HYDROBATTERY *Dependable Capacity for Seven Generations*

Mr. Patrick Wruck, August 30, 2017
Commission Secretary and Manager, Regulatory Services
British Columbia Utilities Commission, Vancouver, BC

Dear Site C Inquiry Panel Members:

This submission to the BC Utilities Commission panel is an effort to make British Columbians fully aware of an alternative dependable power and capacity source that is far superior to that of Site C, with an environmental and economic cost far lower for generations to come.

The following attached 3-page Executive Summary and the Knight-Piésold Hydro Battery Report has been adjusted to reflect rapidly changing circumstances around our future electricity supply and our imperative to maintain momentum towards a lower carbon Future Grid and at the same time lower land impacts by avoiding the building of dams wherever possible.

Our project was envisioned by way of a collaborative effort among a group of entrepreneurs with various backgrounds and experience in the renewable energy sector in BC and elsewhere.

We were also inspired by the Feb 2017 release 100% renewable grid study developed and modelled by the Australian National University (ANU), led by Professor Andrew Blakers. Their study confirms our belief that Energy Storage such as Pumped Storage Hydro can add high value at low cost and upgrade variable wind and solar buildout in BC and Beyond in an environmentally acceptable manner.

Our effort to best describe the reasons why we have taken the trouble, expense and effort to submit this hidden-in-plain-sight BC resource to the BCUC, can look no further than the Professor Annie Booth BCUC F30-1 submission, posted on the BCUC Site C repository just a few days ago.

As the citizens of the Columbia Valley well know, “economic” evaluations as practised by our current economic system do not account for the services rendered by our natural ecosystems. In Professor Booth’s submission, flooding most all of the Columbia River valley and now, if Site C is not halted, the remainder of what’s left of the Peace River valley in BC, is compellingly refuted as an acceptable outcome.

Our small Hydro Battery team with Big Ideas for a Small Lake would be pleased to meet with the panel members and if necessary, explain the even greater potential for our low-cost Site C alternative.

Sincerely,

Ward Kemerer, President
Hydro Battery Inc., Revelstoke, BC
Ward.Kemerer@hydrobattery.ca

EXECUTIVE SUMMARY - Site C Inquiry Submission to BCUC - Aug 29, 2017

Under the terms of reference for the Site C Inquiry, the BCUC have been asked to consider what portfolio of generating projects and demand-side management initiatives could provide similar benefits to Site C.

Our Mission Purpose

We are committed to making a difference as it relates to renewable energy for our province.

The Hydro Battery Project offers a pragmatic alternative power source that will more than replace the dependable and dispatchable output from the Site C project. This pumped hydro energy storage asset will offer British Columbians an affordable, dependable capacity resource that has over 100 years of world-wide proven ability for balancing the grid and firming up variable renewable energy. The imperative of Climate Change mitigation will increasingly transform our economy in North America towards a low carbon, more reliable, more interconnected Future Grid. The Hydro Battery resource, along with other energy storage technologies, will better support the already well-advanced transition towards the ***Electrification of Everything.***

Company and Management

Hydro Battery Inc (HBI) is headquartered in Revelstoke, BC., a community that knows very well the negative impacts of flooded and lost valleys in order to serve the power needs of far-away fellow citizens of our vast province. The proponents include Ward Kemerer, Greg McMillan and transmission expert, Scott Taylor, PEng. Matt Vickers is our specialist in liaison with First Nations communities. All the shareholders in the company have experience in the independent power business in BC dating back to the late 1980's to when BC Hydro first began purchasing power supply from the private sector. One of them, the 10 MW Akolkolex power plant, now fully paid off after 20 years, is providing power for less than $55/MWh and will continue to do so for decades.

The HBI business plan concept began in 2012, when BC Hydro released their Draft Integrated Resource Plan (IRP) for public input and identified Pumped Storage Hydro (PSH) as the next best low cost option for British Columbia capacity supply. Interestingly, all mention of PSH was removed from the FINAL 2012 BC Hydro IRP. Upon request, Hydro Battery can supply a copy of this Draft 2012 Integrated Resource Plan.

Project Description

The Hydro Battery PSH project is located 120 km North of Revelstoke. Our lower, existing reservoir, Lake Revelstoke, was formed behind the Revelstoke hydroelectric powerplant dam. The Mica powerplant is just 20 km upstream of the Hydro Battery site and behind Mica's earth-filled dam is the Kinbasket Lake reservoir, also a very large "battery" or energy storage device. The power (MW) and energy supply (MWh) of these two valuable BC Hydro assets combine to produce ~ 50% of the dispatchable electricity supply for the entire province.

Our Hydro Battery site consists of a small upper lake that will form the energy storage reservoir for water pumped up from Lake Revelstoke, ~1300 meters below, at times of low power demand and returns the water to Lake Revelstoke, in a continuous charge / re-charge cycle on a daily or weekly basis, as peak power demands may dictate.

The Hydro Battery Project, due to favourable site characteristics, could provide even more flexible capacity that *exceeds* the ~6,000 MW output of both Revelstoke and Mica Powerplants. However, for the purposes of easy comparison to Site C economics, we have chosen to restrict the size of our Project to just 1,100 MW.

Technical Feasibility

Our Hydro Battery Project report has been prepared by Knight-Piesold Consultants, based out of Vancouver. They are specialists in Pumped Storage Hydro (PSH) projects and in 2010 were commissioned by BC Hydro to look for promising PSH project sites in the Lower Mainland and Vancouver Island. They were involved in the design and construction of the INGULA PSH project in South Africa, (Section 2.2.2) which is just coming online.

After investigation, Knight-Piesold found the Hydro Battery project to be technically sound from an initial design perspective. The Hydro Battery is a typical pumped hydro site - more or less an underground mining site. If located elsewhere in the world, in Japan or Europe, it would have been developed many decades ago. However, it's greatest feature will be the installation of the new ternary-type closed loop turbines that allow very fast responses to changing grid demands, many times faster than conventional turbines installed at current powerplants in BC. This means the Hydro Battery can mitigate adverse downstream ramping rate impacts of Unit 5 and 6 capacity upgrades at the Revelstoke Dam.

The Economics of Hydro Battery versus Site C

Knight-Piesold has indicated a capital cost of ~$2.4 Billion for an initial installed capacity of only 1,100 MW. The proposed Western Canada Integrated Grid linking all 4 western provinces will alter the Hydro Battery economic rationale in an even greater positive manner. This grander vision option shall remain a conversation outside the very narrow mandate of the BCUC Site C Inquiry.

There are many proven renewable energy resources in BC, currently stranded due to Site C. Put simply, for a fair comparison to projected Site C costs, when the Hydro Battery project is operationally combined with BC's abundant, low cost wind resources, we would develop an equivalent yet superior total energy/capacity resource for less than $6 Billion. (see Pg 3). Moreover, these resources could be provided without additional debt burden to British Columbians. Our superior Hydro Battery capacity will transform lower value, variable wind energy into firm high value dispatchable power to provide for future power supply for BC and beyond our borders.

Conclusion:

Very soon, the new BC Government will make a final decision on the Site C Project. The citizens of the Columbia River Valley have had their precious, productive valley bottom taken away in order to provide low cost power for all British Columbians. The value of the loss to the communities and ecosystems affected has not been reconciled to date and the impacts are felt daily. Pending local approval for our project, we hope that the citizens of the Peace Region can be spared this same fate. By utilizing a small 60 hectare lake, we can ensure the preservation of greater than 15,000 hectares of prime lands in the Peace for wildlife, farm lands and most of all, adherence to First Nations Treaty Rights and the concept of Free, Prior and Informed Consent.

One cannot put a price on such a value exchange. But it is most certainly ***The Right Thing to Do.***

EXECUTIVE SUMMARY - Site C Inquiry Submission to BCUC - ADDENDUM

For the average person or even power sector experts, it is difficult to compare costs between Site C and other sources of energy and power supply. A new Australian moniker – the Long Term Cost of Balancing or LCOB serves to help with simpler comparison methods between various renewable energy resources.

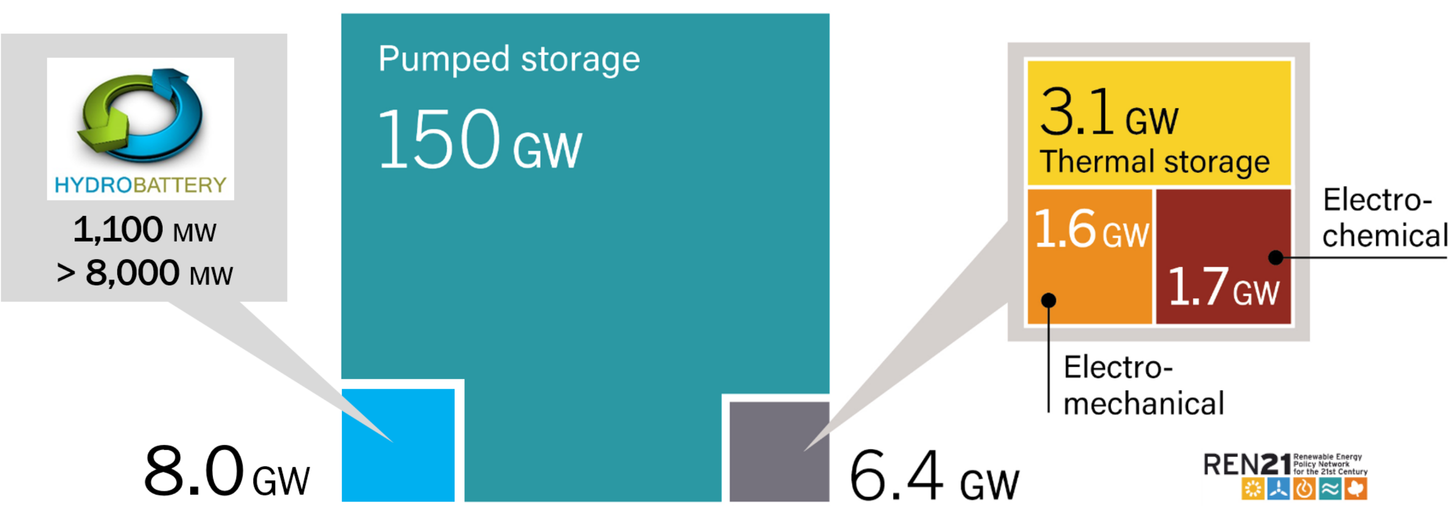
Australian National University — **100% Renewables Scenario for Australia**

		PV (GW/TWh)	Wind (GW/TWh)	PHES (GW/h)	Spillage (%)	Levelised Cost of Balancing ($/MWh)	Levelised Cost of Generation ($/MWh)	Levelised Cost of Electricity ($/MWh)	PHES ($/MWh)	HVDC &AC ($/MWh)	Spillage & loss ($/MWh)
Australia Pumped Hydro ES + Wind and Solar	Unconstrained	23 / 36	45 / 168	16 / 31	7%	28	65	93	14	7	7

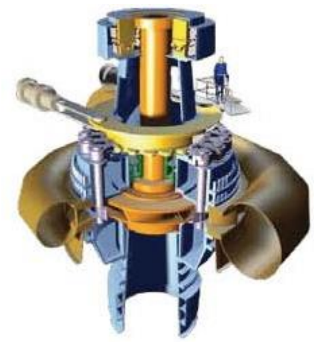
Scenarios for CANADA	Renewable Projects	Solar	Wind	PHES	N/A	LCOB +	LCOG =	LCOE	PHES	Inter-connect costs	N/A
BCUC Site C Inquiry Constraints	BC ONLY	0.2/0.2	1.5 / 5.1	1.1/3.8	0%	20	65	90	15	5	0
Western Canada Integrated HVDC Grid 8 GW of Coal Shutdowns NO Coal-to-Gas Conversions Reserve Margin Reductions	BC-AB-SK-MB 100% Renewables	3/4	16 / 45	4 / 16	0%	18	65	85	10	8	0

Current estimates for Site C LCOE costs range from $84 (BCH) to $141 (CERI) , depending on parameters. It is anticipated that the BCUC panel and Deloitte will choose another number for the ultimate Site C Capex.

This chart below describes the current worldwide capacity of various energy storage types and how large (optimized) the Hydro Battery could be if developed to long term full potential as Canada's GigaBattery.



HYDRO BATTERY INC.
1,100 MW HYDRO BATTERY PUMPED STORAGE HYDRO PROJECT
NEAR REVELSTOKE, BC, CANADA



Single-stage Pump turbine

CONCEPT VALIDATION ASSESSMENT

PREPARED FOR:

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VA103-606/1-1
Rev 1
August 25, 2017

Knight Piésold
CONSULTING
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HYDRO BATTERY INC.
1,100 MW HYDRO BATTERY
PUMPED STORAGE HYDRO PROJECT
NEAR REVELSTOKE, BC, CANADA

CONCEPT VALIDATION ASSESSMENT
VA103-606/1-1

Rev	Description	Date
0	Issued in Final	August 24, 2017
1	Revised Sections 3.1.6 and 3.3.1	August 25, 2017

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Knight Piésold
CONSULTING

EXECUTIVE SUMMARY

Hydro Battery Inc. (HBI) commissioned Knight Piésold Ltd. (KP) to complete a concept validation assessment of the proposed 1,100 MW Hydro Battery Pumped Storage Hydro (PSH) Project, near Revelstoke, BC. HBI's aim is to provide a combined 1,100 MW Pumped Storage Hydro Project and 1,500 -1,800 MW of variable wind power that will provide equivalent or better power and energy characteristics than the 1,100 MW Site C Clean Energy Project that is currently under construction on the Peace River in British Columbia, Canada. The 1,100 MW PSH Project will provide the dispatchable power, and the 1,500 -1,800 MW of wind will provide the 5,100 GWh of annual energy, providing a combined product that delivers equivalent power and energy numbers to that of the Site C Clean Energy Project. The fast acting ternary pump turbines are also able to provide valuable ancillary services such as voltage regulation and energy shaping. HBI also proposes that the fast acting Hydro Battery units could also be used to mitigate the flow ramping concerns of the new BC Hydro Revelstoke Dam units 5 and 6.

The assessment completed by KP provides a high-level overview of the proposed concepts for the development of the 1,100 MW Revelstoke Hydro Battery PSH Project, including:

- Pumped Storage Hydro Basics
- Examples of Similar Projects that are Currently Operating Successfully Around the World
- Costs and Timelines to Develop Similar Projects Around the World
- Characteristics and Proposed Layout of the Hydro Battery PSH Project, including:
    - Project Layouts
    - Technical Characteristics
    - Site Characteristics (Geology, Terrain, Climate, Ecology)
    - Risk Assessment (Geotechnical, Terrain Hazard, Environmental, Permitting, Stakeholders, Interconnection, etc.)
    - Project Costs
    - Development Timelines

The overall conclusion is that the project is technical feasible and capable of delivering 1,100 MW of dispatchable power. The overall project cost is estimated at about $2 Billion ($2.4 Billion including major 500 kV transmission system upgrades).

