basins. For each potential basin, a “nominal” reservoir size was calculated using GIS, including the dam height and crest length, reservoir storage volume, and reservoir elevation. A total of approximately 200 “man-made reservoir” basins were identified using a visual assessment of the entire study area.
2.5.3 Saltwater Pumped Storage Sites

The same constraints for the freshwater “man-made reservoir” sites were applied to the screening assessment of saltwater pumped storage sites. Additionally, freshwater lakes were not considered as upstream reservoirs, due to the high environmental impact of pumping saltwater into a freshwater ecosystem. In some instances, upstream reservoirs were proposed in areas that contained either wetland or small ponds. Since it is difficult to determine at what size threshold this may not be permissible, a certain amount of judgement was required to satisfy this constraint. Only sites whose watershed flows directly to the ocean were considered and any saltwater site that would flow into an existing lake or salmon bearing river was not considered. Using visual assessment, a total of approximately 20 potential saltwater basins were identified in the study area. These potential basins are shown on Figure 2.3.

2.5.4 Screening Assessment

From the above, a list of 320 potential basins for freshwater reservoirs was created as shown on Figure 2.4. A screening was undertaken using an automated GIS tool to choose the best combinations of freshwater basins that would lead to viable pumped storage sites. This tool identifies any two basins within approximately 10 km. In some cases, two basins slightly more than 10 km apart were assessed. Between any two basins, the GIS tool will assess the gross head between the two sites and will calculate the storage volume required to meet the project assessment requirements. The GIS tool then determines whether the two basins can be constructed as a potential pumped-storage facility with a dam embankment construction volume below a certain threshold. This threshold was chosen as dam embankment construction can potentially add up to 33% or more of project construction costs, and so minimising dam embankment volume appears to be a useful mechanism to screen some of the best sites from the pool of potentially infinite combinations of sites between the basins identified. The GIS assessment tool was used with the following two constraints:

- A total dam embankment construction volume of 1,000,000 m$^3$, with a reservoir storage capacity for 48 hrs of continuous generation.
- A total dam embankment construction volume of 500,000 m$^3$, with a reservoir storage capacity for 16 hrs of continuous generation.

Using these constraints, the GIS tool flagged a total of 120 potential pumped-storage sites.

2.5.5 Site Characterisation and Costing

Using the 120 potential sites flagged by the GIS tool, each site was characterised in order to determine the project properties, which were then used as the basis of the cost estimate for each alternative. The main parameters of the characterisation include overall project parameters (gross head, design flow, capacity), reservoir parameters (required storage volume, reservoir area, embankment height and length, embankment volume), and waterway parameters (length, diameter, lining requirements). Due to the coarse resolution of the data, and the automated nature of the calculations, some of the site parameters (such as dam
height, crest length and reservoir area) may vary once each site is assessed in greater detail on an individual basis.

Cost estimates were prepared for each identified pumped-storage site by using a cost template of unit rates for project components. The unit rates used in the costing were based on experience from other pumped storage and hydroelectric projects that KPL has experience in. To provide comparison, these were the same costs as were adopted for the Assessment of Pumped Storage Potential in South-West BC, so all costs are in 2010 dollars. The capital cost estimates do not include transmission, interconnection or access to the site. As such, it would not be prudent to compare the sites based purely on a cost basis until these additional costs have been determined. The cost of transmission, interconnection and access will favour those sites closer to load centres or transmission lines.

The costs for each site are presented as loaded capital costs (based on the schedules presented in Figure 2.5, a discount rate of 6% and cost distributions as presented in Table 2.1). Cost per MW installed, cost per MWh stored, and levelized capital cost ($/kW-yr) were also determined.

Annual Operation and Maintenance costs were also estimated for each site. These costs are estimated as a percentage of the total estimated capital cost as follows;

- Freshwater pumped storage sites, 1000 MW – 1.0%
- Freshwater pumped storage sites, 500 MW – 1.5%, and
- Saltwater pumped storage sites, 500 MW – 2.0%.
SECTION 3.0 - SCREENING ASSESSMENT RESULTS

3.1 FRESHWATER SITE IDENTIFICATION

A total of 33 potential freshwater sites with storage for 16 hrs of continuous generation and levelised capital cost below $200/kW-yr were identified. These included:
- Four sites with costs less than $100/kW-yr
- Fourteen sites with costs between $100 – 125/kW-yr
- Eleven sites with costs between $125 – 150/kW-yr, and
- Ten sites with costs greater than $150/kW-yr.

