Hunting for High Head Hydro with HydroHelp 3

By

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Abstract.

Several high head run-of-river small hydro plants are currently being developed in British Columbia. Many of the sites were identified with the help of RETScreen®, an award-winning free program obtainable from www.retscreen.net. For more detailed cost assessments of hydro sites, the authors have developed a series of programs called HydroHelp, and the first, HydroHelp 1, for turbine selection is also available free at http://www.hydrohelp.ca. HydroHelp 3 is specifically developed for high head impulse site assessment, and this paper shows how desktop pre-feasibility assessments and cost estimates can be developed using Google Earth and the program, with only a few hours of work. HydroHelp 3 is a Microsoft Excel-based computer program developed with financial help from CANMET (Natural Resources Canada), to evaluate impulse-powered hydro sites. The program occupies just over 8.3MB, and has an input sheet where data from 186 input cells are used to develop a detailed 72-line cost estimate. The program output includes dimensioned generic drawings for all structures, calculates all project hydraulics and selects the most appropriate impulse turbine for the site from 13 types, including Turgo and cross-flow turbines. The program can be used on all impulse sites of more than about 1MW capacity. This paper includes an example on how to use the program to estimate the cost of the 10MW, 455m head site at Chipmunk Creek in south-west British Columbia.

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Introduction.

Both authors developed the original version of the RETScreen® hydro assessment module in 1994. The RETScreen® hydro module is part of the RETScreen® Clean Energy Project Analysis Software – a decision support tool developed with the contribution of numerous experts from government, industry, and academia. The software, provided free-of-charge, can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). The software (available in multiple languages) also includes product, project, hydrology and climate databases, a detailed user manual, and a case study based college/university-level training course, including an engineering e-textbook. RETScreen® has been downloaded by over 160,000 users worldwide since being introduced in 1998.

Unfortunately, many users of RETScreen® are attempting to use the program for more detailed site optimization work than the program can support. To remedy this situation, the authors have co-operated on the development and marketing of a series of Excel-based programs for the design and costing of hydro sites in far greater detail than is possible with RETScreen®. There are presently 6 programs available from http:///www.hydrohelp.ca. Programs 1 to 4 were developed with financial help from Natural Resources Canada’s CanmetENERGY. HydroHelp 1 can be used to select the appropriate turbine from a list of 29 different turbines. HydroHelp 2, is used for costing Francis-turbine sites, HydroHelp 3 for impulse-turbine sites, HydroHelp 4 for Kaplan-turbine sites, all with surface powerplants. HydroHelp 5 for pump-turbine sites and HydroHelp 6 for Francis-turbine underground powerplant sites are also available.

This paper provides a working example showing how HydroHelp 3 can be used on a small high-head run-of-river site at Chipmunk Creek, in south-west British Columbia, currently being considered for development by the Syntaris Power Corporation. Neither of the authors have any connection with Syntaris.

Program input.

The location of Chipmunk Creek, the capacity (10MW) and the energy (42GWH) were obtained from the Independent Power Producers of British Columbia (IPPBC) email notice of their annual conference issued on 21 October 2008. The Chipmunk site location is shown in Figure 1, copied from the notice. The site is located in the bottom left corner. An enlargement of the site, as obtained from Google Earth, is shown in Figure 2, with the locations of the dam, pipeline, penstock and powerplant shown as an overlay. Fortunately, Chipmunk Creek is located in a Google Earth (GE) high-resolution zone, where it is almost possible to identify individual trees, a distinct advantage when undertaking a pre-feasibility study with HydroHelp 3 (HH3).

The first task was to identify the location for the dam and powerplant. These were located by running a profile down the creek with GE, using the software in HH3. By entering elevation, latitude and longitude for up to 24 points down the creek, the program develops the profile. An examination of the profile indicated that the dam should be located near the upper end of the creek, where the creek gradient starts to flatten out at El 2,766ft, Latitude 48-8-11.61, Longitude 121-41-27.05. For the powerhouse site, the GE image was tilted and rotated to find a location where the ground was relatively flat, and this was found at the end of a U-shaped bend in the Chilliwack River, a short distance downstream of the confluence with Chipmunk Creek, at 1041ft, Latitude 49-6-6.75, Longitude 121-39-17.97.

