Parametric Analysis of Pump-Turbine Sites

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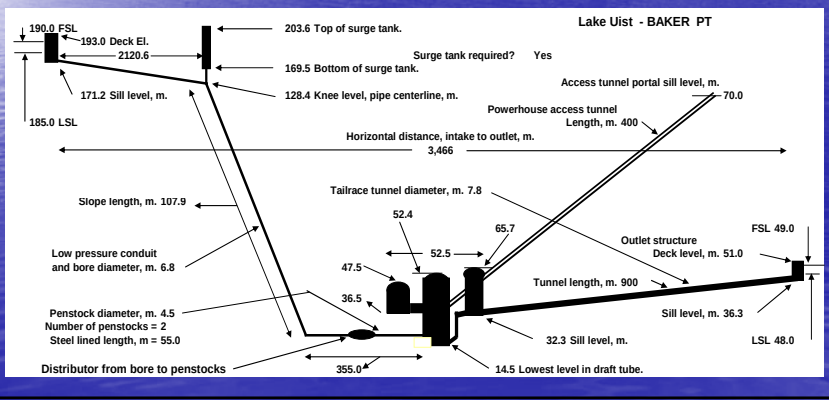


Introduction – reason for paper

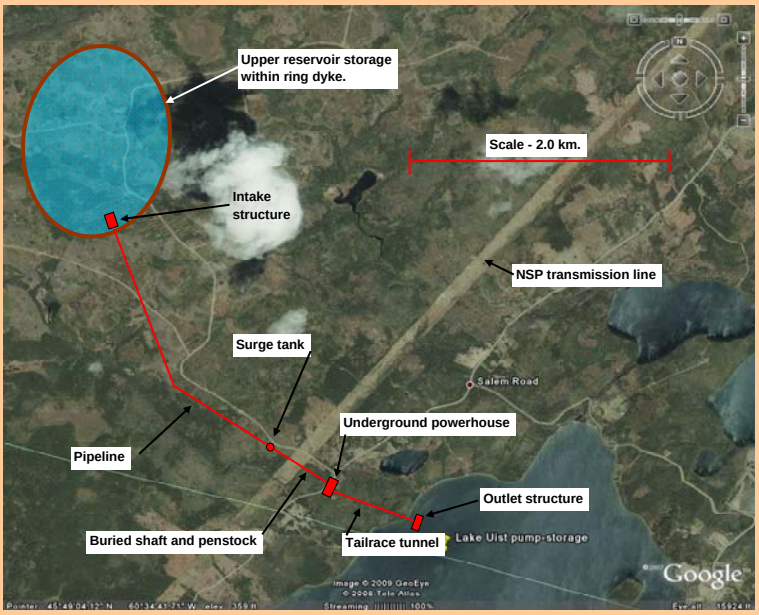
- Author has looked for PT sites in Canada.
- Well over 40 sites identified.
- Economic sites had limiting parameters.
- Limiting parameters were found to be a function of easily identifiable site characteristics.
- And these are investigated in this paper.

Major cost factors for pump-turbine sites -

- Capacity - higher capacities produce lower cost per MW due to the economies of scale.
- Conduit length – from upper intake/outlet to lower outlet/inlet .... shorter conduit = lower costs.
- Developed head - higher heads produce lower costs per MW.
- Energy cost differential - higher differential between the off-peak energy and peaking energy, results in more economic developments.
- Cost of developing storage - lower costs = more economic development – relatively unimportant.

HydroHelp 5 for pump-turbines

- Computer program developed to cost pump-turbine sites.
- 173 inputs – most from Google Earth.
- Output – 3-page cost estimate.
- Output – schematic dimensioned drawings of all structures.
- Output – all project quantities, hydraulics and equipment parameters.
- More details at ⟶ www.hydrohelp.ca



Google Earth Image of Lake Uist pump-storage site with structures added to image.

Demo of HH5 use.