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ABBREVIATIONS

1,100 MW Hydro Battery PSH Project .... the project
ARD .... acid rock drainage
DFO .... Fisheries and Oceans Canada
EIS .... environmental impact statement
EPCM .... engineering, procurement and construction management
HBI .... Hydro Battery Inc.
KP .... Knight Piésold Ltd.
PSH .... Pumped Storage Hydro
MASL .... Meters Above Sea Level

1 – INTRODUCTION

1.1 INTRODUCTION

Hydro Battery Inc. (HBI) commissioned Knight Piésold Ltd. (KP) to complete a concept validation assessment of the proposed 1,100 MW Revelstoke Hydro Battery Pumped Storage Hydro (PSH) Project. HBI's aim is to provide a combined 1,100 MW Pumped Storage Hydro Project and 1,500 - 1,800 MW of wind power that will provide equivalent or better power and energy characteristics than the 1,100 MW Site C Clean Energy Project that is currently under construction on the Peace River in British Columbia, Canada. The 1,100 MW PSH Project will provide the dispatchable power, and the 1,500 - 1,800 MW of wind will provide the 5,100 GWh of annual energy, providing a combined product that delivers equivalent power and energy numbers to that of the Site C Clean Energy Project. The fast acting ternary pump turbines are also able to provide valuable ancillary services such as voltage regulation and energy shaping. HBI also proposes that the fast acting Hydro Battery units could also be used to mitigate the flow ramping concerns of the new BC Hydro Revelstoke Dam units 5 and 6.

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    - Project Costs
    - Development Timelines

Knight Piésold Ltd. (KP) completed an initial screening assessment of the proposed Revelstoke Pumped Storage Project in 2013. (KP Report - Revelstoke Pumped Storage Project. February 6, 2013. Vancouver, BC. Ref. No. VA103-436/1-A.01, Rev 0). This Concept Validation Assessment builds on this 2013 assessment plus the additional work completed by HBI over the last 5 years.

2 – PUMPED STORAGE HYDRO

2.1 INTRODUCTION TO PUMPED STORAGE HYDRO – THE BASICS

Pumped Storage Hydro has been around for over 100 years with over 125,000 MW of Pumped Storage Hydro capacity currently operating worldwide. (i.e. more than 10 times the total installed capacity of BC Hydro). It is still the most cost effective utility scale "battery" around and new projects are being built around the world to provide dispatchable power on demand and helping to shape the increasing number of intermittent renewables like solar and wind power that are being added to the electrical grids around the globe.

The first recorded pumped storage hydroelectric projects were commissioned in Italy and Switzerland in the 1890's. It is a tried and tested technology, with the largest pumped storage hydropower project in the World currently being the 3,003 MW Bath County Pumped Storage Project in the USA.

Traditionally pumped storage hydro was used to absorb excess cheap power during the low load hours and generate peak power during the peak load hour times. But over the last few decades pumped storage hydro has been used for far more, including shaping intermittent renewable energy, providing dispatchable power, providing voltage regulation, frequency regulation and other ancillary services essential to electric utilities around the world who are required to provide a stable reliable grid.

The key components of a typical pumped storage hydroelectric project are shown below.

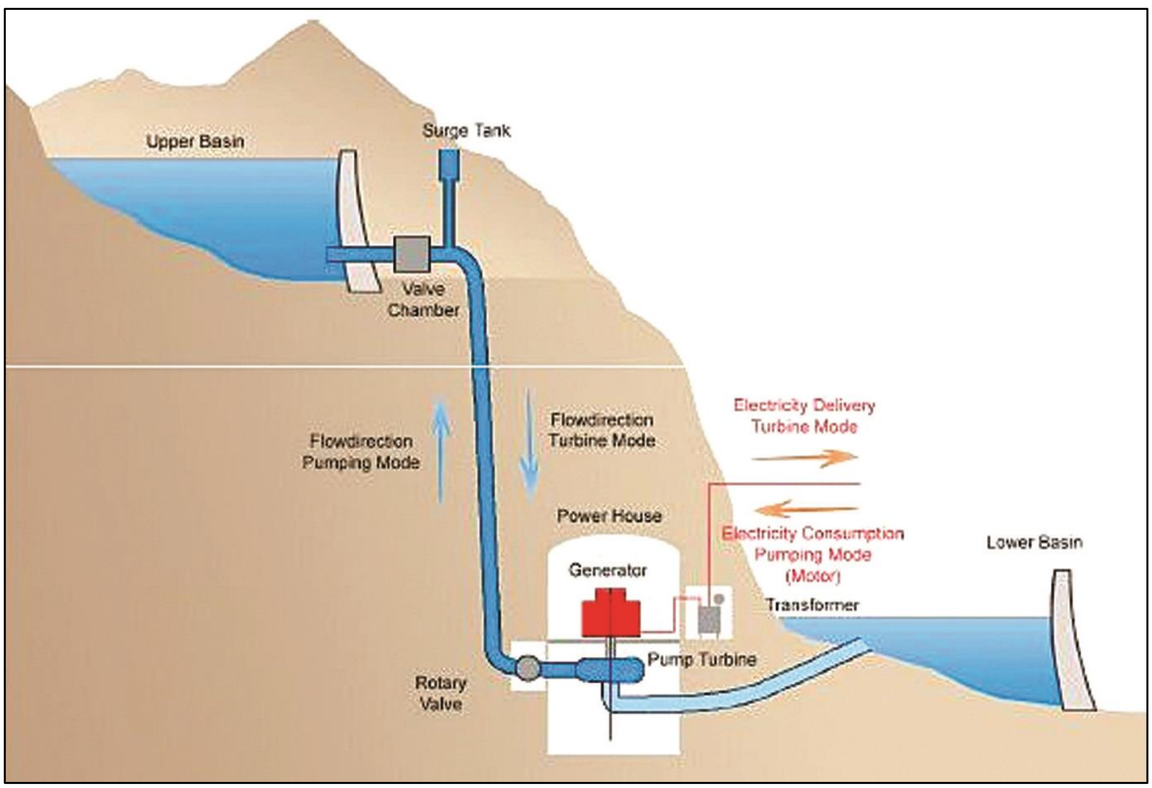

Figure 2.1 Schematic Layout of Pumped Storage Hydro (Source Wikipedia)

2.2 SIMILAR OPERATING PROJECTS AROUND THE WORLD

2.2.1 Key Characteristics of the 1,100 MW Hydro Battery PSH Project

The key characteristics of the proposed 1,100 MW Hydro Battery PSH Project, near Revelstoke, BC, are as follows:

• Capacity (MW)	1,100
• Number of Units	4
• Storage Volume (10^6 x m^3) (5 m/20 m/40 m Upper Dam)	3.8 / 15.2 / 36.0
• Lower Reservoir Elevation (m)	572
• Upper Reservoir Elevation (m)	1,835
• Average Gross Head (m)	1,265
• Design Flow in Turbine Mode (m^3/s)	110
• Design Flow in Pump Mode (m^3/s)	72
• Water Conveyance Length (m)	8,300

The conceptual layout of the proposed project, as provided by HBI, is shown below.

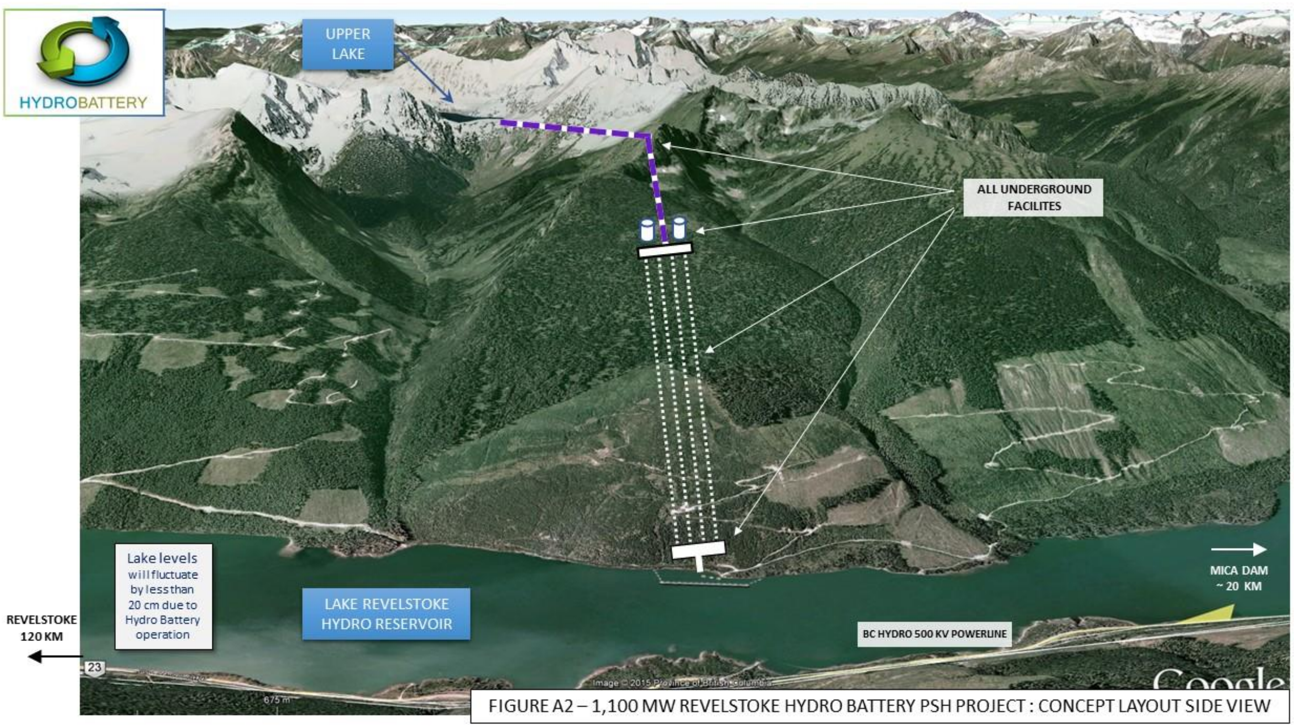

Figure 2.2 Conceptual Layout of 1,100 MW Hydro Battery (Source HBI)

2.2.2 Projects with Similar Characteristics

The first step in validating the project was to compare it to other recently constructed pumped storage projects around the world as well as those with similar characteristics (i.e. installed capacity, head, flow, etc.) Table 2.1 below summarizes a few of the recently constructed projects as well as those with similar characteristics that have been in operation for decades.

Table 2.1 Projects with Similar Characteristics

Project	Country	Size (MW)	Head (m)	Year Completed
Linthal	Switzerland	1,000	630	2016
Ingula	South Africa	1,333	480	2016
Kops II	Austria	450	800	2008
Frades II	Portugal	766	414	2015
Raccoon Mountain	USA	1,652	313	1978
Edolo	Italy	1,000	1,265	1985
Siah Bishe	Iran	1,000	520	2015

The project that is most similar in terms of head, flow, installed capacity and underground workings is the 1,000 MW Edolo Pumped Storage Hydroelectric Project that was commissioned in 1985. The cross sectional profile of this project is shown in Appendix A – Figure A7.

The project that has a similar lower lake intake structure is the 1,652 MW Raccoon Mountain Pumped Storage Hydroelectric Project in the USA. This project has been in operation since 1978, and the intake/outlet structures for the project are shown in Appendix A – Figure A8.

The project with similar underground workings (i.e. tunnels, penstocks and submerged powerhouse) is the 1,333 MW Ingula Pumped Storage Hydroelectric Project in South Africa that was commissioned last year. The layout of the Ingula project is shown in Appendix A – Figure A9. The Linthal Pumped Storage Hydroelectric Project in Switzerland also has similarly extensive underground workings and was successfully completed in 2016.

All the proposed components that make up the proposed 1,100 MW Hydro Battery PSH Project have been successfully built for other projects as presented above.

2.2.3 Costs of Recently Constructed Pumped Storage Hydro Projects

The two most recently completed pumped storage hydroelectric projects listed in Table 2.1 above probably provide the most realistic order of magnitude cost estimate comparison for the 1,100 MW Hydro Battery PSH Project concept. These include the:

1,000 MW Linthal Project, which was completed at a cost of Swiss Francs 2.1 Billion (US$ 2.18 Billion, CAN$ 2.73 Billion).

1,333 MW Ingula Project, which was completed at a cost of US$ 2.3 Billion (CAN$ 2.89 Billion). It should be noted that the Ingula Project required the construction of two new large dams to act as the upper and lower reservoirs, and this contributed to the higher cost of the project (i.e. Where the cost of the dams was approximately 40-50% of the total project cost.

3 – 1,100 MW HYDRO BATTERY PUMPED STORAGE HYDRO (PSH) PROJECT

3.1 PROJECT LAYOUT

The conceptual layouts for the proposed 1,100 MW Hydro Battery, near Revelstoke, BC are presented in Appendix A – Figures A1 through A6 as follows:

- Figure A1 Conceptual Layout Plan
- Figure A2 Conceptual Layout Side View
- Figure A3 Cross Sectional Profile
- Figure A4 Site Photos
- Figure A5 Upper Lake
- Figure A6 Interconnection to BC Hydro Grid

The project has the following key characteristics:

- Capacity: 1,100 MW
- Head: 1,265 m
- Flow: 110 m^3/s
- Lower Reservoir: Existing Lake Revelstoke
- Upper Reservoir: Existing unnamed Lake
- Powerhouse: Underground Powerhouse
- Water Conveyance: Tunnels
- Interconnection: 500 kV lines to existing BC Hydro Revelstoke and Mica Substations

The conceptual project arrangement consists of the upper reservoir on an existing lake, low pressure headrace water conveyance tunnel, four surge chambers, four high-pressure underground penstocks, underground powerhouse housing four ternary turbine-pump units and the lower reservoir (Lake Revelstoke).

3.1.1 Upper Reservoir (Upper Lake)

Three dam heights (water storage volumes) have been assessed for the upper reservoir. These included adding a dam and spillway at the outlet of the Upper Lake, with a height of 5 m, 20 m and 40 m respectively. A conservative approach has been taken at this stage, assuming the available live storage is only the water stored above the existing lake level (i.e. no draw down of the existing lake), and the associated live storage volumes are as follows (also shown in Appendix A – Figure A6):

- 5 m Dam - 3.8 million m^3 or 10.6 GWh of energy stored per filling cycle
- 20 m Dam - 15.2 million m^3 or 42.3 GWh of energy stored per filling cycle
- 40 m Dam - 36.0 million m^3 or 100.1 GWh of energy stored per filling cycle

The proposed dam at the outlet of the Upper Lake could be constructed using numerous techniques, including a roller compacted concrete (RCC) dam or a concreted faced rockfill dam (CRFD). An example of the 40 m high RCC dam that was constructed for the 1,333 MW Ingula PSH Project in South Africa is shown below. It should be noted that this example presents the “biggest upper reservoir case scenario” and that the proposed dam for the upper reservoir of the Hydro Battery Project could likely be much smaller than the 40 m high dam shown in this Photo (i.e. Hydro Battery Upper Reservoir would be between 5 to 40 m high depending on what BC Hydro and HBI determine to be the optimal energy storage capacity requirements for this fast acting dispatchable facility.

Figure 3.1 Dam Example 40 m High RCC Dam (Ingula PSH, South Africa)

3.1.2 Water Conveyance (Tunnels, Shafts, Penstocks)

The majority of the water conveyance systems will be underground, and will include pressurized tunnels and shafts as shown on the concept layouts in Appendix A (Figures A1 – A6). The pressure shafts will likely be constructed using raise bore construction techniques, and the tunnels will either be constructed using the drill and blast technique or tunnel boring machine (TBM). The very high pressure sections of the tunnel will need to be steel lined with steel penstocks leading into the powerhouse machine hall. Examples of similar tunnels and shafts as recently constructed for the 1,333 MW Ingula PSH project are shown below. It should be noted that the tunnels required for the Ingula Project are larger in diameter than those that will be required for the Hydro Battery PSH Project, as the Hydro Battery Site has a smaller design flow and larger generating head.