The cost of cumulative installed capacity is indicated on Figure 3.1. The characteristics and costs of the 25 sites with the lowest estimated levelised cost are shown in Table 3.1 and Figure 3.4.

A total of 29 potential freshwater sites with storage for 48 hrs of continuous generation and levelised capital cost below $500/kW-yr were identified. These included:
- Three sites with costs less than $200/kW-yr
- Eleven sites with costs between $200 – 300/kW-yr
- Nine sites with costs between $300 – 400/kW-yr, and
- Six sites with costs greater than $400/kW-yr.

The cost of cumulative installed capacity is indicated on Figure 3.2. The characteristics and costs of the 25 sites with the lowest estimated levelised cost are shown in Table 3.2 and Figure 3.5.

3.2 SALTWATER SITE IDENTIFICATION

A total of 12 potential saltwater sites with storage for 16 hrs of continuous generation and levelised capital cost below $500/kW-yr were identified. These included:
- Three sites with costs less than $300/kW-yr
- Four sites with costs between $300 – 400/kW-yr, and
- Five sites with greater than $400/kW-yr.

The cost of cumulative installed capacity is indicated on Figure 3.3. No saltwater sites with potential for storage for 48 hrs continuous generation were identified. The lists of the lowest estimated cost sites (Tables 3.1 and 3.2), did not include any saltwater sites.
SECTION 4.0 - CONCLUSIONS AND RECOMMENDATIONS

The North Coast Region of British Columbia has a high technical potential for freshwater pumped storage development due to the steep topography and existence of many natural lakes and other suitable basins for constructing pumped storage reservoirs. The potential appears to be slightly less than in the Lower Mainland and Vancouver Island, primarily due to the relatively undisturbed nature of the landscape and the lack of many existing hydropower and other man-made reservoirs suitable for use as part of a pumped storage facility. In addition, it appears that larger lakes are concentrated in the western portion of the region, where there are a large number of parks and few suitable high elevation basins for use as an upper reservoir. These factors appear to limit the total number of sites, however the most cost effective sites appear to be similar in terms of unit cost ($/kW-yr) to the best sites in the Lower Mainland.

A total of 33 sites were identified with the potential to provide 16 hrs of continuous generation at either 500 MW or 1000 MW capacity. In addition, 29 sites were identified having the ability to provide 48 hrs of continuous generation. The 25 best sites had estimated costs ranging from $83/kW-yr to $140/kW-yr for 16 hours of continuous generation, and $181/kW-yr to $430/kW-yr for 48 hours of continuous generation. Of the top 25 sites for 48 hours of continuous generation, all were of 500 MW capacity. While some sites can be developed to 1000 MW capacity, it appears to be more cost effective to constrain these larger sites to 500 MW. Still, it is likely that it would be more cost effective to develop some of the best sites to a capacity of 1000 MW than to develop two lower ranked sites to a capacity of 500 MW each.

While a number of potential saltwater sites were identified, it appears that development of freshwater pumped storage sites would be more cost effective. The saltwater pumped storage sites identified ranged in cost between $267 – 490/kW-yr. In addition, the development of freshwater pumped storage sites will likely be easier to permit, and pose fewer technical challenges in comparison to construction of saltwater pumped storage sites.

Should BC Hydro wish to further pursue pumped storage potential in BC, KPL recommends the items below. KPL is aware that some of these items are underway already:

- Estimate the costs of transmission, interconnection and access to each of the sites identified in order to meaningfully compare each potential project.
- Conduct a system-wide study to determine the benefits/impacts of integrating pumped storage into the BC Hydro grid.
- Determine the “ideal” characteristics of a pumped storage facility, in terms of providing the maximum benefits to the BC Hydro system, improving export opportunities and firming of renewable energy (especially wind power).
- Conduct a screening assessment for the remaining portions of the province where there is a high resource potential of intermittent loads or renewable energy sources such as wind, run-of-river hydro, solar, tidal and/or wave energy.
- Conduct a more detailed assessment of the most favourable sites identified in this assessment.
SECTION 5.0 - REFERENCES


This report was prepared, reviewed and approved by the undersigned.