Figure 1.
Chipmunk Creek site as obtained from IPPBC website.

The next task was to locate the pipeline and penstock. The gross head from GE is 1,725ft, or 526m. The conduit length was first measured with the GE ruler, and this preliminary measure was used as a first run on the program, to determine a preliminary level for the intake gate sill and the conduit slope to avoid negative surge pressures. The program, which calculates all hydraulic parameters, indicated that a 15% loss in the conduit would be about the optimum, and the net head would be about 447m. The pipeline was then set to slope down from the intake at a grade of 4% to the start of the penstock at El. 660m. Again, GE was used to develop the conduit profile using the HH3 software, with the pipeline and penstock alignment set to avoid excessive cuts and fills. With the site located on GE, the task of entering all the 186 inputs required by the program could commence. However, this reduced to only 83 inputs since data on such options as embankment dams, tunnels, shafts, surge tanks, and de-sanders was not required for this particular site layout. All inputs could then be easily developed by a hydro engineer with only a few years of experience, by relying on the “comment” cells for advice on inputs (in effect having a senior hydro engineer looking over his/her shoulder while working with the program!). A section of the input sheet is reproduced in Figure 3, showing input data for the intake and pipeline. The ruler option in GE was again used to determine the side-slope on the pipe and penstock, for entry on lines 145 and 146.