Figure 3.2 Low-Pressure Headrace Tunnel (Ingula PSH, South Africa)

Figure 3.3 Surge Shaft (Ingula PSH, South Africa)

In terms of concept validation and costing it has been assumed that the tunnels and steel penstocks are sized to limit the velocities in the tunnels to 3 m/s and the steel penstocks to 6 m/s. Construction access adits will also be required.

3.1.3 Powerhouse

The underground powerhouse complex will house the turbine generating equipment, turbine inlet valves, electrical, protection and controls systems. It has been assumed that 4 equally sized units will be installed, as presented in section 3.1.4 below. An access tunnel will be constructed to provide both construction and operations access to the powerhouse, and additional smaller tunnels will be required for construction, ventilation, cabling and emergency egress. An example of the access tunnel in shown below.

Figure 3.4 Main Access Tunnel (Ingula PSH, South Africa)

An example of the underground powerhouse cavern is shown below, with the photo showing the machine hall of the 1,333 MW Ingula PSH Project under construction. The lower levels of the powerhouse will be approximately 65 m below the low water level mark of Lake Revelstoke in order to provide adequate submergence on the pump turbines to prevent cavitation. The fact that the powerhouse and water conveyance systems are buried help to minimize the visual impacts of the project and the disturbance to the surrounding lands.

Figure 3.5 Similar Underground Powerhouse Cavern (Ingula PSH, South Africa)

3.1.4 Generating Equipment

Considering the high head of the project and other technical and economical factors, the most appropriate turbine/pump arrangement is a ternary unit with a Pelton turbine. Ternary systems connect the turbine and pump on a common shaft using a hydraulic torque converter, which allows the machines to be mechanically decoupled in order to reduce frictional and rotational (windage) losses of the free-wheeling pump during the turbine operation and vice versa. Ternary systems can switch between pumping and generating mode much faster than a reversible pump turbine without the need to completely stop and reverse the direction of the flow. This allows the generator to remain near or at synchronous speed while the switch between modes occurs. Because of this arrangement units can go from zero generation to maximum output in less than 60 seconds and switchover from turbine to pumping mode, and vice versa, in less than 30 seconds. Because of their operational flexibility ternary systems are ideal for shaping renewables and offer a possibility of providing the greatest range of ancillary services. A typical ternary unit arrangement is shown below.

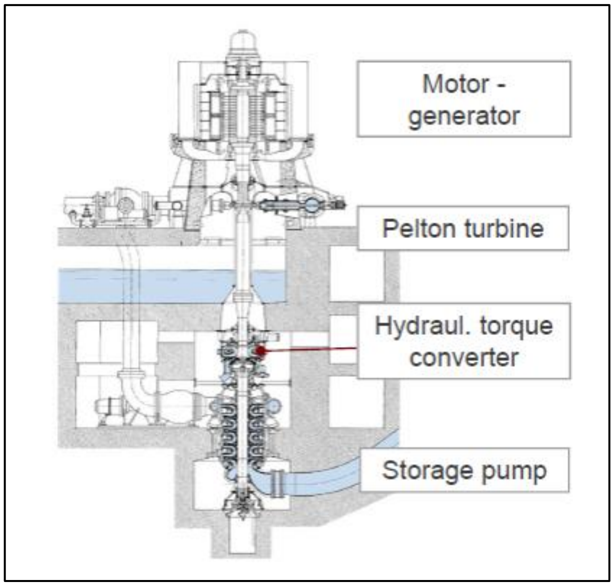

Figure 3.6 Typical ternary unit arrangement

3.1.5 Transmission and Interconnection to the Grid

To facilitate interconnection of the project to the BC Hydro grid, two new 500 kV transmission lines would be built from the BC Hydro Mica Substation to the Revelstoke Hydro Battery PSH Project and also down to the BC Hydro Revelstoke Substation. It is possible that a viable interconnection may be done by tying into only one of the existing 500 kV corridors that connect the Mica and Revelstoke plants to the Lower Mainland, but a conservative approach has been taken at this stage. This conservative approach includes a reinforcement loop between Mica and Revelstoke generating plants. The length of the line would be approximately 135 km.

3.1.6 Lower Reservoir (Lake Revelstoke)

One of the advantages of the Revelstoke Hydro Battery PSH Project site is that the Lower Reservoir (Lake Revelstoke) already exists, which is a major saving for the project. What will be required is a new intake/outlet structure in Lake Revelstoke, which might look similar to the example in Raccoon Mountain provided below. The water levels in Lake Revelstoke only vary about 2 to 4 m annually due to the operation of the BC Hydro generating station at Revelstoke Dam. This small fluctuation is an advantage to the proposed Hydro Battery in terms of both the design and costs associated with the Intake/Outlet Structure for the project in Revelstoke Lake and the depth and submergence requirements of the powerhouse. The impact on the lake levels due to the operation of the Hydro Battery PSH Project will be minimal as Lake Revelstoke is so large (i.e. less than 20 cm water level impact due to the operation of the PSH project).

Figure 3.7 Similar Lower Lake Intake Structure (Raccoon Mountain PSH, USA)

3.2 SITE CHARACTERISTICS

3.2.1 Climate

The Hydro Battery Project is located in the Columbia Mountains approximately 120 km north of Revelstoke, BC and approximately 20 km downstream of the Mica Dam on the Columbia River. The Project's upper reservoir is at approximately 1,840 masl on an existing lake of a tributary that drains east into the Columbia River. The tributary has catchment elevations as high as 2,500 masl on the surrounding mountain peaks, and has a confluence with the Columbia River at approximately 570 masl. The Project's lower reservoir is Lake Revelstoke. This reservoir is behind the BC Hydro Revelstoke Dam, located approximately 120 km south of the proposed Hydro Battery PSH Project.

The Project is located within the North Columbia Mountains Ecoregion. The Columbia Mountains intercept eastward flowing moist Pacific air bringing high amounts of rain or snowfall and generally humid conditions to the region. In winter, dense Arctic air can move down the Columbia River Trench bringing cold weather to the valleys (Demarchi, 2011). The region experiences cool winters and warm summers, and has a snowmelt dominated hydrologic regime.

3.2.2 Geotechnical Assessment

The purpose of the assessment was to identify any showstoppers with respect to the geotechnical site considerations. For the purpose of this assessment, a showstopper was considered to be any condition that cannot be mitigated in an economically feasible manner.

3.2.3 Geology

The geology is mapped as the Horsethief Creek Group, which is Upper Proterzoic in age (BCGS 2005). The Horsethief Creek Group is mapped as consisting of metamorphosed sedimentary rocks (sandstone containing at times quartz and feldspar), conglomerate, and amphibolite (BCGS 2005).

This group extends along the west side of Lake Revelstoke from south of Hydro Battery to well north of Mica Dam. This indicates that similar rock mass conditions, which are present within the underground workings of the Mica Generating Station, can be expected at the Revelstoke Hydro Battery site. Based on previous experience at the Mica Generating Station, KP considers the anticipated rock mass conditions at Hydro Battery to be consistent with those at Mica Dam, and therefore suitable for the proposed underground workings.

Regional geology maps indicate that several regional faults are present in the local area (BCGS 2005):

- A normal fault approximately 5 km north of the site
- A thrust fault approximately 25 km south of the site, and
- A normal fault along the western edge of Lake Revelstoke that intersects the tailrace.

It is not uncommon for watercourses to be surface expressions of faults, as faults tend to be the path of least resistance for water flow. As such, it is possible that unidentified faults are present along the Twenty-one Creek (CTI 2001), which is located immediately north of Hydro Battery, and the unnamed creek (CTI 2001) directly south of the Revelstoke Hydro Battery site.

The surficial geology in the proximity of the site is mapped as quaternary cover, which could consist of one or more of alluvium, glaciofluvial gravels and sand, and glacial till (BCGS 2005). The quaternary cover should be expected on the lower slopes of the project, including at the edge, and on the submerged bank, of Lake Revelstoke.

3.2.4 Facilities

3.2.4.1 Upper Reservoir (Upper Lake)

The Upper Reservoir consists of a natural lake, which is currently unnamed. The lake level is proposed to be raised using a dam to increase the live storage depth. Alpine lakes in BC can contain fine grained soils deposited by glacial outwash. If the lake is drawn down to the extent of exposing any lake bed sediments, the sediments could be destabilized due to excess pore water pressures and/or seepage induced instability. If any lake bed sediments were to fail into the lake, the sediments would likely be drawn into the intake and deposited in the Lake Revelstoke through the tailrace. Such an event would likely be considered an environmental incident. Based on an example of a similar event (i.e. Tyson Creek Hydroelectric Project) this would likely be considered a showstopper. However, operational controls that limit the drawdown of the upper reservoir would likely be sufficient to mitigate this hazard. If lake bed sediments are present in the upper reservoir, the live storage depth should be limited so as to not expose the sediments during drawdown operations. A conservative approach would be to assume no drawdown of the Upper Lake until this issue can be addressed. Knight Piésold has taken this conservative approach is accessing the energy storage capabilities of the Hydro Battery.

3.2.4.2 Conveyance (Tunnels and Shafts)

Previous work completed by KP (2013) provided conceptual level optimization of the layout for the conveyance tunnels (low and high pressure tunnels, shafts, surge chambers, and access adits) with respect to in-situ rock mass stress being exceeded by water pressures. Based on this assessment, no geotechnical showstoppers were identified. However, any future geotechnical investigation programs should include in-situ stress testing. The earlier in the design phase that in-situ stress testing can be completed, the better the engineer’s cost estimate can be for tunnel and shaft linings, which can have significant cost implications. Recent experience has shown that cost overruns can occur if the length of linings is not finalized before tender.

3.2.4.3 Powerhouse and Tailrace

Both the Powerhouse and Tailrace could be affected by the normal fault mapped along the western edge of Lake Revelstoke. However, modern tunneling practices can be used in this terrain; although tunneling through faults will require more support than in more component rock mass conditions.

The presence of quaternary cover on the lower slopes of the project, up to, and likely within, Lake Revelstoke, could make tunneling difficult for establishing the discharge end of the tailrace. Tunneling through unconsolidated and fully saturated sediments can be difficult and could be the most challenging portion of the works. However, tunneling methods are available to overcome this challenge, but this area needs to be thoroughly investigated to reduce the likelihood of claims from the contractor during construction.

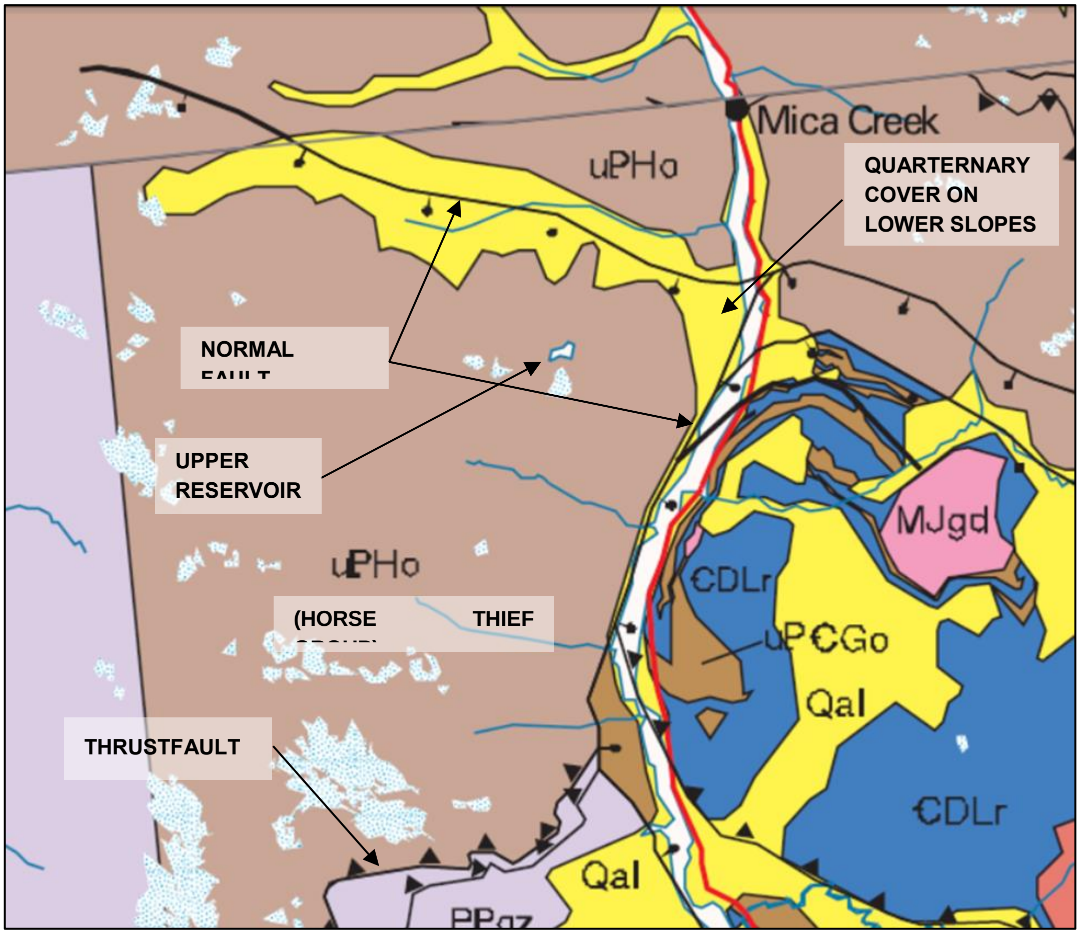

Figure 3.8 Bedrock and surficial geology at and surrounding the Hydro Battery project site

3.3 ENVIRONMENTAL AND PERMITTING CONSIDERATIONS

3.3.1 Project Area

The Hydro Battery PSH Project is located of the west side of the Revelstoke Reservoir (elevation 571 masl) approximately 120 km north of Revelstoke, BC in the Upper Columbia River watershed. The proposed upper reservoir utilizes an unnamed 60 ha alpine lake (elevation 1,835 masl), near the headwaters of an unnamed tributary to Revelstoke Reservoir (Lake Revelstoke) that drains the east slope of the Monashee Mountains. This tributary has a watershed area of 24 km^2 and discharge to Lake Revelstoke approximately 20 km downstream from the BC Hydro Mica Dam. Lake Revelstoke was formed following the completion of the Revelstoke Dam construction in 1984.

Resident fish are present in Lake Revelstoke (bull trout, kokanee, mountain whitefish, rainbow trout, burbot, redside shiners, and northern pike minnow), and at the mouth of the unnamed tributary draining the upper lake. The Reservoir supports a sports fishery primarily targeting bull trout, kokanee, rainbow trout, and mountain whitefish. The project area is within a regional area designated and managed as critical habitat for the southern mountain population of woodland caribou. The majority of the proposed project area is on Crown Land. Beaumont Timber owns land within the project's lower impacted area. Forest cut blocks and roads are present on the lower valley slopes. Regional commercial tenures for heli-skiing and heli-hiking overlap the proposed development. The project area is located within Shuswap Nation Tribal Council Bands and Ktunaxa First Nations Traditional Territories.