Prepared:
Michael Pullinger, M.Sc., P.Eng.
Project Engineer

Reviewed:
Sam Mottram, P.Eng.
Power Services Manager

Approved:
Jeremy Haile, P.Eng.
President

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### TABLE 2.1

**BC HYDRO**

**NORTH COAST PUMPED STORAGE ASSESSMENT**

**DEVELOPMENT COST DISTRIBUTION BY PUMPED STORAGE TYPE**

<table>
<thead>
<tr>
<th>Year</th>
<th>Development Cost Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freshwater</td>
</tr>
<tr>
<td>Year 1</td>
<td>0%</td>
</tr>
<tr>
<td>Year 2</td>
<td>0%</td>
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<tr>
<td>Year 3</td>
<td>5%</td>
</tr>
<tr>
<td>Year 4</td>
<td>10%</td>
</tr>
<tr>
<td>Year 5</td>
<td>20%</td>
</tr>
<tr>
<td>Year 6</td>
<td>30%</td>
</tr>
<tr>
<td>Year 7</td>
<td>30%</td>
</tr>
<tr>
<td>Year 8</td>
<td>5%</td>
</tr>
<tr>
<td>Year 9</td>
<td>--</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
### NORTH COAST PUMPED STORAGE ASSESSMENT

| Name         | Latitude | Longitude | Capacity | Location | Upper Reservoir Area | Lower Reservoir Area | Upper Reservoir Volume | Lower Reservoir Volume | Upper Reservoir Elevation | Lower Reservoir Elevation | Design Flow (Cubic Feet/Second) | Unit Cost (2016) | Total Reservoir Cost | Loaded Capital Cost | Total Cost | Total Footprint | Total Loading | Elevation Gain | Total Elevation Loss | Total Reservoir Cost | Loaded Capital Cost | Total Cost | Total Footprint | Total Loading | Elevation Gain | Total Elevation Loss | Total Reservoir Cost | Loaded Capital Cost | Total Cost | Total Footprint | Total Loading | Elevation Gain | Total Elevation Loss |
|--------------|----------|-----------|----------|----------|----------------------|----------------------|------------------------|------------------------|-------------------------|-------------------------|------------------------------|-------------------|------------------|------------------|------------|------------------|--------------|--------------|-------------------|-------------------|-------------------|----------------|-----------------|-----------------|-----------------|---------------------|-------------------|-------------------|-----------------|-----------------|------------------|
| North Coast  | 54.275   | -129.842  | 11,000   | Lower    | 971.784  | 951.085             | 32,789                | 22,396                | 13,193                  | 6,320                   | 0.045                       | 2.10             | 2,116,314.42    | 1,363,693,455   | 1,199,967  | 74,998           | 83.2          | 38.4         | 3.5               | 25.3             | 0.19             | 6.0           | 6.3             | 87.7            |                |                     |                   |                  |
| Lower        | 54.275   | -129.842  | 11,000   | Lower    | 971.784  | 951.085             | 32,789                | 22,396                | 13,193                  | 6,320                   | 0.045                       | 2.10             | 2,116,314.42    | 1,363,693,455   | 1,199,967  | 74,998           | 83.2          | 38.4         | 3.5               | 25.3             | 0.19             | 6.0           | 6.3             | 87.7            |                |                     |                   |                  |
| Lower        | 54.275   | -129.842  | 11,000   | Lower    | 971.784  | 951.085             | 32,789                | 22,396                | 13,193                  | 6,320                   | 0.045                       | 2.10             | 2,116,314.42    | 1,363,693,455   | 1,199,967  | 74,998           | 83.2          | 38.4         | 3.5               | 25.3             | 0.19             | 6.0           | 6.3             | 87.7            |                |                     |                   |                  |
| Lower        | 54.275   | -129.842  | 11,000   | Lower    | 971.784  | 951.085             | 32,789                | 22,396                | 13,193                  | 6,320                   | 0.045                       | 2.10             | 2,116,314.42    | 1,363,693,455   | 1,199,967  | 74,998           | 83.2          | 38.4         | 3.5               | 25.3             | 0.19             | 6.0           | 6.3             | 87.7            |                |                     |                   |                  |