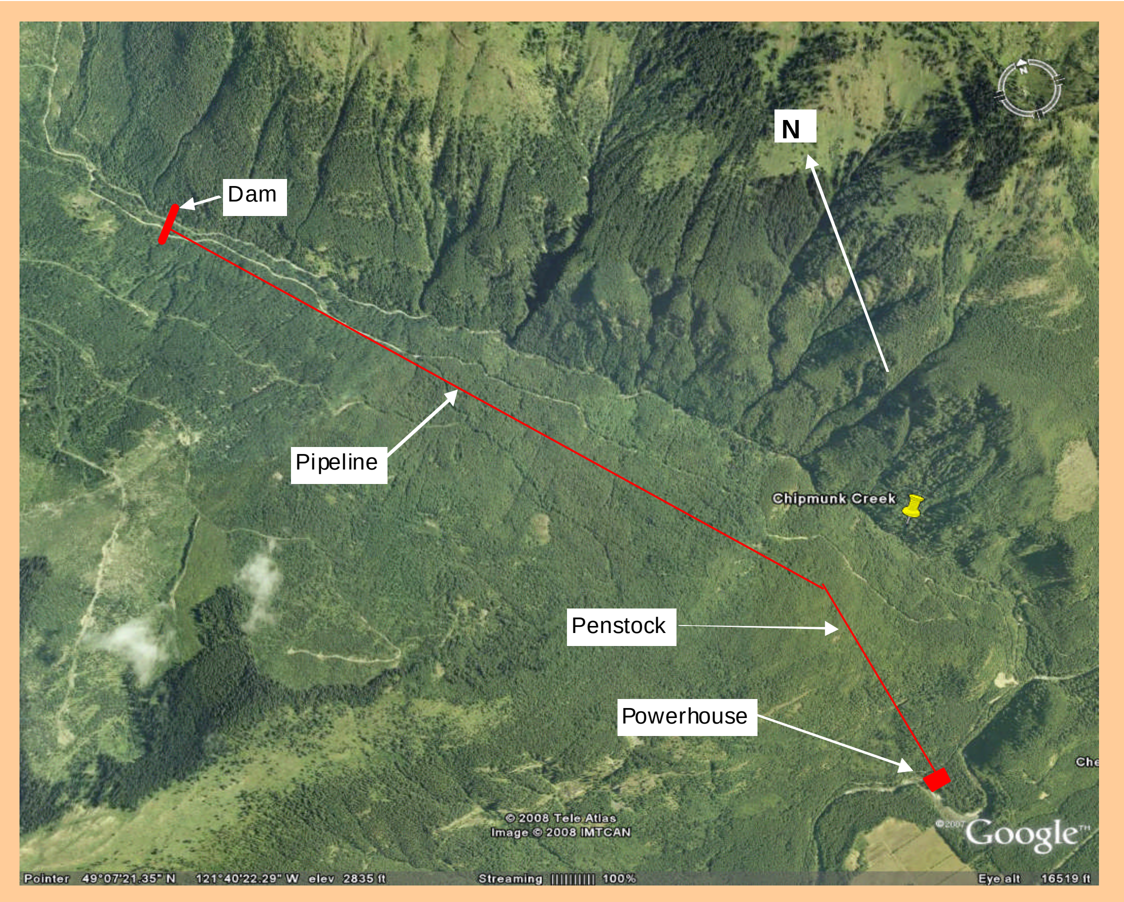

Figure 2.
Chipmunk Creek site as obtained from Google Earth with site layout overlay.

The conduit input requires an estimate of the excavation length in rock and in earth, for the buried pipeline and penstock. This was assumed to be 1/3 rock and 2/3 earth based on experience on other similar small hydro projects in BC. A drive along the forestry road adjacent to the creek, clearly visible in the Google Earth image in Figure 2, would be required to arrive at a more accurate assessment. The side-slope roughness factor can vary between 1.5 and 3.0. This factor (line 147) takes into account the fact that the conduit cannot exactly follow the desired grade without some additional cut and fill at bends. An optimistic assessment would be 1.5, and if the hillside was very rough, the factor could increase to about 3.

Beside each input cell, where some instruction on data entry may be needed, there is a comment cell, which opens when the cursor is positioned on the cell. For example, the comment cell on line 137 in Figure 3 has the following instruction *"The loss through racks is usually higher than expected due to partial blockage by debris. Select a minimum blockage ratio of 0.15 where there is no automatic raking. Use 0.05 where auto raking."* The program can thus be used without a manual. The program has many safety over-rides wherein warnings appear for details such as too high a surge tank, negative quantities, too small a conduit, incorrect net head, and so forth. The program can be used in either a manual mode, or an automatic mode. In the automatic mode, the program will select the optimum pipe and penstock diameter, calculate all hydraulic losses, waterhammer pressures, governor times and select the least cost turbine from a range of 13 impulse units, including Turgo and cross-flow turbines. The selected turbine can be de-selected by the user, and the program will then revert to the next least cost unit. For the pipeline, the program will select a HDPE pipe if within the suitable range for such pipe diameters and pressures. For North America, all unit prices for the civil work are computed and used in the detailed cost output. For new users, it would be wise to “benchmark” the program by running the program on an existing site where costs and quantities are known, and then comparing the results. This will show whether the costs and quantities as developed by the program are reasonable, and where changes may be necessary. Since the program is not protected, changes are possible at the user’s option.

127				
128	**Intake.**			
129	**Length of intake channel, meters.**	5.0		Comment
130	**Average level of rock at intake, meters.**	842.0	Should be >	840.76
131	**Average depth of overburden excavation at intake, meters.**		2.0	
132	**Normal FSL at trashracks, m. (by program)**	847.30	**Trashr. LSL, m**	844.00
133	**Water cleanliness factor. (0.5 to 1.0)**	0.90	Comment	
134	**Percentage of reservoir cleared. (10% to 100%)**	0	Comment	
135	**Approach flow angle to racks. (45 to 0 degrees)**	10	Comment	
136	**Rack inclination to horizontal. (60 to 90 deg.)**	80	Comment	
137	**Rack blockage ratio. (0.0 to 0.25)**	0.2	Comment	
138	**Intake pipeline concrete encased length, m.**	5	Comment	
139				
140	**Pipeline intake to surge tank.**			
141	**Pipeline on surface (1) or buried (2).**	2	Comment	
142	**Pipe length in rock sidehill, m.**	1100		
143	**Pipe length in earth sidehill, m.**	2580		
144	**Elevation of end of pipeline, m.**	660	Comment	Read comment
145	**Average sidehill slope in rock, hor. to 1 vert.**	2.1	Comment	
146	**Average sidehill earth slope, horiz. to 1 vert.**	2.3	Comment	
147	**Sideslope roughness factor. (1.5 to 3.0)**	1.5	Comment	
148				

Figure 3.
HydroHelp 3 input data for intake and pipeline.