3.3.2 Key Issues

The key issues related to developing the Hydro Battery PSH Project would be addressed through a comprehensive environmental assessment and consultative process, once the specific project parameters and transmission interconnection are defined. Some of the key issues are expected to include:

- Impacts of the project on First Nations traditional and current use
- Potential conflicts with backcountry recreational land use including visual impacts
- Fisheries impacts specifically entrainment of fish through the intake on Revelstoke Reservoir and fluctuating water levels (although the impact is expected to be negligible, as the Revelstoke Reservoir water levels will only fluctuate by 20 cm as a result of the Hydro Battery PSH project operations)
- Impacts on water quality related to erosion of the upper lake shoreline drawdown zone (predicted to be up to 40 m)
- Potential impacts on wildlife and wildlife habitat including species at risk
- Socio-economic impacts associated with project benefits and local communities, and
- Fish impacts to lower reach of the unnamed creek.

The project provides economic and social benefits and has a small surface footprint in a relatively isolated area of the province, while utilizing an existing hydroelectric reservoir with existing drawdown zone related impacts. The potential adverse impacts of the project appear to be manageable with no apparent showstoppers.

3.3.3 Regulatory

The proposed generating capacity of the project (1,100 MW) is expected to trigger both federal and provincial environmental assessment review. The following sections outline the steps and timelines for both processes, which are expected to be harmonized under a single review envelope.

3.3.3.1 Federal

The *Canadian Environmental Assessment Act* 2012 (CEAA 2012) applies to projects described in the Regulations Designating Physical Activities and to projects designated by the Minister of the Environment. The relevant designated physical activities listed in the regulations for new projects include:

- A new hydroelectric generating facility with a production capacity of 200 MW or more.
- The construction, operation, decommissioning and abandonment of a new dam or dyke that would result in the creation of a reservoir with a surface area that would exceed the annual mean surface area of a natural water body by 1,500 ha or more.
- The construction, operation, decommissioning and abandonment of a new structure for the diversion of 10,000,000 m^3/year or more of water from a natural water body into another natural water body.
- The construction, operation, decommissioning and abandonment of a new electrical transmission line with a voltage of 345 kV or more that requires a total of 75 km or more of new

right of way (potentially triggers a federal environmental assessment conducted by the National Energy Board).

The key steps in a federal environmental assessment conducted by the CEA Agency include:

- Proponent prepares and submits Project Description
- Determination of whether or not an Environmental Assessment is required
- Proponent prepares and submits Environmental Impact Statement (EIS) guidelines
- Proponent completes environmental studies prepares and submits EIS report
- EIS report is reviewed and comments addressed by the Proponent, and
- Federal Minister issues the environmental assessment decision statement with enforceable conditions.

The timelines depend on the type of environmental assessment conducted (CEA Agency or Review Panel), the complexity of issues, and whether or not extensions are granted. Officially an environmental assessment conducted by the Agency must be completed within 12 months, while a review panel must be completed in 24 months. This does not account for the timeline to undertake baseline studies and impacts analysis. For large projects the environmental assessment process may take 3 to 5 years.

Following a federal environmental assessment decision that allows a project to proceed, there is normally a period to obtain permits under provincial and federal legislation. If a *Fisheries Act* Authorization permit is required the process to obtain a permit approval may take up to one year or more, depending on the complexity of issues.

3.3.3.2 Provincial

The *British Columbia Environmental Assessment Act* 2002 (BCEAA 2002) applies to projects described in the Reviewable Projects Regulation and to projects designated by the Provincial Minister of the Environment. There is also a contingency for Proponents to potentially "opt-in" as a designated project. The relevant designated reviewable projects listed in the regulations include:

- A new hydroelectric facility with a rated nameplate capacity of > 50 MW of electricity, and
- A new electric transmission line of > 40 km in length on a new right of way.

The key steps in a provincial environmental assessment conducted by the BC Environmental Assessment Office (EAO) are similar to the federal process. The timelines depend on the complexity of issues and whether or not extensions are granted. Officially an environmental assessment conducted by the EAO must be completed within 180 days following submission of the Application report. This does not account for the timeline to undertake baseline studies and impacts analysis. For large projects the environmental assessment process may take 3 to 5 years.

For large projects it is common for both the CEAA and BCEAA to apply and for the review to be harmonized under one process, considering there are common information requirements. Normally both provincial and federal approvals are required in order for a project to proceed under these circumstances.

Hydroelectric projects that are below the reviewable thresholds under the CEAA and BCEAA (e.g., < 50 MW) will normally require an environmental assessment under the BC *Water Sustainability Act* and *Land Act* to obtain project approvals. The BC MFLNRO typically oversees the water licencing process for these types of projects. The key steps are similar to those for federal and provincial environmental assessments, with reduced oversight and consultation requirements. There are no official review process timelines. For hydroelectric projects < 50 MW the environmental assessment/water licencing process normally takes 2 to 4 years.

Following a provincial environmental assessment decision that allows a project to proceed, there is normally a period to obtain permits under provincial and federal legislation.

3.4 ENERGY, STORAGE AND CYCLE TIMES

Refer to Table 3. The base case (Case 1) for the pump-turbine equipment this conceptual study is four ternary type pump-turbine units operating on a daily generation-pumping cycle. A ternary unit consists of separate pump and turbine rotating in the same direction on a common shaft equipped with a hydraulic torque converter. Because the pumping and generating functions are separated, much higher heads (as is the case with this project) can be accommodated. Refer to Figure 3.6 for the layout of a typical ternary pump-turbine unit. A Pelton turbine is used for generating, since it is the only practical turbine type capable of operating under this head in a single stage. A multi-stage pump is used for the pumping mode. In this case, the pump will have five stages, which allows the high dynamic head to be achieved. Note that a typical reversible pump-turbine (RPT) unit has significant head limitations since the turbine is a Francis type, and the unit is limited to two stages, which limits the achievable head compared to the ternary unit. Discussions with a major pumped storage equipment supplier indicate that the plant could consist of either four or five units, to be determined at a later stage in the design. However, for the sake of this study, we have adopted four ternary units as the base case, with Pelton turbines and five stage pumps. Note that the pumps for this configuration will require a submergence of 65 m below minimum tail water level.

Refer to Table 3. One of the key parameters in the design of a pump-turbine unit is the ratio of turbine power (output) versus pump power (input). Typical values of this ratio given in the US Bureau of Reclamation documentation vary from roughly 90% to 110%. In this case, we have assumed the ratio to be unity (1100 MW turbine power out equal to 1100 MW pump power in) as shown in Table 3. Hydraulic conveyance losses have been assumed to be 10% in each direction, and typical turbine/pump and generator/motor efficiencies have been assumed in order to calculate the required flows in each direction at full rated power under net rated head, as shown in Table 3.

Another key parameter is the cycle time. This is the time for the full volume of water to be pumped up and turbined down at full power. For this study, we have assumed a single day (24 hours) for a complete 24 hour cycle. Based on the given inputs it has been calculated that this cycle would consist of 10 hours of generation and 14 hours of pumping assuming 100% generation and pumping load during the cycle. The storage volume needed to operate in this cycle is 3.8 million m^3. Based on the volume it has been estimated that the dam height needed to create this storage in the upper reservoir is 5 m and the average annual generation would be approximately 3,822 GWh.

There is also an option of expanding the upper reservoir to allow for a multi-day or weekly cycle for a reasonable additional cost by raising the dam to a height of 20 or 40 m to achieve additional storage volume. This is shown in Cases 2 (20 m) and 3 (40 m) in Table 3, and the 20 m and 40 m reservoir areas and dams are shown in Figure 3. However, note that the annual generation does not increase with increasing dam heights. This is due to using the same assumed efficiencies for pumping and generating, but also because of the assumption that the ratio of turbine power output versus pump power input is unity. The ratios of resulting turbine and pump flows, and operating times, therefore does not change for increasing cycle times. However, as the cycle time increases, the required dam height and cost also increases, as shown in Table 3.

The dam heights shown in the table are calculated from the live storage volumes and heights required in the upper reservoir in each case, so the dam heights shown are equal to the required live storage heights. The actual dams will be slightly larger to accommodate some freeboard. The live storage heights shown are also assumed to go up from the lake outlet elevation. The dam heights do not take into account the existing body of water in the lake, since its bathymetry is not known at this time. Therefore, it is possible that the actual dam heights can be lower than those shown here if required live storage heights can extend downwards below the outlet sill level. This could significantly reduce the dam heights and costs. It is, however, assumed that the lake is deep enough to allow for an intake submergence of 10 m. The intake will be in the form of an intake tower with an integral gate facility and a bridge connecting it to the shore.

3.5 SHAPING CAPABILITY

Pump storage plants are ideal for providing grid stabilization by being able to perform quick power regulation, including primary frequency regulation, as well as daily or weekly energy balancing to assist in "shaping" the generation from renewable energy plants such as wind and solar. Of all the PSH technologies the ternary unit offers the most operational flexibility which enables the facility to provide a wide range of ancillary services to aid grid stabilization, including frequency regulation, load following, spinning reserve (both positive and negative), black start capability, synchronous condensing operation, voltage regulation. Most importantly, its fast switchover times are ideal for balancing renewable energy sources (particularly wind) and by doing that assisting with grid stability. This could be particularly interesting for grids like that in Alberta, especially as they move to decommission their coal plants and add more intermitant renewables like wind and solar to their grid.

HBI proposes that another benefit of the fast acting ternary units proposed for the Hydro Battery PSH Project and their ability to switch quickly between pumping and generating modes will be the ability to mitigate BC Hydro's Revelstoke Dams Units 5 and 6 downstream flow ramping rate concerns.

3.6 EXPANDABILITY OF PROJECT SITE

Another benefit of the proposed Hydro Battery PSH Project site is that it can accommodate future expansion in terms of both dispatchable capacity (i.e. adding additional ternary units) and energy storage (i.e. raising the upper dam to increase its capacity). The Hydro Battery would also support the expansion of the transmission network to more fully integrate the Western Canadian Electrical Grid, as shown in Appendix A – Figure A13, to improve security of supply and assist the integration of more intermittent renewables such as run of river hydro, wind and solar power. This would also assist Alberta in its ambitious plans to decommission its coal power generation facilities and replace them with clean energy technologies such as solar and wind power.

3.7 PROJECT COSTS

The concept layout, and preliminary site data shown on Figure A1 and Table 1 respectively form the basis of a preliminary capital cost estimate, which includes the following:

- Preliminary and General, which includes costs for mobilisation, demobilisation, bonds, insurance and construction related permits.

- Access and Site Preparation, including site clearing, new roads, bridges and culverts. An allowance for the cable crane access to the upper reservoir is also included.
- Intake and tailrace/outlet components includes a reinforced concrete intake/outlet tower, trash racks, controls gates and instrumentation.
- The Upper Reservoir storage dam consists of a concrete faced rockfill dam, with a 1:1.5 slope angle, and 6 m wide crest. Cost includes site clearing, rock quarrying and spoil, reinforced concrete face and spillway.
- Water Conveyance System, including a drill and blast tunnel (or TBM), with a minimum 3.5 m diameter, or 3 m/s flow velocity (whichever is greater). Also includes surge towers, which are sized at 2 ½ times the tunnel diameter. The tunnels are steel lined where required, in accordance with the “Norwegian Criteria” for minimum rock cover.
- Powerhouse and ancillary services includes dewatering, concrete, crane, heating, lighting, electrical systems and other ancillary components. For the underground powerhouse, the cavern is excavated through underground drill and blast techniques, and two additional tunnels are included – one for access, and one for ventilation and power cable/bus systems.
- Power generation equipment consists of ternary units (multi-stage pump, coupling, Pelton turbine and motor-generator on a same shaft), plus inlet valves, excitation systems, switchgear, hydraulic pressure units, protection and control, installation and commissioning. This cost is based on a per MW rate based on previous project experience as well as budgetary quotations from equipment suppliers.
- Switchyard, transmission and interconnection costs are estimated based on similar experience on previous projects.

The project costs are summarised in Table 2. The estimated capital cost for the 1,100MW Hydro Battery PSH Project, near Revelstoke, BC is approximately $2,420 million.

3.8 DEVELOPMENT TIMELINES

Based on recent and relevant experience with the development and permitting of other similar sized projects in Canada it could take approximately 10 years to develop the project. This would include:

- 3-5 years for environmental studies, bankable feasibility studies and project permitting, and
- 5-8 years for detailed design, procurement, construction and commissioning.

It should be noted that these two phases might overlap to some extent, thereby shortening the overall development timeline.

4 – CONCLUSIONS

The overall conclusion is that the project is technical feasible and capable of delivering 1,100 MW of dispatchable power. No major technical show stoppers were identified in this screening level assessment that would prevent the project from being developed. The overall project cost is estimated at about $2 Billion ($2.4 Billion including major 500 kV transmission system upgrades) and could take approximately 10 years to develop. It is however possible that the project development may be expedited due to accelerated load growth in BC or needs of the Alberta system and Western Interconnected Grid.

5 – REFERENCES

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Knight Piésold Ltd. (KP), 2013. Revelstoke Pumped Storage Project. February 6. Vancouver, BC. Ref. No. VA103-436/1-A.01, Rev 0.

E-mail of August 17, 2017 from Lawson Crichton (VOITH Hydro) to Rob Adams (KP) concerning costs and configurations for pump storage units.

6 – CERTIFICATION

This report was prepared and reviewed by the undersigned.