Lake Uist - BAKER PT	150 MW	10-Jan-09

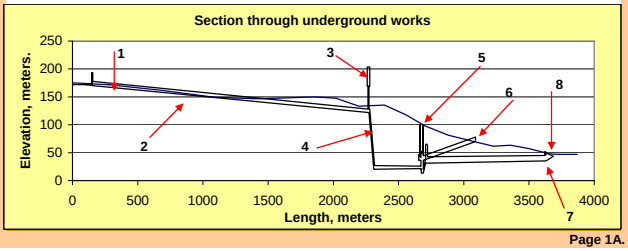
Project parameters determined by program.

Turbine output at rated head and flow, MW.	**76.64**	**Estimated pay-back time not including taxes, years.**	
Powerplant output at rated head and flow, MW.	**150.36**		
Turbine rated net head, m.	**129.54**		**17.7**
Daily maximum generation MWh.	**1,187**		
Corresponding daily power consumption, MWh.	**1,641**		
Overall generating/pumping efficiency factor, %.	**72.4**	# turbines =	**2**
Pump-turbine runner diameters, inlet, m.	**3.901**	Outlet d, m.	**2.602**
Estimated cost, in $M, including interest.	**$574.9**	**$ CAN.**	

Summary of project parameters copied from HH5

Schematic – to scale of underground works, copied from HH5.

1 = Intake and channel.
2 = Low pressure tunnel.
3 = Surge tank.
4 = Shaft or bore.
5 = Powerplant with cable and elevator shafts to surface.
6 = Access tunnel to powerhouse and adjacent galleries.
7 = Tailrace tunnel.
8 = Outlet structure and channel.



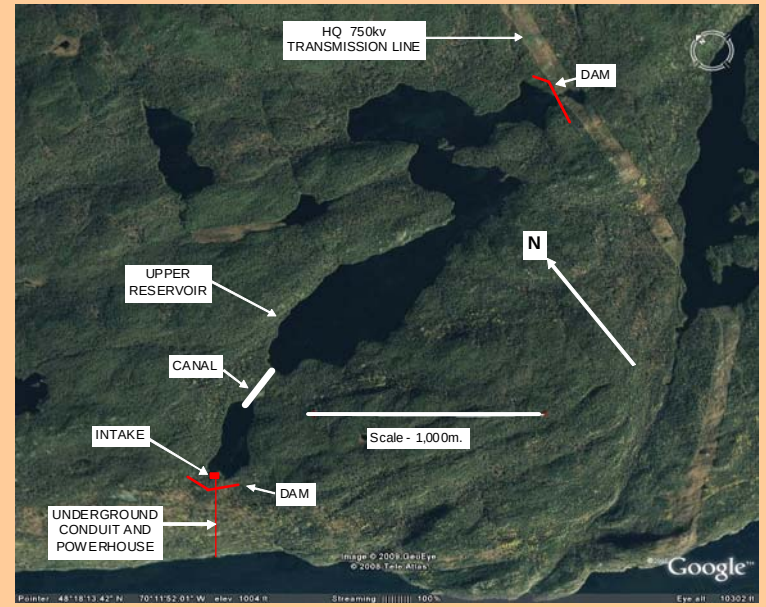
Page 1A.

HH 5 cost estimate for Lake Uist.