In the manual mode, the user has to turn off the automatic iteration function in EXCEL and then has the option of selecting any other combination of pipe and penstock size. Also, any other unit cost can be entered for the civil works. The program will calculate all project hydraulics and display an index of energy cost, so that the user can optimize conduit sizes. An over-ride within the program prevents the selection of too small a conduit.

A schematic of the HDPE alternative is included in Figure 4. For Chipmunk, the program selected a pipe diameter of 0.981m, well within the range of HDPE pipe, and used an HDPE length of 1,957m. Penstock diameter is 0.804m, all in steel.

The input includes the option of either a “Utility” or “Industrial” design standard. The former would generate a higher cost due to the much higher design, construction, project documentation and testing standards required by a utility. Conduit losses would also be lower, due to the use of a larger conduit (in the automatic mode) and corresponding higher energy output, due to the higher costs permissible with lower returns on capital accepted by utilities.

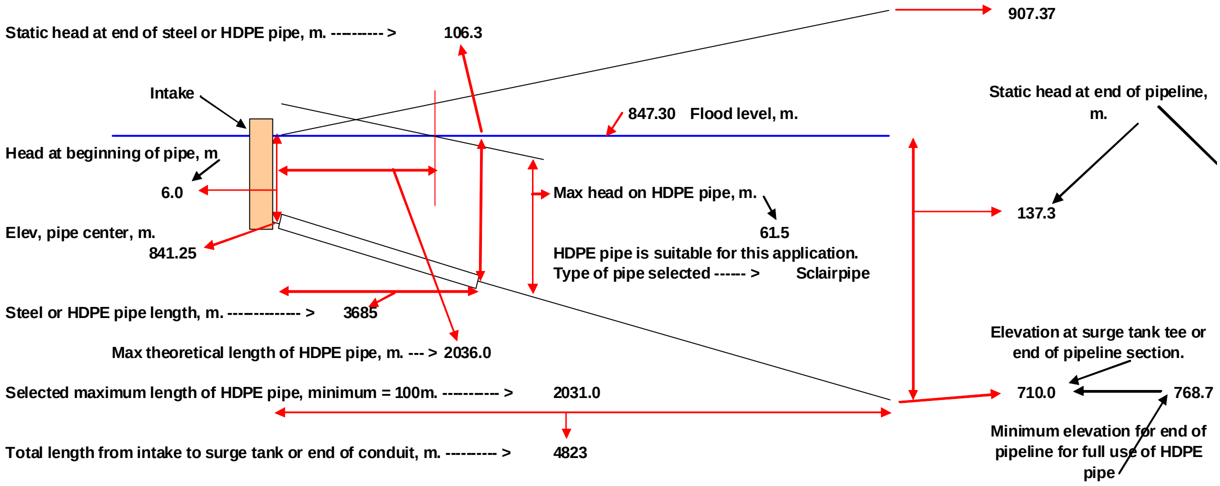

Figure 4.
Program schematic showing calculation of HDPE pipe length.

Program output.

The program output is very comprehensive and can be printed on 22 pages. A full copy of the Chipmunk output can be seen on the HydroHelp website (www.hydrohelp.ca). The program calculates everything from the dam rip-rap (D_{50}) size to trashrack bar spacing and the required capacity of the powerhouse crane. An example of the program output for the powerhouse in shown in Figure 5.