PROFESSIONAL ENGINEER
R.D. ADAMS
25 Aug 2017

Prepared: ______________________________

Rob Adams, P.Eng.
Specialist Hydromechanical Engineer

Reviewed: ______________________________

Sam Mottram, P.Eng.
Managing Principal, Power Services

Approval that this document adheres to Knight Piésold Quality Systems: SRM

APPENDIX A

CONCEPT LAYOUTS AND FIGURES

(Pages A-1 to A-13)

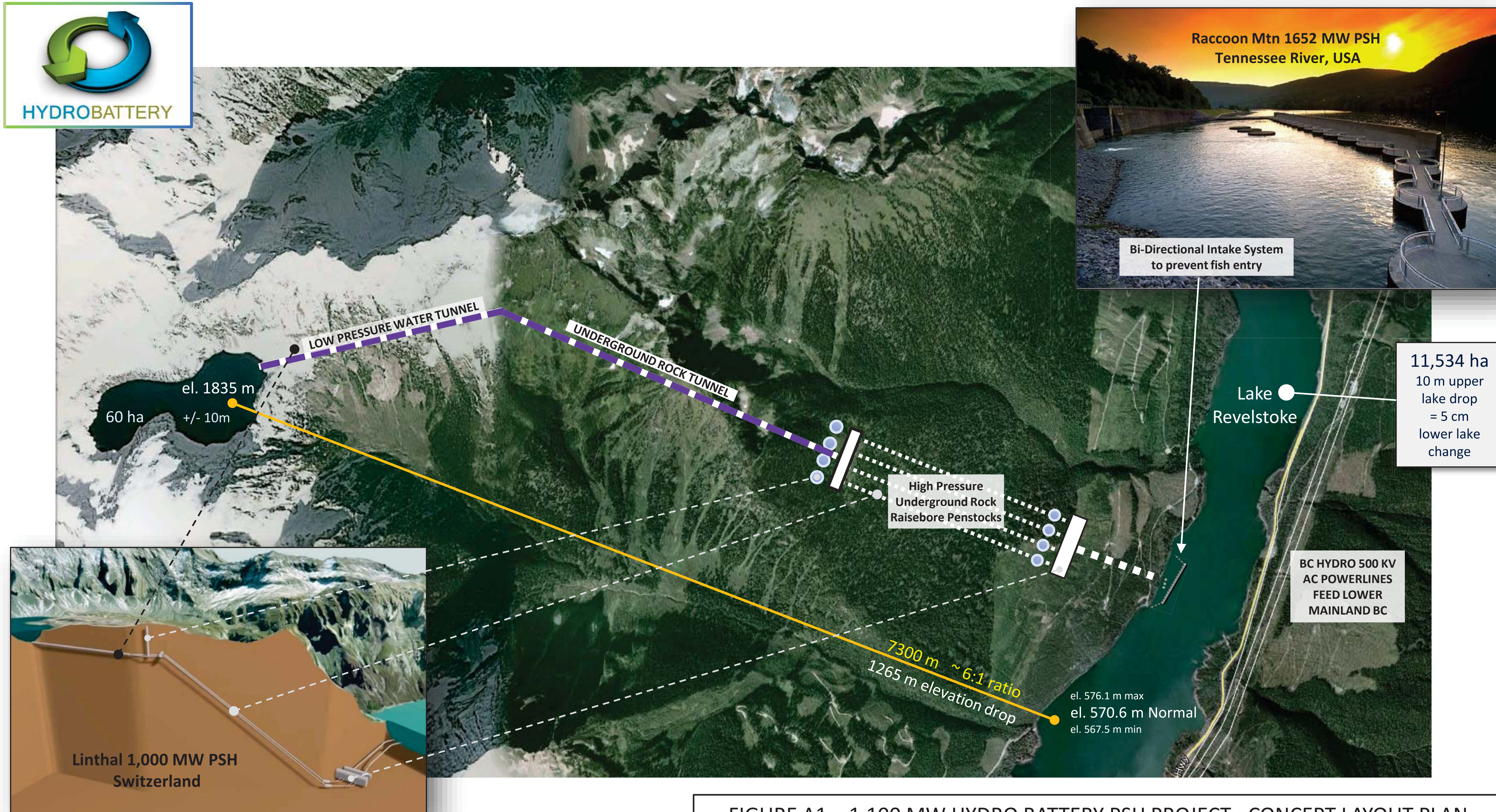


FIGURE A1 – 1,100 MW HYDRO BATTERY PSH PROJECT : CONCEPT LAYOUT PLAN

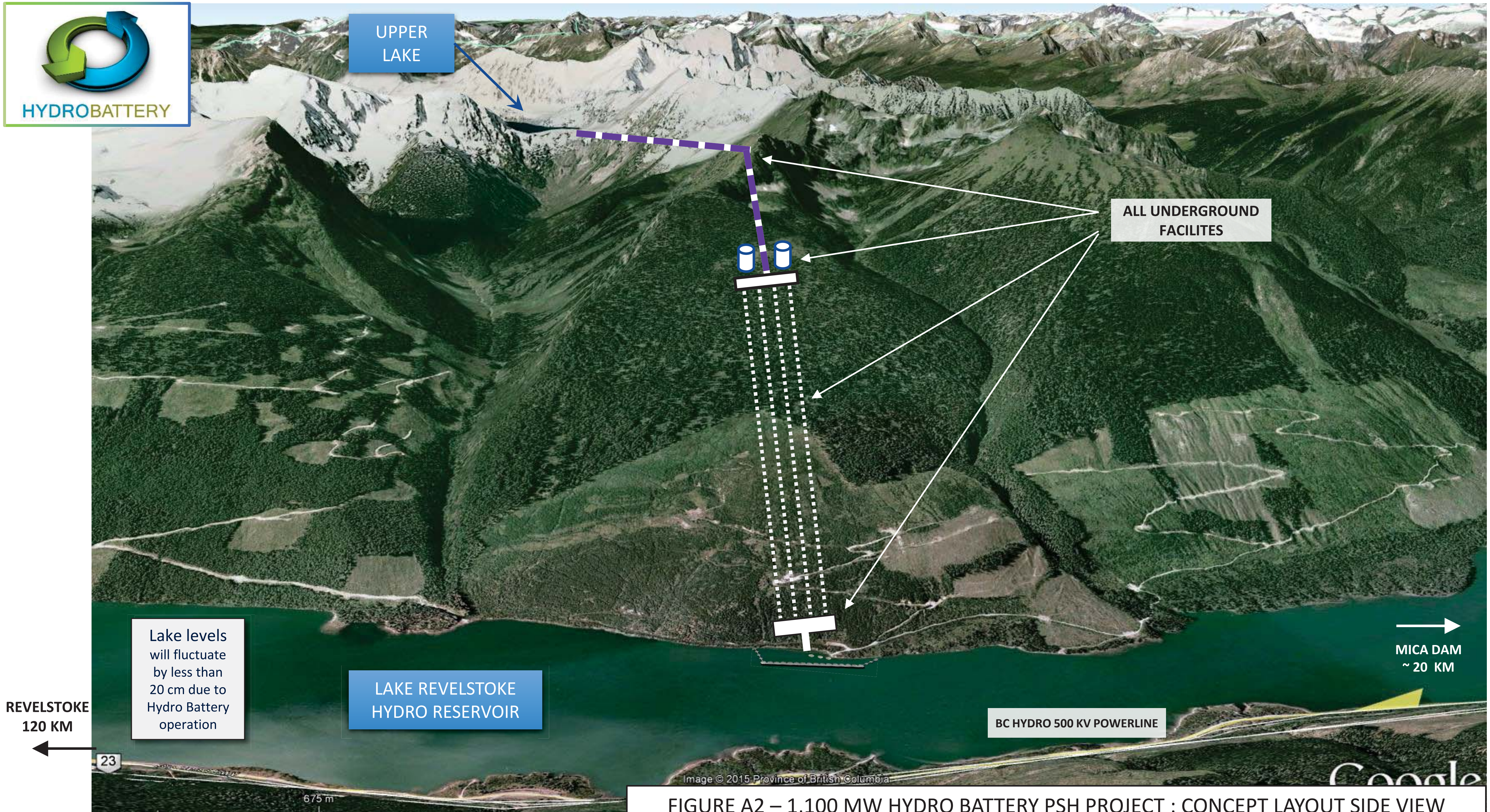


FIGURE A2 – 1,100 MW HYDRO BATTERY PSH PROJECT : CONCEPT LAYOUT SIDE VIEW

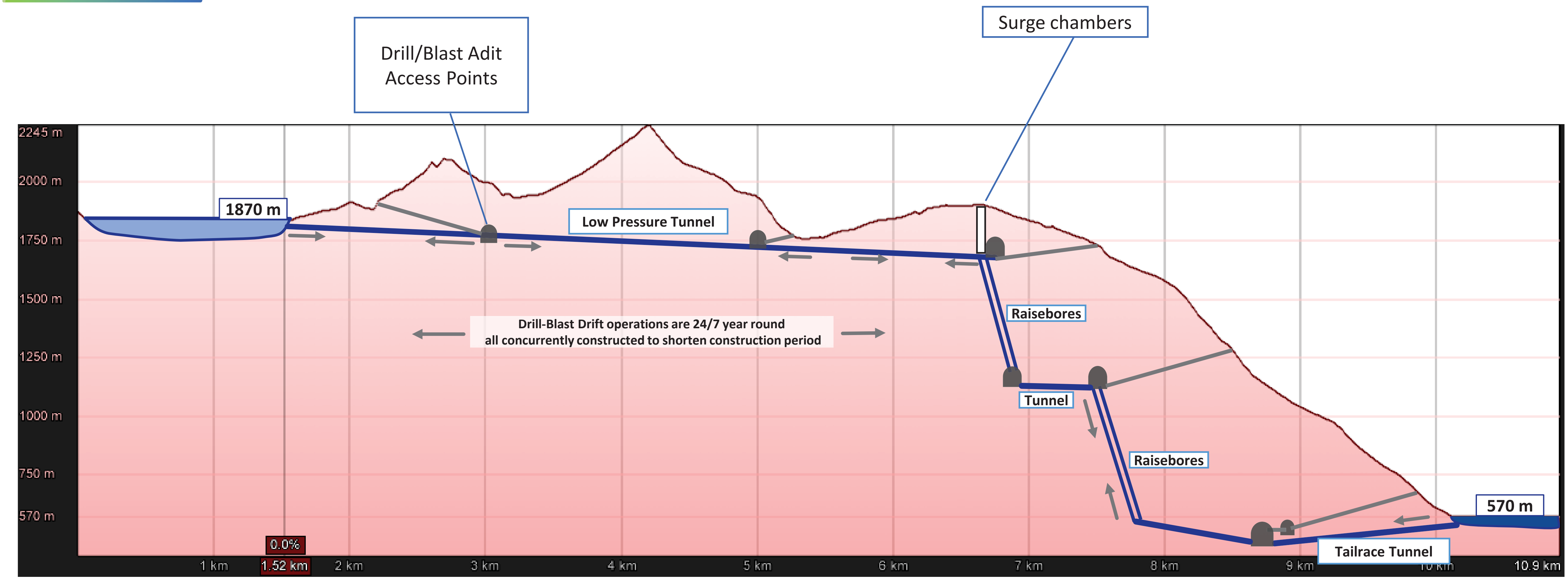


FIGURE A3 – 1,100 MW HYDRO BATTERY PSH PROJECT : CROSS SECTIONAL PROFILE

HYDROBATTERY

Deep Unnamed Remote
Upper Lake
@ about 60 hectares
At 1835 m elevation

Lake Revelstoke
1300 + metres below Upper Lake
(View from Upper Lake)