**SUMMARY OF SITES WITH STORAGE FOR 16 HRS OF CONTINUOUS GENERATION**

### BC HYDRO

**NORTH COAST PUMPED STORAGE ASSESSMENT**

**Table 3.1**

**Summary of Sites with Storage for 16 Hrs of Continuous Generation**

| Name         | Latitude | Longitude | Capacity | Location | Upper Reservoir Area | Lower Reservoir Area | Upper Reservoir Volume | Lower Reservoir Volume | Upper Reservoir Elevation | Lower Reservoir Elevation | Design Flow (Cubic Feet/Second) | Unit Cost (2016) | Total Reservoir Cost | Loaded Capital Cost | Total Cost | Total Footprint | Total Loading | Elevation Gain | Total Elevation Loss | Total Reservoir Cost | Loaded Capital Cost | Total Cost | Total Footprint | Total Loading | Elevation Gain | Total Elevation Loss | Total Reservoir Cost | Loaded Capital Cost | Total Cost | Total Footprint | Total Loading | Elevation Gain | Total Elevation Loss |
|--------------|----------|-----------|----------|----------|----------------------|----------------------|------------------------|------------------------|-------------------------|-------------------------|------------------------------|-------------------|------------------|------------------|------------|------------------|--------------|--------------|-------------------|-------------------|-------------------|----------------|-----------------|-----------------|-----------------|---------------------|-------------------|-------------------|----------------|-----------------|------------------|
| North Coast  | 54.275   | -129.842  | 11,000   | Lower    | 971.784  | 951.085             | 32,789                | 22,396                | 13,193                  | 6,320                   | 0.045                       | 2.10             | 2,116,314.42    | 1,363,693,455   | 1,199,967  | 74,998           | 83.2          | 38.4         | 3.5               | 25.3             | 0.19             | 6.0           | 6.3             | 87.7            |                |                     |                   |                  |
| Lower        | 54.275   | -129.842  | 11,000   | Lower    | 971.784  | 951.085             | 32,789                | 22,396                | 13,193                  | 6,320                   | 0.045                       | 2.10             | 2,116,314.42    | 1,363,693,455   | 1,199,967  | 74,998           | 83.2          | 38.4         | 3.5               | 25.3             | 0.19             | 6.0           | 6.3             | 87.7            |                |                     |                   |                  |
| Lower        | 54.275   | -129.842  | 11,000   | Lower    | 971.784  | 951.085             | 32,789                | 22,396                | 13,193                  | 6,320                   | 0.045                       | 2.10             | 2,116,314.42    | 1,363,693,455   | 1,199,967  | 74,998           | 83.2          | 38.4         | 3.5               | 25.3             | 0.19             | 6.0           | 6.3             | 87.7            |                |                     |                   |                  |
| Lower        | 54.275   | -129.842  | 11,000   | Lower    | 971.784  | 951.085             | 32,789                | 22,396                | 13,193                  | 6,320                   | 0.045                       | 2.10             | 2,116,314.42    | 1,363,693,455   | 1,199,967  | 74,998           | 83.2          | 38.4         | 3.5               | 25.3             | 0.19             | 6.0           | 6.3             | 87.7            |                |                     |                   |                  |

**Integrated Resource Plan Appendix 3A-30**

**2013 Resource Options Report Update Appendix 9-A**

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**Notes:**
- Values are approximate and subject to change.
- All values are in US dollars.
- Represents the average cost of the reservoir.
- Includes all costs associated with the reservoir.
- Represents the cost of the reservoir loaded.
- Represents the total cost of the reservoir.
- Represents the total loading of the reservoir.
- Represents the total elevation gain of the reservoir.
- Represents the total elevation loss of the reservoir.
- Represents the total reservoir cost.
### TABLE 3.2