49				
50	**Powerhouse and crane data.**			
51	Powerhouse crane capacity, tonnes.	20.86	# of cranes	1
52	Powerhouse crane span, with crane over valve, m.	7.42		
53	Powerhouse length, m.	22.40		
54	Powerhouse width, m.	8.14	Walls, m2	401
55	Powerhouse height, repair bay floor to roof, m.	6.57	Roof, m2.	182
56	Powerhouse roof elevation, m.	329.07		
57	Powerhouse concrete volume, m3.	265.78	PH Vol, m3.	1198
58	Powerhouse formwork, m2.	318.94		
59	Powerhouse structural steel weight, tonnes.	53.41		
60	Powerhouse repair bay floor level, m.	322.50		
61	Distance between unit centerlines, m.	8.56		
62				

Figure 5.
Program output, part of sheet TURB+PH.

The program does not include any hydrology or financial analysis. Hydrology programs are available from other sources and all developers have their own methodology for financial analysis. Also, the RETScreen® financial analysis and hydrology functions can be used with costs based on the HH3 detailed 3-page, 72-line cost output, with quantities and unit prices. The unit costs are developed for North America and are a function of frost days at the site, union or non union labor, and quantity of work. The user has the option to use any other unit price based on their experience. The output also includes dimensioned generic drawings for all the structures.

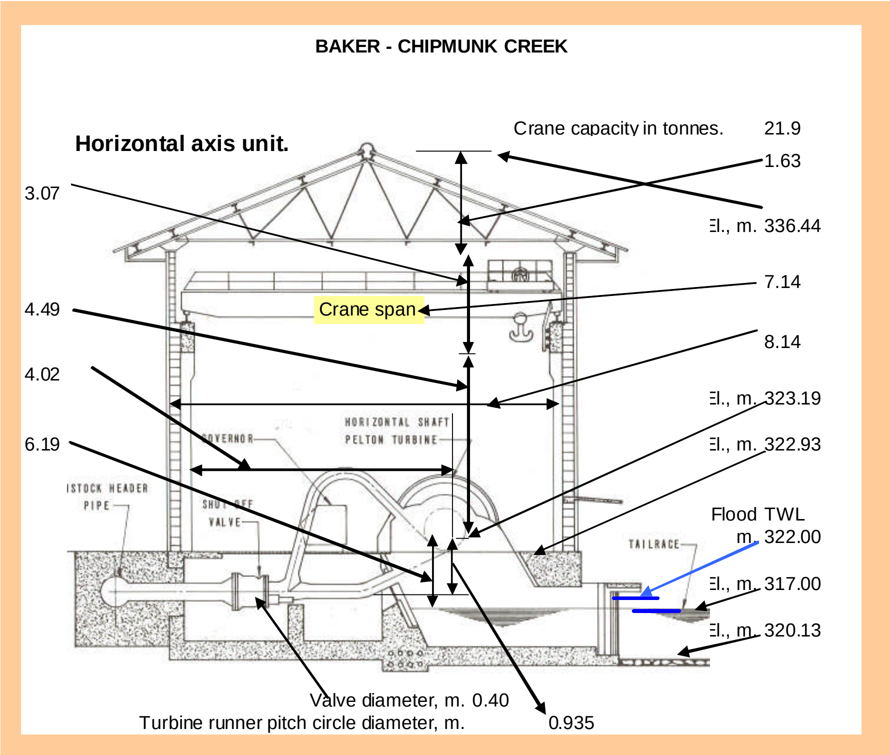

Figure 6.
Section through 2-unit Chipmunk Creek powerhouse.

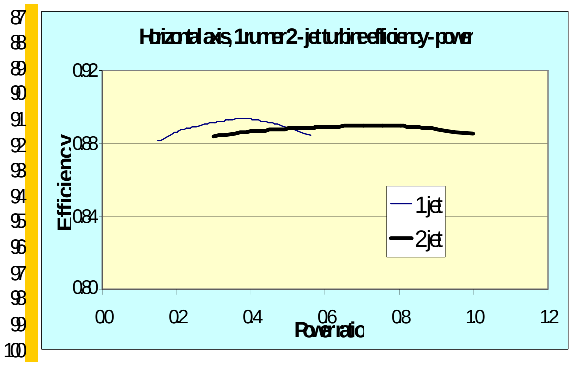

Figure 7.