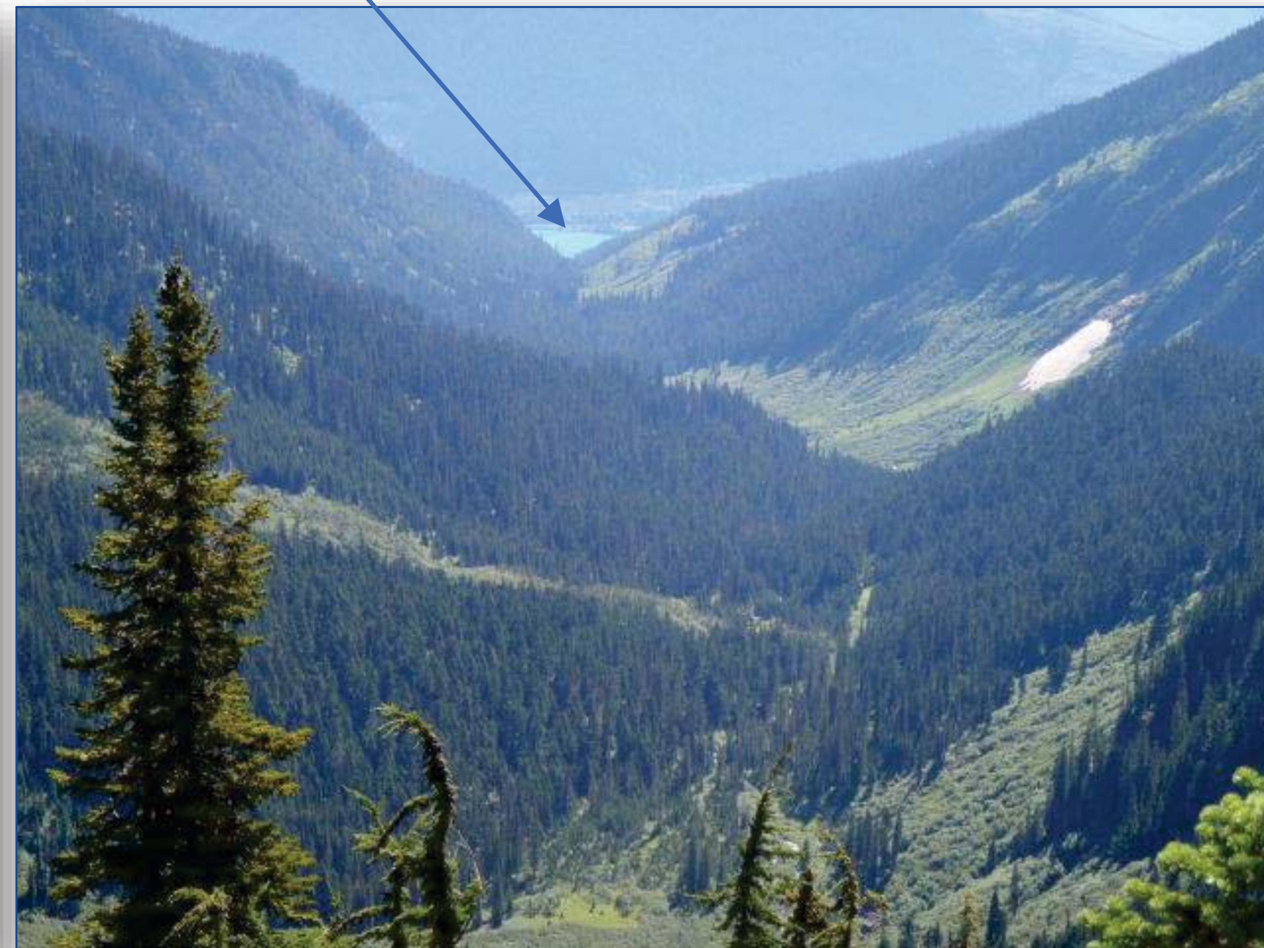


FIGURE A4 – 1,100 MW HYDRO BATTERY PSH PROJECT : SITE PHOTOS

HYDROBATTERY

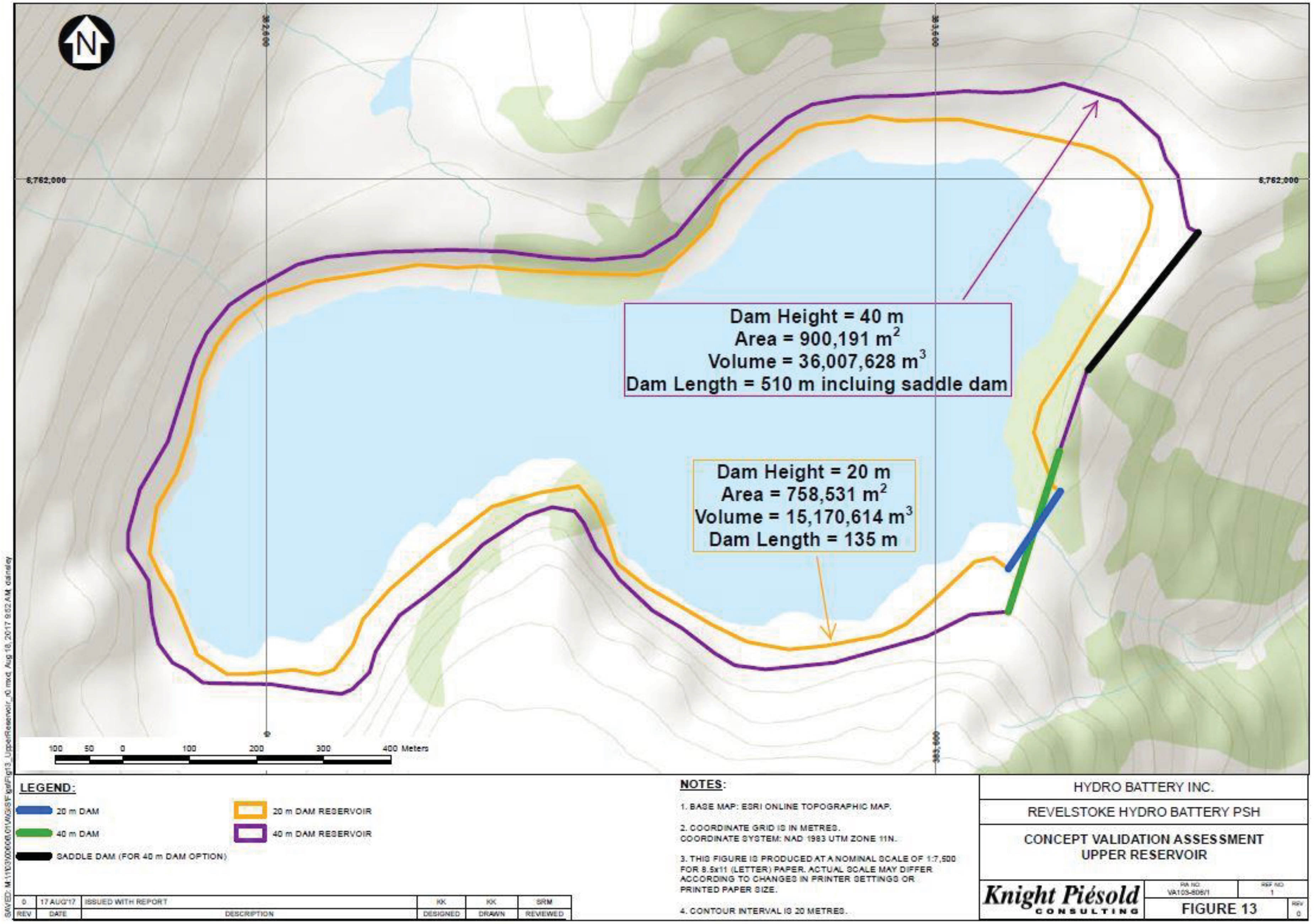
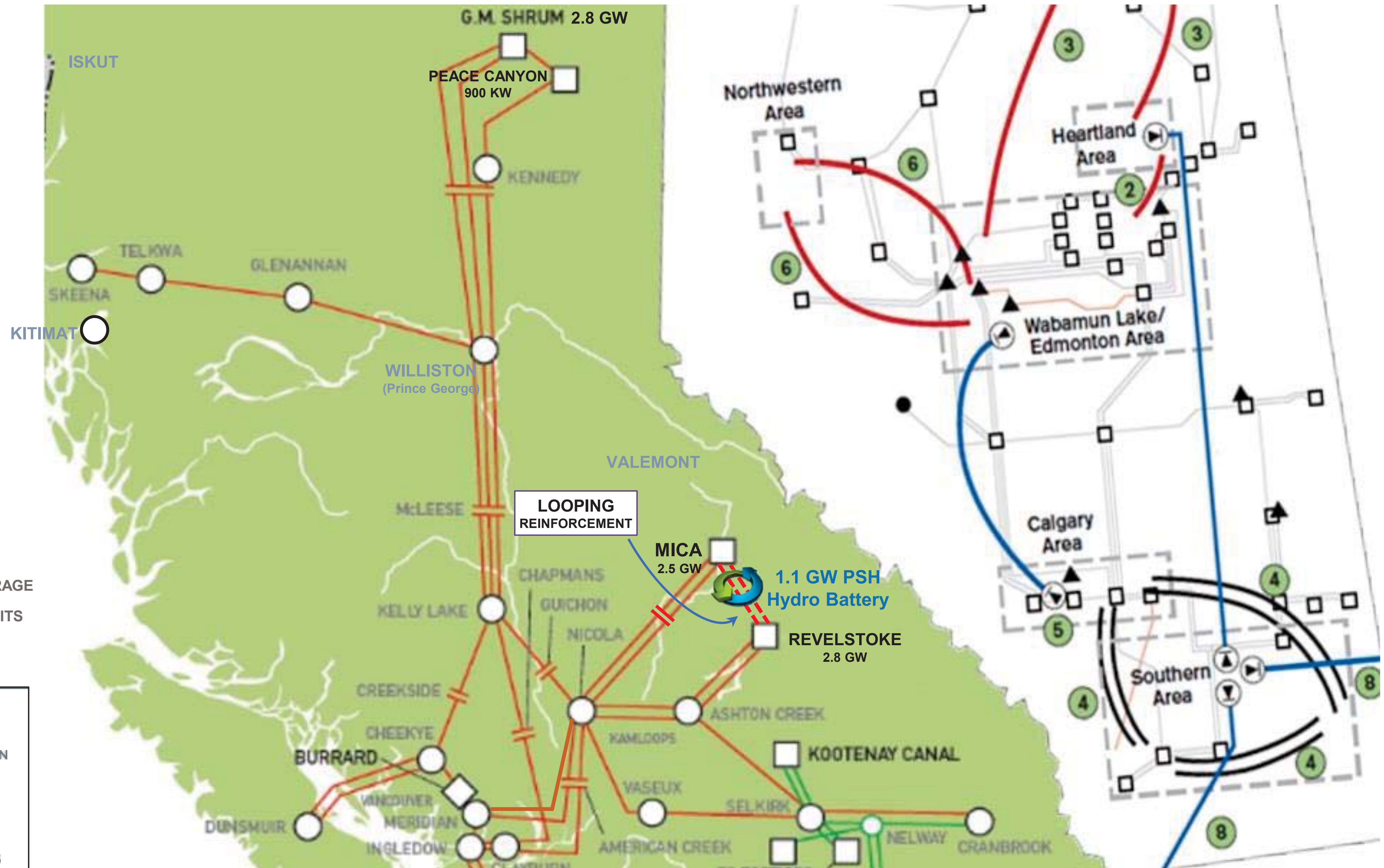


FIGURE A5 – 1,100 MW HYDRO BATTERY PSH PROJECT : UPPER LAKE

HYDROBATTERY

Pumped-Storage Hydro-Battery
Stage 1 Electrical Grid Interconnection



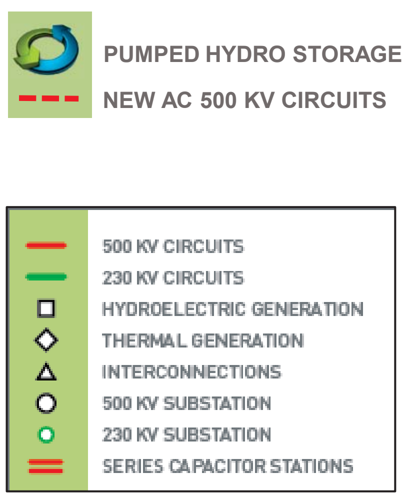


FIGURE A6 – 1,100 MW HYDRO BATTERY PSH PROJECT : INTERCONNECTION TO BC HYDRO GRID

EDOLO PSH (ITALY)
OPERATIONAL 1980

1,000 MW
PUMPED STORAGE
HYDRO
with similar
characteristics
as the
HYDRO BATTERY
PSH SITE

The Hydro Battery project will include the latest fast-response ternary hydraulic loop pump-turbine design

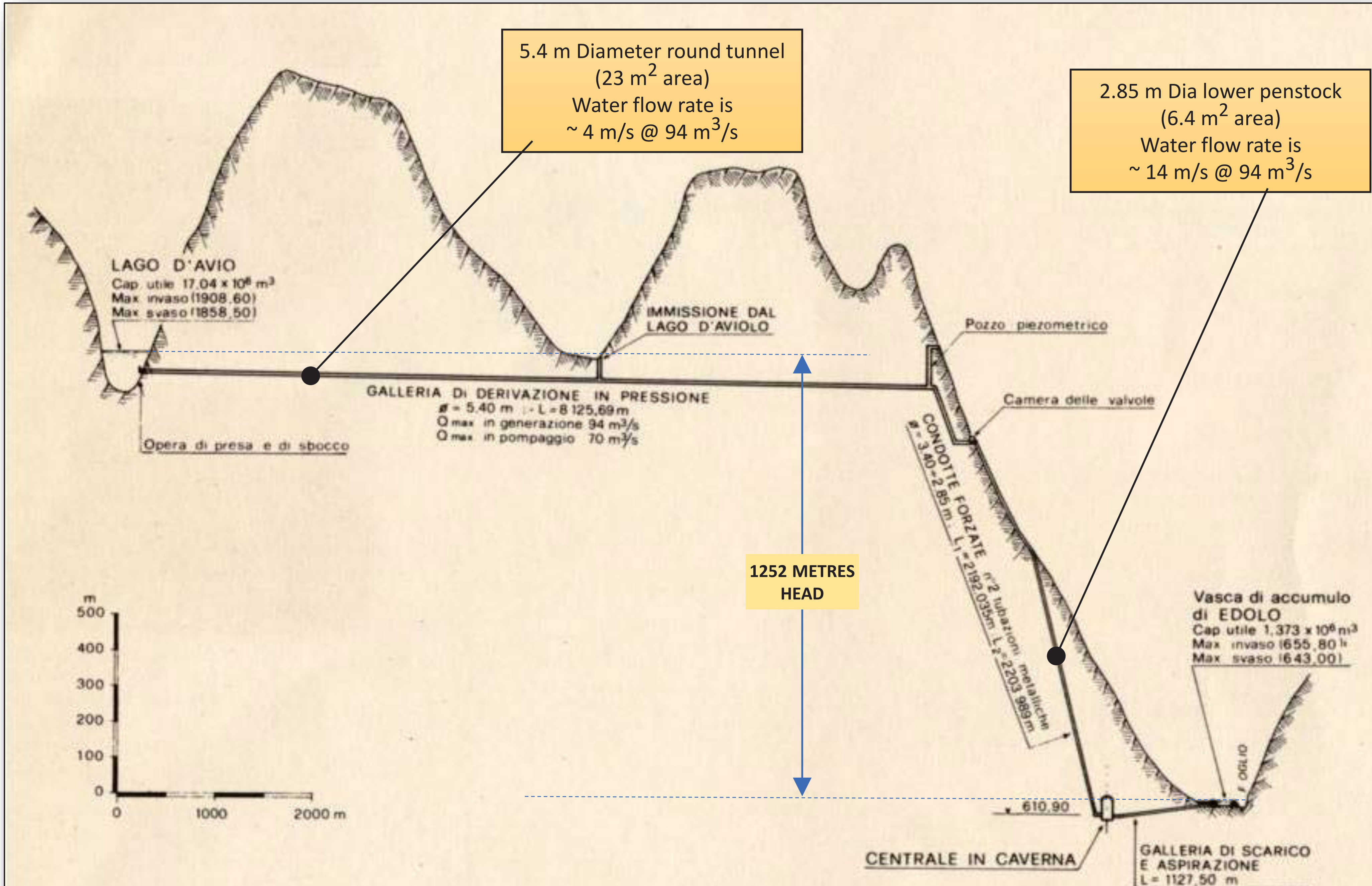


FIGURE A7 – EXAMPLE OF SIMILAR HIGH HEAD PSH – 1,000 MW EDOLO PSH (ITALY)