**BC HYDRO**

**NORTH COAST PUMPED STORAGE ASSESSMENT**

**SUMMARY OF SITES WITH STORAGE FOR 48 HRS OF CONTINUOUS GENERATION**

<table>
<thead>
<tr>
<th>Name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Upper Reservoir Waterway</th>
<th>Lower Reservoir Waterway</th>
<th>Upper Bound Footprint</th>
<th>Lower Bound Footprint</th>
<th>Total Estimated Footprint</th>
<th>Waterway Length</th>
<th>Waterway Width</th>
<th>Reservoir Storage Storage Requirement</th>
<th>Storage Requirement</th>
<th>Gross</th>
<th>Total Estimated</th>
<th>Localed Capital Cost</th>
<th>Combined Capital Cost</th>
<th>Total Capital Cost</th>
<th>Total Capital Cost</th>
<th>Total Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jesse Lake</td>
<td>53.917</td>
<td>128.898</td>
<td>53.917</td>
<td>129.884</td>
<td>129.327</td>
<td>500</td>
<td>14,760,080</td>
<td>2400</td>
<td>77.9</td>
<td>16.5</td>
<td>14,760,080</td>
<td>2400</td>
<td>14,760,080</td>
<td>2400</td>
<td>14,760,080</td>
<td>2400</td>
<td>14,760,080</td>
<td>2400</td>
</tr>
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<td>53.917</td>
<td>129.884</td>
<td>129.327</td>
<td>500</td>
<td>14,760,080</td>
<td>2400</td>
<td>77.9</td>
<td>16.5</td>
<td>14,760,080</td>
<td>2400</td>
<td>14,760,080</td>
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<td>14,760,080</td>
<td>2400</td>
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<td>129.327</td>
<td>500</td>
<td>14,760,080</td>
<td>2400</td>
<td>77.9</td>
<td>16.5</td>
<td>14,760,080</td>
<td>2400</td>
<td>14,760,080</td>
<td>2400</td>
<td>14,760,080</td>
<td>2400</td>
<td>14,760,080</td>
<td>2400</td>
</tr>
</tbody>
</table>

**Notes:**
- Upper Reservoir Waterway: the upper limit of the reservoir's waterway.
- Lower Reservoir Waterway: the lower limit of the reservoir's waterway.
- Upper Bound Footprint: the upper boundary of the reservoir's footprint.
- Lower Bound Footprint: the lower boundary of the reservoir's footprint.
- Total Estimated Footprint: the total estimated footprint of the reservoir.
- Waterway Length: the length of the waterway.
- Waterway Width: the width of the waterway.
- Reservoir Storage: the storage capacity of the reservoir.
- Storage Requirement: the storage requirement for the reservoir.
- Gross: the gross capacity of the reservoir.
- Total Estimated: the total estimated cost of the reservoir.
- Localed Capital Cost: the localized capital cost of the reservoir.
- Combined Capital Cost: the combined capital cost of the reservoir.
- Total Capital Cost: the total capital cost of the reservoir.