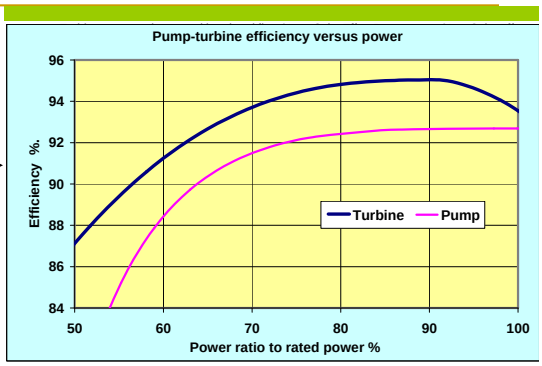
Cost summary copied from HH5

Ballpark cost by quantities in millions $.		
Clearing at structure sites. Ha.	1.444	
Offices - cost per square meter.	0.300	
Sub-total cost of embankment dam and weir spillway.	129.168	
Sub-total intake/outlet civil work cost.	13.287	
Sub-total underground excavation work cost.	70.903	
Upper low pressure conduit surge tank cost, if required.	13.285	
Sub-total pipelines and penstocks.	32.082	
Total powerhouse civil work cost.	22.463	
Total civil work cost, millions $ ---------- >		$282.932
Sub-total cost auxiliary mechanical systems.	7.637	
Sub-total cost electrical equipment, except units and valves.	7.877	
Sub-total cost of electrical equip, except units and valves.	63.217	
Total electro-mechanical component cost, millions $ ---------- >		$78.731
Site access and transmission. ---------- >		$5.427
Feasibility studies and site investigations.	14.418	
Environmental work.	9.083	
Detailed designs and contract documents.	18.712	
Site supervision work.	19.834	
Contingencies on civil and overheads.	87.602	
Contingencies on electromechanical work.	3.937	
Sub-total indirect costs. ---------- >		$153.585
Total project cost, millions $CAN.	**$521**	
Interest rate, %.	6.0	
Estimated construction time, months.	46	
Interest during construction, $M.		$54.25
Total cost including interest, million $.	**$575**	

Saguenay PT site located with Google Earth



Saguenay PT site Unit operating efficiency and project data, as developed by HH5.



Project parameters determined by program.

Turbine output at rated head and flow, MW.	**169.74**	**Estimated pay-back time not including taxes, years.**	
Powerplant output at rated head and flow, MW.	**500.03**		
Turbine rated net head, m.	**300.85**		
Daily maximum generation MWh.	**3,943**		**12.0**
Corresponding daily power consumption, MWh.	**5,088**		
Overall generating/pumping efficiency factor, %.	**77.5**	# turbines =	**3**
Pump-turbine runner diameters, inlet, m.	**3.150**	Outlet d, m.	**1.992**
Estimated cost, in $M, including interest.	**$552.2**	**$ CAN.**	

Jim Gordon 9

Parametric analysis using HH5.

Basic input data 1.

- An installed capacity of 300MW to 1,200MW.
- A gross head of 150m, 300m, 450m and 600m.
- The concrete-lined conduit would include an inclined shaft at 55 degrees from the intake down to the powerhouse, except for very short conduits, where the shaft would be vertical.
- An upper reservoir having a drawdown of 10m and formed with a ring dyke 10m high, with the perimeter length being a function of the required storage volume.
- A lower reservoir assumed to be a large lake at El. 200m, with a nominal drawdown of 1m.

Jim Gordon 10

Parametric analysis using HH5.

Basic input data 2.

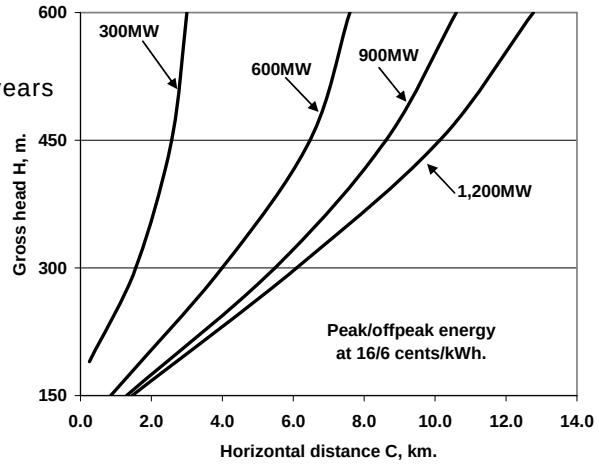
- A powerhouse located at a maximum conduit distance of 3 times head from the intake, to avoid using an upstream surge tank.
- An access tunnel sloping down to the powerhouse at a grade of 12%.
- A surface building at a height of 75% of the gross head above the powerhouse, with a 4-ton capacity elevator down to the powerhouse.
- A nominal 10km of access roads in hilly terrain to the site.
- A 500kV transmission line having a nominal length of 50km.

Parametric analysis using HH5.

8 hour daily cycle.