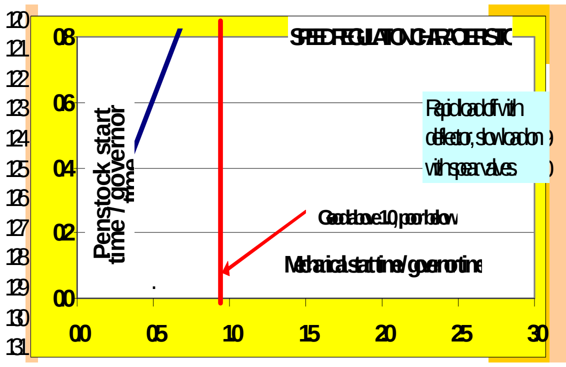

Figure 9.

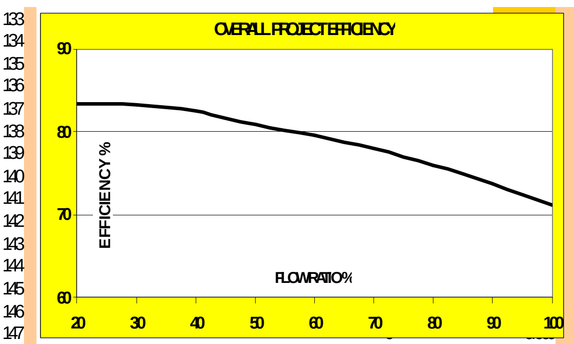

Figure 8.

Figure 7. Efficiency chart for the 5MW, 454.8m net head, 2-jet horizontal axis impulse turbine.

Figure 8. Overall efficiency chart, includes the generating unit and penstock losses.

Figure 9. Chart indicating speed regulation capability when operating isolated from the utility transmission system.

The Chipmunk powerhouse section as developed by the program is shown in Figure 6. Charts showing unit performance are also produced as shown in Figures 7, 8 and 9. The data in Figure 9 is used to develop a comment on isolated operation shown on Line 34 of Figure 11.

A summary of the cost estimate is developed for inclusion in a pre-feasibility report, and is reproduced in Figure 10. Interest is based on an estimated construction time of 14 months, as shown in Line 35, Figure 11. Finally, the program generates a summary of the more important program outputs in a format suitable for inclusion on a full page in the pre-feasibility report. Part of this summary is included in Figure 11.

BAKER - CHIPMUNK CREEK Estimated cost, in millions of dollars. CAN $	Estimate date	12-Nov-08
Clearing for all structures.	0.36	
Access roads and bridge.	7.82	
Embankment dam.	0.41	
Side stream approx. total cost, including intake and equip.	0.00	
Intake, de-sander and weir spillway.	2.41	
Tunnels and vertical bore.	0.00	
Surge tank cost, if required.	0.00	
Steel pipelines and penstocks.	4.24	
Tailrace.	0.05	
Powerhouse.	1.06	
Sub-total civil work including access.		16.36
Ancilliary mechanical equipment, summary.	1.14	
Substation cost, disconnects and transformer.	0.12	
Transmission lines.	1.31	
Generating equipment, inlet valve, switchgear and controls.	6.11	
Sub-total electromechanical and transmission work.		8.68
Feasibility studies and site investigations.	0.50	
Environmental work.	0.51	
Detailed designs and contract documents.	0.52	
Site supervision work.	1.06	
Civil contingencies and unforseen cost allowance.	4.06	
Electromechanical contingencies.	0.59	
Interest during construction.	1.04	
Sub-total overheads and interest.		8.28
Total project cost in millions of $ ----------------------------- >	33.3	CAN $

Figure 10.
Cost estimate summary for Chipmunk Creek.