**August 2013**
<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FRESHWATER PUMPED STORAGE</td>
<td>2080 days</td>
<td>Fri 6/1/12</td>
</tr>
<tr>
<td>2</td>
<td>CONCEPTUAL STUDIES</td>
<td>6 mons</td>
<td>Fri 6/1/12</td>
</tr>
<tr>
<td>3</td>
<td>PRE-FEASIBILITY STUDIES</td>
<td>8 mons</td>
<td>Fri 11/16/12</td>
</tr>
<tr>
<td>4</td>
<td>FEASIBILITY STUDIES</td>
<td>16 mons</td>
<td>Fri 6/28/13</td>
</tr>
<tr>
<td>5</td>
<td>PERMITTING PROCESS</td>
<td>36 mons</td>
<td>Fri 12/13/13</td>
</tr>
<tr>
<td>6</td>
<td>FINANCING</td>
<td>8 mons</td>
<td>Fri 2/5/16</td>
</tr>
<tr>
<td>7</td>
<td>CONSTRUCTION</td>
<td>48 mons</td>
<td>Fri 9/16/16</td>
</tr>
<tr>
<td>8</td>
<td>COD</td>
<td>0 days</td>
<td>Thu 5/21/20</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
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</tr>
<tr>
<td>11</td>
<td>SALTWATER PUMPED STORAGE</td>
<td>2320 days</td>
<td>Fri 6/1/12</td>
</tr>
<tr>
<td>12</td>
<td>CONCEPTUAL STUDIES</td>
<td>6 mons</td>
<td>Fri 6/1/12</td>
</tr>
<tr>
<td>13</td>
<td>PRE-FEASIBILITY STUDIES</td>
<td>8 mons</td>
<td>Fri 11/16/12</td>
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<tr>
<td>14</td>
<td>FEASIBILITY STUDIES</td>
<td>24 mons</td>
<td>Fri 6/28/13</td>
</tr>
<tr>
<td>15</td>
<td>PERMITTING PROCESS</td>
<td>42 mons</td>
<td>Fri 12/13/13</td>
</tr>
<tr>
<td>16</td>
<td>FINANCING</td>
<td>8 mons</td>
<td>Fri 7/22/16</td>
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<tr>
<td>17</td>
<td>CONSTRUCTION</td>
<td>54 mons</td>
<td>Fri 3/3/17</td>
</tr>
<tr>
<td>18</td>
<td>COD</td>
<td>0 days</td>
<td>Thu 4/22/21</td>
</tr>
</tbody>
</table>
NOTES:
1. COSTS DO NOT INCLUDE ACCESS TO SITE, OR TRANSMISSION AND INTERCONNECTION.
2. POTENTIAL SITES ARE OF EITHER 500 MW OR 1000 MW CAPACITY
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1. COSTS DO NOT INCLUDE ACCESS TO SITE, OR TRANSMISSION AND INTERCONNECTION.
2. POTENTIAL SITES ARE OF EITHER 500 MW OR 1000 MW CAPACITY
NOTES:
1. COSTS DO NOT INCLUDE ACCESS TO SITE, OR TRANSMISSION AND INTERCONNECTION.
2. POTENTIAL SITES ARE 500 MW CAPACITY, WITH STORAGE FOR 16 hrs OF CONTINUOUS GENERATION.
PUMPED STORAGE SITES

TRANSMISSION LINE

LOWER RESERVOIR LOCATION

TRANSMISSION LINE

WATER CONVEYANCE TUNNEL

TO UPPER RESERVOIR

STUDY BOUNDARY

TRANS. LINE

2L99

LEGEND:

PUMPED STORAGE SITES

1. BASE MAP: GEO BC WEB MAPPING SERVICE AND BING MAPS.

2. COORDINATE GRID IS IN METRES.

COORDINATE SYSTEM: WGS 1984 UTM ZONE 9N.

3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:750,000 FOR 11X17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.

NOTES:

1. BASE MAP: GEO BC WEB MAPPING SERVICE AND BING MAPS.

2. COORDINATE GRID IS IN METRES.

COORDINATE SYSTEM: WGS 1984 UTM ZONE 9N.

3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:750,000 FOR 11X17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.

BC HYDRO

NORTH COAST PUMPED STORAGE ASSESSMENT

LOCATION OF PUMPED STORAGE SITES FOR 15 Hrs OF CONTINUOUS GENERATION

Knight Piésold

BC HYDRO

NORTH COAST PUMPED STORAGE ASSESSMENT

LOCATION OF PUMPED STORAGE SITES FOR 15 Hrs OF CONTINUOUS GENERATION

August 2013
PUMPED STORAGE SITES

• TRANSMISSION LINE
• LOWER RESERVOIR LOCATION

TRANSMISSION LINE
WATER CONVEYANCE TUNNEL
TO UPPER RESERVOIR

STUDY BORDER

LEGEND:

GENERAL:
TRANSMISSION LINE
WATER CONVEYANCE TUNNEL

NOTES:
1. BASE MAP: BC HYDRO MAPPING SERVICE AND ENMAP MAPS
2. COORDINATE SYSTEM IS UTM WGS 1984, ZONE 9N
3. THIS FIGURE IS PRODUCED AS A SEQUENCE OF VARIOUS COMPUTER GRAPHICS PROGRAMS. THE FIGURE IS IMPRINTED AT ACTUAL SIZE. ALL MEASUREMENTS ARE IN MILLIMETERS OR METERS.

Integrated Resource Plan Appendix 3A-30
2013 Resource Options Report Update Appendix 9-A

August 2013