Payback time = 10 years

Chart shows maximum horizontal distance between reservoirs as a function of head and capacity – with 16/6 cents/kWh energy.

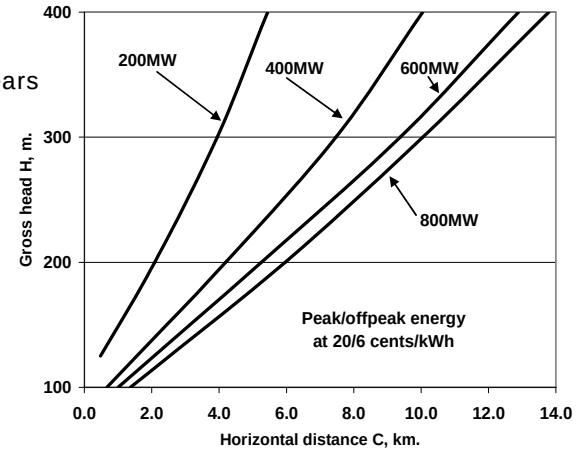


Parametric analysis using HH5.

8 hour daily cycle.

Payback time = 10 years

Chart shows maximum horizontal distance between reservoirs as a function of head and capacity – with 20/6 cents/kWh energy.



Parametric analysis using HH5

for site with underground lower reservoir.

Basic input data –

Cost of off-peak energy in $ per MWh	20
Value of on-peak energy in $ per MWh.	55
Value of capacity in $ per MW per month.	12100

Capacity – 1,000MW in 3 reversible Francis pump-turbines on 8-hour daily cycle.

Gross head = 630m – about maximum.

Underground rock excavation cost = $150/m^3.

Parametric analysis using HH5

for site with underground lower reservoir.

Summary of program output for some parameters.

Overburden excavation, cubic meters.	**63,453**	Rock Exc.	**2,835**
Rock tunnel excavation, cubic meters.	**6,211,942**	Conc, m3.	**61,173**
Steel penstock and tunnel liner weight, tonnes.	**2,541**	Penst. D, m.	**2.371**
Rated turbine flow m3/s.	**45.0**	Pump m3/s	**37.3**
Powerhouse crane capacity, tonnes.	**352**	# cranes =	**1**
Live storage volume, millions of m3.	**5.184**	Stab. Index =	**5.8**
Annual peak turbine energy, MWh.	**1,995,084**		
Annual off-peak pump energy, MWh.	**2,627,732**	**Daily cycle**	

Parametric analysis using HH5

for site with underground lower reservoir - cost.

Ballpark cost by quantities in millions $.		
Clearing at structure sites. Ha.	1.242	
Offices - cost.	0.300	
Sub-total cost of embankment dam and weir spillway.	14.538	
Sub-total intake/outlet civil work cost.	20.451	
Sub-total underground excavation work cost.	992.001	
Upper low pressure conduit surge tank cost, if required.	0.000	
Sub-total pipelines and penstocks.	30.833	
Total powerhouse civil work cost.	29.191	
Total civil work cost, millions $ ---------- >		$1,088.556
Sub-total cost auxiliary mechanical systems.	11.235	
Sub-total cost electrical equipment, except units and valves.	38.596	
Cost of W/W generating equip. TIV, switchgear and controls.	151.169	
Total electro-mechanical component cost, millions $ ---------- >		$201.001
Site access and transmission. ---------- >		$38.488
Feasibility studies and site investigations.	56.352	
Environmental work.	35.502	
Detailed designs and contract documents.	73.134	
Site supervision work.	77.522	
Contingencies on civil and overheads.	342.388	
Contingencies on electromechanical work.	10.050	
Sub-total indirect costs. ---------- >		$594.948
Total project cost, millions $CAN.		**$1,923**
Interest rate, %.	5.0	
Estimated construction time, months.	80	
Interest during construction, $M.		$287.25
Total cost including interest, million $.		**$2,210**