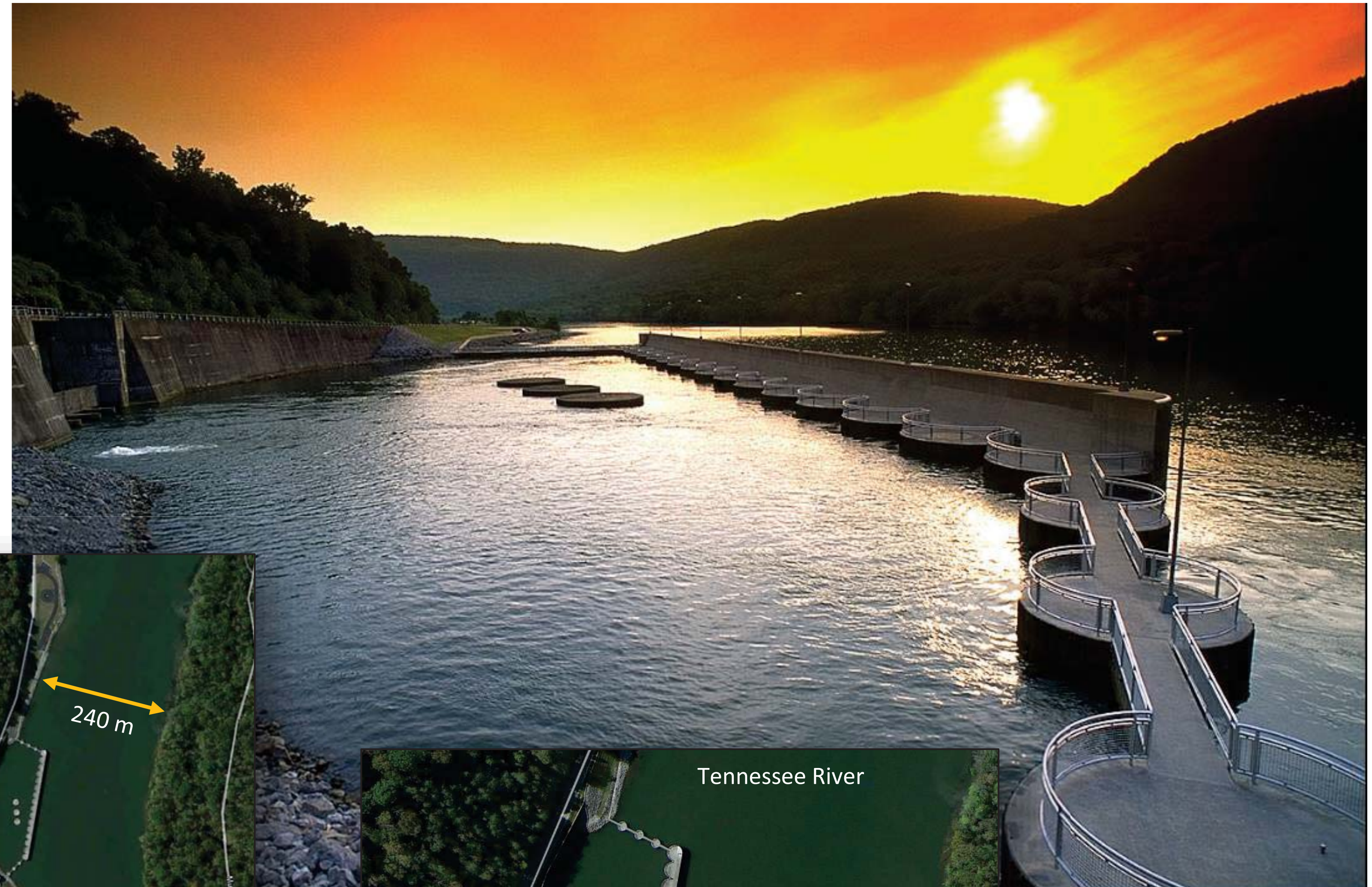
HYDROBATTERY

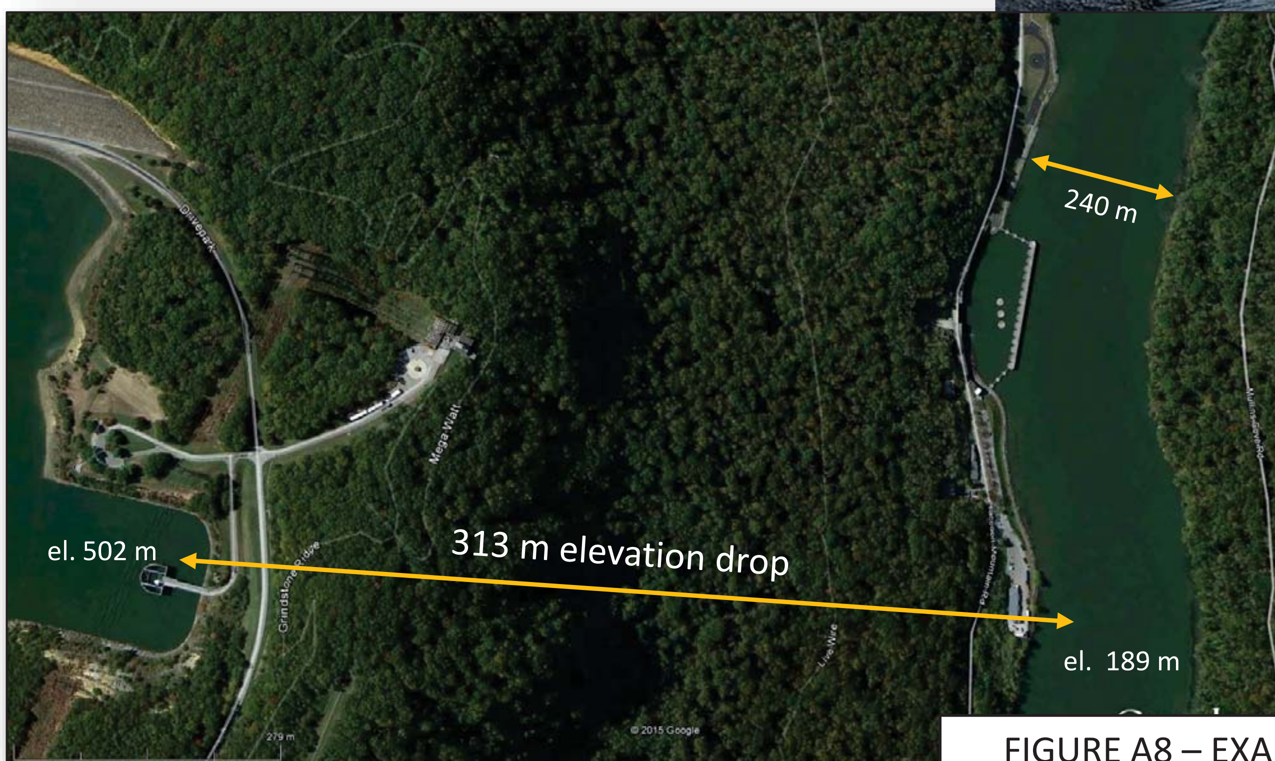
Raccoon Mountain 1,652 MW
Pump-Storage Hydro
Tennessee River Two-Way
Intake-Outflow Facility
Structure to prevent fish entry

Raccoon Mtn has 46 Million cubic metres of water energy storage in their upper reservoir
Therefore, 22 Hours @ full capacity output (1652 MW) = **580 m^3/s**

This is approximately the same maximum water flows as a
6,000 MW Hydro Battery @ full output for ~ 22 hours.

This corresponds with the 4-times head difference 1265 m vs. 313 m





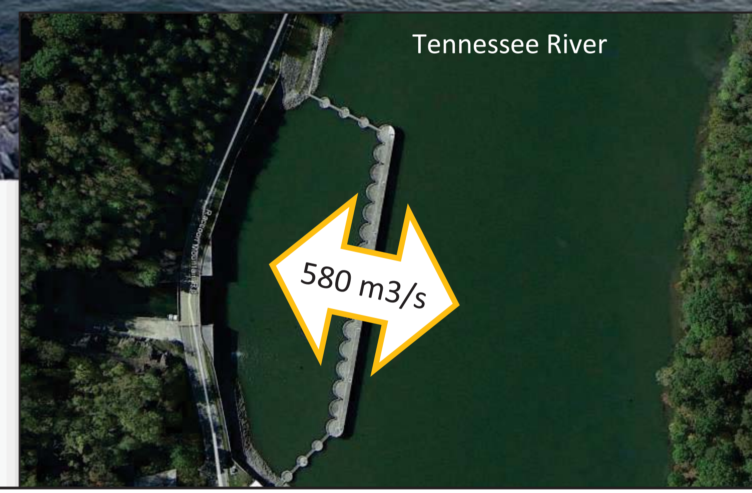
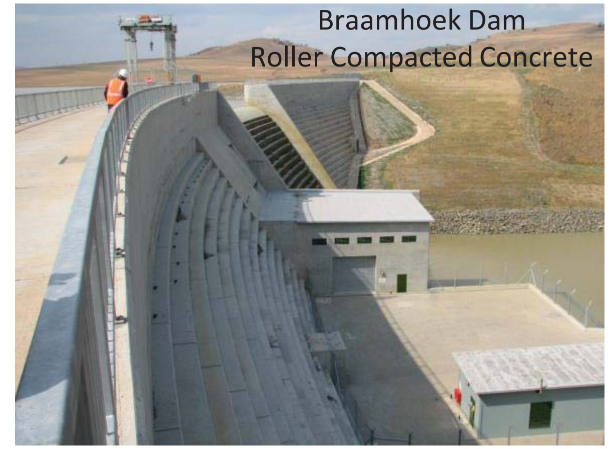


FIGURE A8 – EXAMPLE OF INTAKE/OUTLET STRUCTURE FROM RACCOON MOUNTAIN PSH (USA)



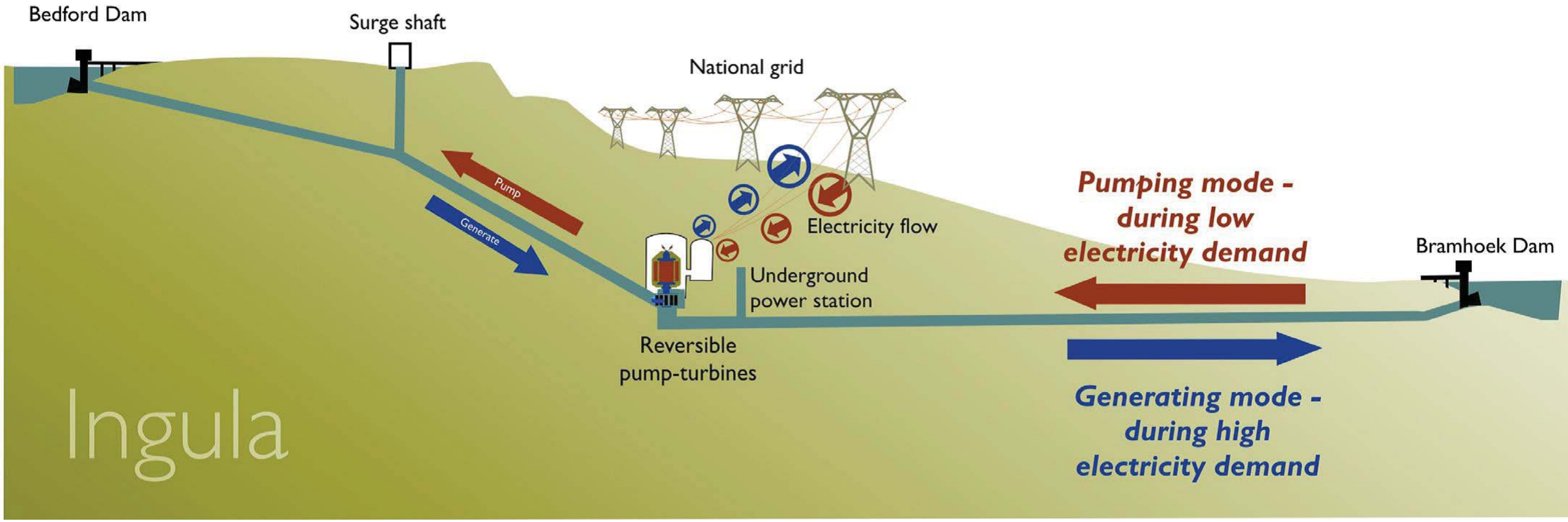


FIGURE A9 – EXAMPLE OF TUNNELS AND RAISEBORES FROM 1,333 MW INGULA PSH (SOUTH AFRICA)

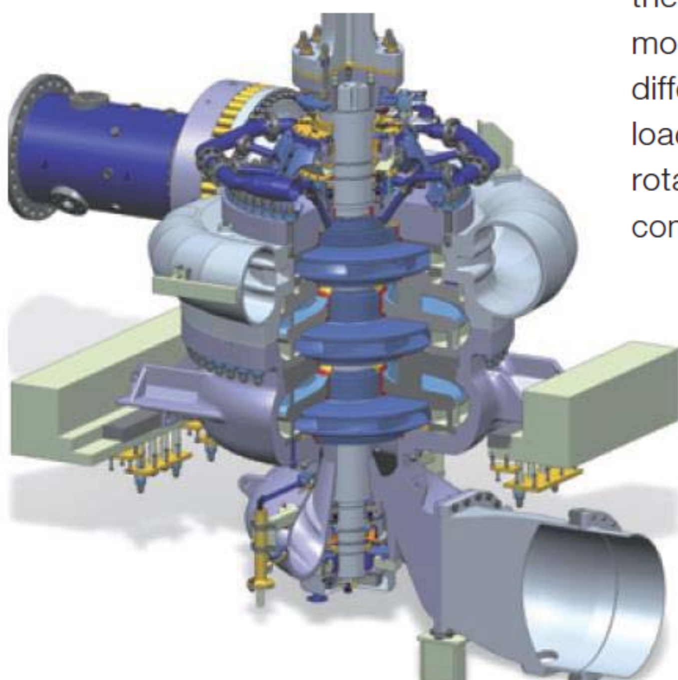
HYDROBATTERY

Voith Ternary Pumped Storage Technology

Ternary sets

Ternary sets consist of a motor-generator, a separate turbine (typically Francis or Pelton) and a pump set. As two separate hydraulic machines, the rotational direction of the motor-generator can be the same in both operational modes. This results in considerable commercial value for the power plant's operation. For switching between turbine and pump operation, the following components can be provided: a clutch operable at standstill, a starting turbine or a synchronizing tourque converter. With the configuration of a ternary set the, so-called hydraulic short circuit within the machine set can be implemented. It offers the best answer for a very fast grid response, being carried out with the torque converter which allows fast change over between turbine and pump mode. Full regulating capability exists in both, the turbine and the pump mode operation from 0% to 100% of the unit output.

Storage Pump, 3D model



Hydraulic short circuit

By using the hydraulic short circuit concept almost the full power range of the plant is available. Moreover, this application helps to control the energy flow into the grid. The principle of this operation mode is based on the idea that only the difference between the constant pump load and the flexible turbine output, both rotating on one common shaft, should come to the grid.

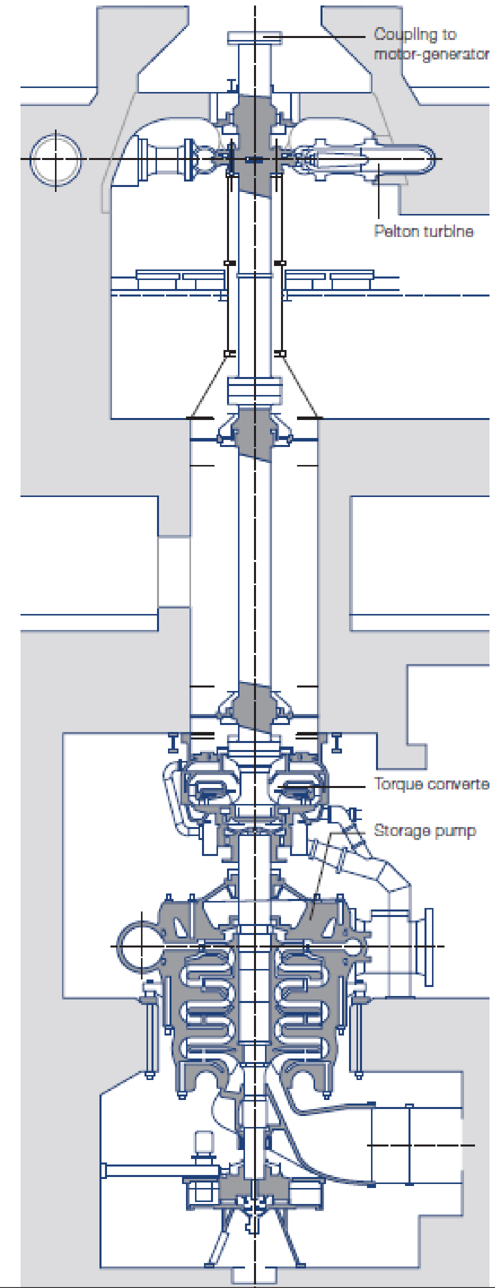
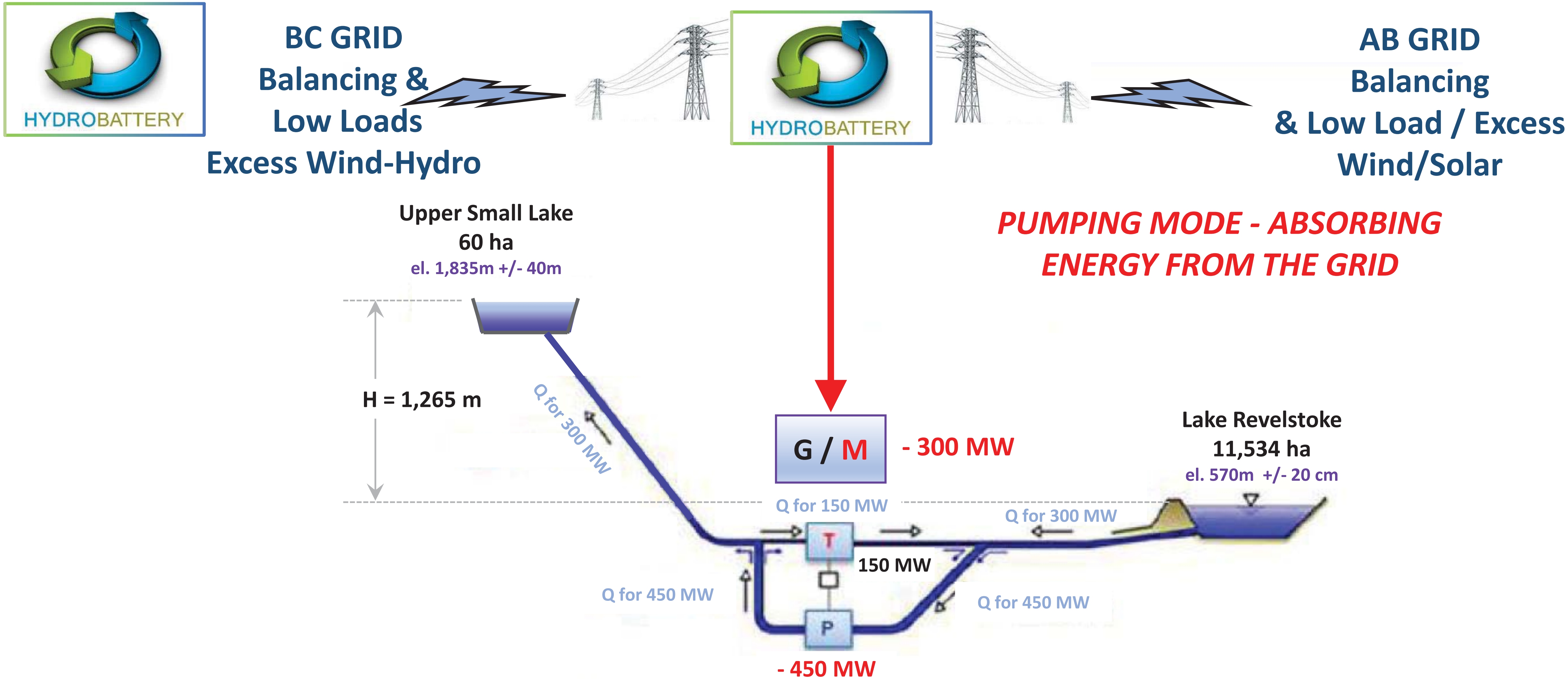