For sites outside North America, the program can be used in two ways. One is to first "benchmark" the program by using it to cost an existing site, and then change the unit costs to obtain a match with the known site cost. The other method is to alter the program to include a dual currency option, for $US (or other convertible currency) and the local currency. All civil work costs would then be in two currencies, and the value of each unit cost would again have to be obtained from experience on other similar hydro projects.

A major benefit in the program is the opportunity to undertake "what if" exercises. For example, only one cell needs to be changed to select the number of units. If one unit was required, the cost would increase to $36.5M. Two would cost $35.4M and three would cost $37.9M, quickly indicating that 2 units are the optimum. If a vertical axis unit is preferred, the 4-jet single unit project would cost $36.7M. The user also has the option of using different pipe and penstock diameters, and the program will calculate hydraulic losses and cost along with an index of energy cost so that the user can see if the option is more economic. If a “Utility” design standard was required, the cost would increase to $40.3M, and the output would increase to 10.34MW for the same flow.

For projects where there is storage, and this is a function of dam height, the program calculates the water use in cubic-meters-years, so that the use factor can be changed to match the hydrology data. The program is open and not protected, so that the user can see how the data is calculated, and perhaps change the algorithms to suit their preferences.

BAKER - CHIPMUNK CREEK		Date --	12-Nov-08
Project parameters determined by program.		**Executive summary**	
Turbine output at rated head and flow, MW.	**5.13**		
Powerplant output at rated head and flow, MW.	**9.83**		
Turbine rated net head, m.	**454.86**		
Conduit average diameter, m.	**0.922**		
Powerplant average annual generation, GWh.	**42.3**		
Estimated cost, in millions of dollars.	**$33.3**	**CAN $**	
Summary of input data for project.			
Number of turbines and flow in m3.	**2**	Flow, m3	**2.60**
Access road and transmission lengths, km.	**1.2**		
Headpond full supply level, m. (FSL)	**847.30**	LSL =	**844.00**
Normal tailwater level at powerhouse, m.	**317.00**	Trans. km.	**1**
Number of water conduits to powerhouse.	**1**	Length to head	
Conduit length, intake to powerhouse, m.	**4,823**	ratio ------ >	**10.6**
Summary of program output for some parameters.		Powerplant utilization	
Overburden excavation, cubic meters.	**28,907**	factor, %	**46.0**
Rock tunnel excavation, cubic meters.	**0**	Rock Ex. m3.	**5,459**
Steel penstock and tunnel liner weight, tonnes.	**689**	Turbine runner outside	
Total concrete volume, cubic meters.	**2,630**	diameter, m.	**1.19**
Turbine type selected by program.	**Horizontal axis, 2 jet, 1runner impulse turbine.**		
Turbine type eliminated from consideration during operation of program.	**None.**		
Powerhouse footprint, width and length, m.	**8.1**	Length, m	**22.4**
Overall turbine + generator + transformer + conduit efficiency at full load, %.			**71.07**
Average overall project efficiency, excluding transmission, for energy calc. %			**78.76**
Head loss in conduit as a % of rated net head on turbine --------- >	**14.98**	**Comment**	
Speed regulation on an isolated system.	**Absolutely no speed regulation capability.**		
Estimated time required for construction, months.	------------------------------------ >		**14**
Data input and options selected during data input, may vary for each alternative.			
Surge tank on conduit.	**No**	Diam., m.	**0.00**
Turbine equipped with inlet valve.	**Yes**	Diam., m.	**0.395**
Conduit optimization option.	**By program**		

Figure 11.
Executive summary data from program.

Conclusions.

HydroHelp 3 is a comprehensive Excel-based program that can be used to produce a desktop study, at a pre-feasibility level, for impulse-powered hydro sites. It is particularly useful for the initial assessment of several sites, to determine the most attractive alternative, and to rapidly undertake assessments of alternative layouts. As experience with use of the programs is gained, and as comments from users are received, the programs are being changed and expanded. The latest “Baker” series was issued in January, 2009.

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The program algorithms are based mostly on published data as listed below. Some algorithms are based on data in the Montreal Engineering “Manual of Hydraulic Engineering Practice,” second edition, August 1980.

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