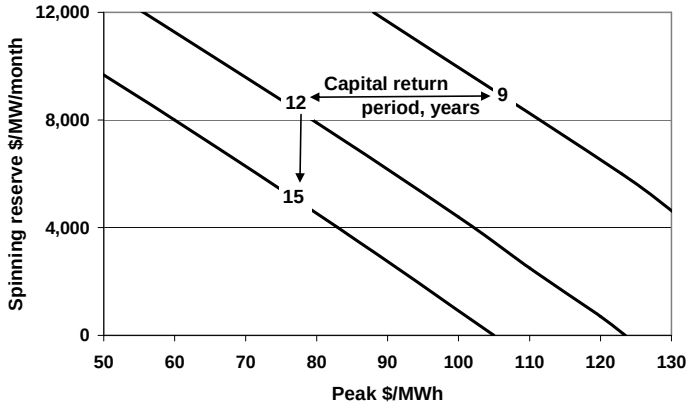
Parametric analysis using HH5

underground work cost for 1,000MW at 630m head.

Underground rock excavations.	Cost $/unit.	Quantity.	Cost $ M.
Powerhouse access road tunnel cost $/m3.	238	256,547	61.007
Vertical shafts for air vents, $/m3.	357	4,532	1.617
Vertical shafts for busbars, $/m3.	357	4,532	1.617
Vertical shafts for elevator, $/m3.	357	4,532	1.617
Powerhouse gallery, $/m3.	238	37,381	8.889
Transformer gallery, $/m3.	238	7,785	1.851
Draft tube gate hoist gallery, $/m3.	238	420	0.100
Upper/lower underground reservoir rock excav, $/m3.	150	5,844,180	873.723
Tunnels and vertical power conduit shaft.	Cost $/unit.	Quantity.	Cost $ M.
Horizontal tunnel rock excavation cost. (m3)	238	7,307	1.738
Horizontal tunnel concrete lining cost. (m3)	1,494	6,527	9.753
Water shaft rock excavation cost. (m3)	357	22,321	7.962
Water shaft concrete lining cost. (m3)	1,992	6,824	13.596
Draft tube horizontal tunnel excavation cost (m3)	238	2,064	0.491
Draft tube vertical tunnel excavation cost (m3)	357	3,330	1.188
Tailrace tunnel rock excavation cost. (m3).	238	17,011	4.045
Tailrace tunnel concrete lining cost. (m3)	1,494	1,880	2.809
Sub-total underground excavation work cost. ---------- >			**992.001**

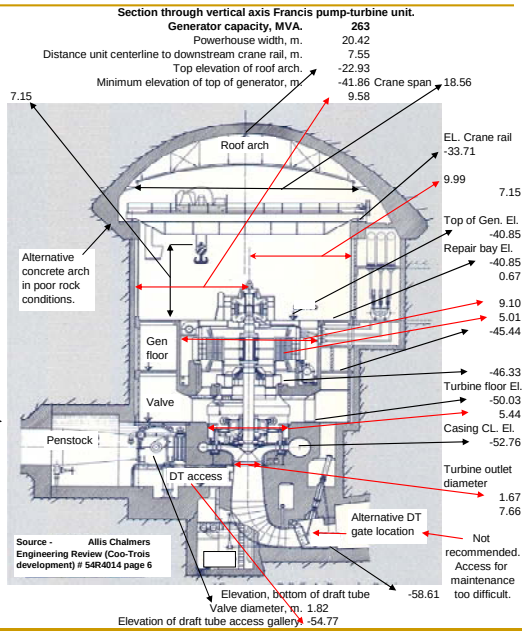
Parametric analysis using HH5

Relationship between value of spinning reserve and peak energy on a base of off-peak energy at $20/MWh, with an underground lower storage.



Parametric analysis using HH5

Generic dimensioned drawing of underground powerhouse – copied from HH5 program.



Parametric analysis using HH5 conclusions.

- HH5 can be used to obtain a pre-feasibility assessment of a pump-turbine site.
- Time required is about 2 to 4 hours per site.
- Site inspection preferable, but not essential for a first appraisal.
- High heads and short conduits produce more economic developments – as expected.
- Underground reservoirs are very expensive.

Parametric analysis using HH5

End of presentation.

Thanks for your attention –

Any questions?