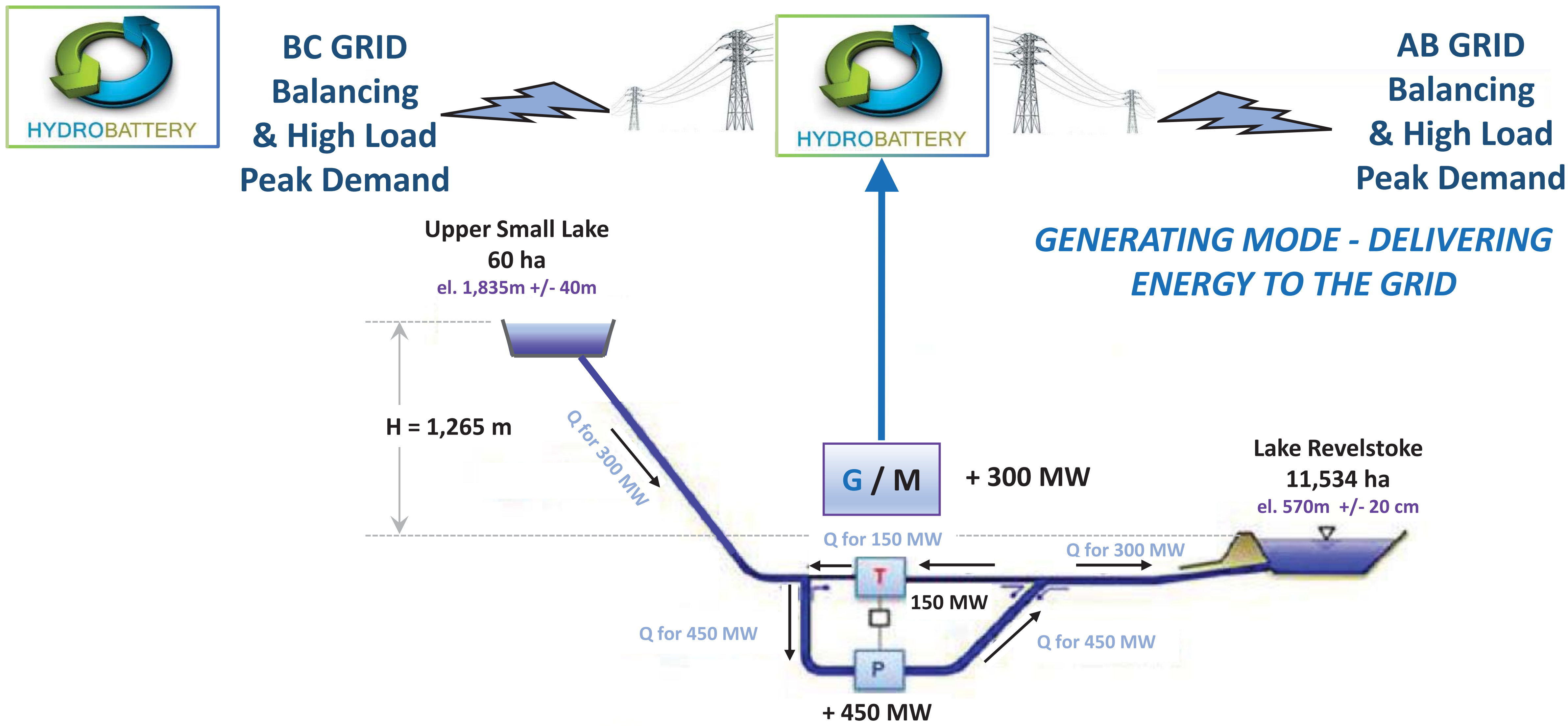
FIGURE A10 – VOITH TERNARY PUMPED STORAGE TECHNOLOGY (COMBINED PELTON TURBINES AND PUMPS)



G/M	Generator/Motor takes 300 MW from grid NET (150 – 450 MW)
T	Turbine generates 150 MW
P	Pump uses / absorbs 450 MW
Q	Flows or Discharges

This load sink process can reverse to generate for grid demands - 300 MW > 0 MW > +300 MW = 600 MW swing in 2 minutes

FIGURE A11 – HYDRO BATTERY PUMPING MODE SCHEMATIC



G/M	Generator/Motor DELIVERS 300 MW NET to the grid (450 – 150 MW)
T	Turbine ABSORBS / USES 150 MW
P	Pump GENERATES 450 MW
Q	Flows or Discharges

This power generation process can reverse to ABSORD for grid demands – + 300 MW > 0 MW > -300 MW = 600 MW swing in 2 minutes

FIGURE A12 – HYDRO BATTERY GENERATION MODE SCHEMATIC

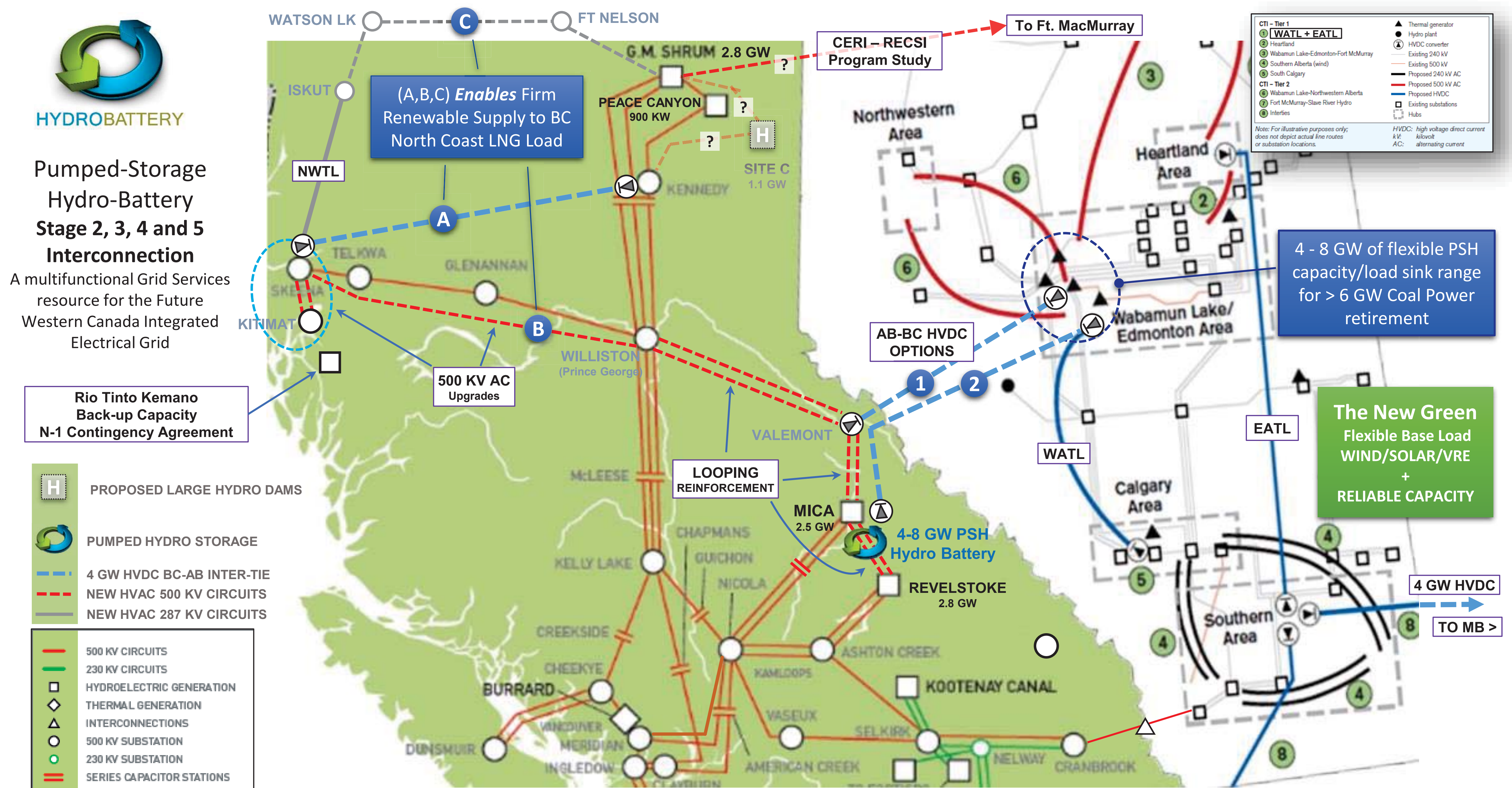


FIGURE A13 – POSSIBLE EXPANSION OPTIONS FOR HYDRO BATTERY TO SUPPORT THE WESTERN CANADA HVDC GRID INTEGRATION PROPOSAL

APPENDIX B

PROJECT DATA TABLES

(Pages B-1 to B-3)

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TABLE 1

HYDRO BATTERY INC.
1,100 MW REVELSTOKE HYDRO BATTERY (PSH)

CONCEPT VALIDATION ASSESSMENT
SITE DATA

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Capacity (MW)	1,100
Number of Units	4
Storage Volume (10^6 x m^3) (5m/20m/40m Dam)	3.8 / 15.2 / 36.0
Lower Reservoir Elevation (m)	572
Upper Reservoir Elevation (m)	1,835
Average Gross Head (m)	1,265
Design Flow in Turbine Mode (m^3/s)	110
Design Flow in Pump Mode (m^3/s)	72
Water Conveyance Length (m)	8,300
Transmission Line (500 kV) Length (km)	135
New Road Length (km)	20.0
Estimated Capital Cost ($ million)	2,400
Unit Cost of Capacity ($million/MW)	2.18

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NOTES:

1. CONCEPTS AS PROVIDED BY HYDRO BATTERY INC. CHECKED BY KP.
2. CAPITAL COST ESTIMATES ARE CONSIDERED ACCURATE TO -50% TO +100%.
3. CAPACITY ASSUMES 10% HEADLOSSES AND 90% MECHANICAL/ELECTRICAL EFFICIENCY.

0	16AUG'17	ISSUED WITH REPORT VA103-606/1-1	MB	RDA	SRM
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

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TABLE 2

HYDRO BATTERY INC.
1,100 MW REVELSTOKE HYDRO BATTERY (PSH)

CONCEPT VALIDATION ASSESSMENT
COST ESTIMATE

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ITEM	DESCRIPTION	SUB-TOTAL ($CAD)
000	PRELIMINARY & GENERAL	$342,000,000
100	ACCESS ROADS	$29,000,000
200	UPPER RESERVOIR, INCL. INTAKE/OUTLET STRUCTURE	$23,000,000
300	WATER CONVEYANCE SYSTEM (TUNNELS, PENSTOCKS)	$281,000,000
400	POWERHOUSE and ANCILLARY SERVICES	$165,000,000
500	POWER GENERATION EQUIPMENT	$722,000,000
600	LOWER RESERVOIR INTAKE/OUTLET STRUCTURE	$17,000,000
700	SWITCHYARD, TRANSMISSION and INTERCONNECTION	$315,000,000
	SUBTOTAL	$1,894,000,000
	EPCM (Engineering) Cost (8% of Subtotal)	$151,000,000
	CONTINGENCY (20% of Subtotal)	$379,000,000
	TOTAL ESTIMATED CAPITAL CONSTRUCTION COST	**$2,420,000,000**

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NOTES:

1. ESTIMATE BASED ON CONCEPT DESIGN FOR THE WATER LICENSE APPLICATION. ESTIMATE IS A CLASS 5 ESTIMATE AS PER AACE (CONCEPT SCREENING, LESS THAN 2% PROJECT DEFINITION, ACCURACY -50% TO +100%).
2. ESTIMATE DOES NOT INCLUDE COSTS FOR PERMITTING, NOR ENVIRONMENTAL COMPENSATION WORKS.

0	16AUG'17	ISSUED WITH REPORT VA103-606/1-1	MB	RDA	SRM
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

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TABLE 3

HYDRO BATTERY INC
REVELSTOKE HYDRO BATTERY PUMPED STORAGE HYDRO PROJECT

PUMPED STORAGE OPERATION WITH VARYING CYCLES AND UPPER RESERVOIR DAM HEIGHTS

8/24/2017 14:27

Calculations for selected live storage (dam) heights	Case 1	Case 2	Case 3
Dam height above water surface at sill (m)	5	20	40
GENERATING MODE			
Rated power (MW):	1,100.00	1,100.00	1,100.00
Gross head (m):	1,265.00	1,265.00	1,265.00
Head losses (%):	10%	10%	10%
Net head (m):	1,139	1,139	1,139
BEP Pelton turbine efficiency (%):	91%	91%	91%
BEP generator efficiency (%):	99%	99%	99%
BEP unit efficiency as turbine (%):	90%	90%	90%
Calculated rated flow (cms):	110	110	110
PUMP MODE			
Rated power (MW):	1,100	1,100	1,100
Gross head (m):	1,265	1,265	1,265
Head losses (%):	10%	10%	10%
Dynamic head (m):	1,392	1,392	1,392
BEP 5-stage pump efficiency:	91%	91%	91%
BEP motor efficiency:	99%	99%	99%
BEP unit efficiency:	90%	90%	90%
Calculated rated flow (cms):	72	72	72
CYCLE DATA			
Number days in cycle (n)	1	4	8
Total cycle time (h):	24	96	192
Time pumping in cycle Tp (h)	14	58	116
Time generating in cycle Tg (h)	10	38	76
Ratio of pumping to generating time over cycle	1.5	1.5	1.5
% cycle time pumping	60%	60%	60%
%cycle time generating	40%	40%	40%
Volume (m3) to generate at rated power for Tg:	3,800,000	15,100,000	30,100,000
Volume (m3) to pump at rated power for Tp:	3,800,000	15,100,000	30,100,000
Dam height (live storage above outlet sill) (m):	5	20	40
Generation over cycle (GWh):	10.5	41.9	83.8
Upper Lake Live Storage (m3)	3,800,000	15,200,000	36,000,000
Upper Lake Energy Stored per Filling (GWh)	10.6	42.3	100.1
Annual generation (GWh/annum):	3,822	3,822	3,822

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NOTES:

1. CASE 1 IS THE BASE CASE USED FOR CAPEX ESTIMATES

1	24AUG'17	ISSUED WITH REPORT VA103-606/1-1	RDA	SRM
REV	DATE	DESCRIPTION	PREP'D	RVW'D