Rapid Hydropower Assessment Model
Identify Hydroelectric Sites Using Geographic Information Systems

By Ron Monk, M.Eng., P.Eng.; Stefan Joyce, P.Eng.; and Mike Homenuke, P.Eng.
Kerr Wood Leidal Associates Ltd., Burnaby, BC Canada

ABSTRACT

The ability to identify renewable energy resources is of paramount importance in reducing fossil fuel dependency and addressing climate change. The Rapid Hydropower Assessment Model (RHAM) uses a Geographic Information System (GIS) to identify hydroelectric power opportunities. Using a Digital Elevation Model (DEM) and regional hydrologic data, RHAM calculates the amount of hydroelectric power available on all streams in a study area, screening out sites within parks and environmentally sensitive areas, and estimates project costs. RHAM can also assess the suitability of hydroelectric development in a given area, taking into account economic, environmental and social factors, and can assess storage hydro and clustered developments.

In 2007, RHAM was used to assess run-of-river hydroelectric potential for the Province of British Columbia, Canada, an area of approximately 95 million hectares. Over 8,000 potential hydroelectric opportunities were identified. The Consulting Engineers of British Columbia recognized RHAM with an Award of Merit in 2008. RHAM is being applied in other parts of the world to unlock hydroelectric potential, reduce carbon fuel dependence, and help ensure a sustainable energy future for the world.

INTRODUCTION

In 2007, BC Hydro and the BC Transmission Corporation (BCTC) retained Kerr Wood Leidal Associates Ltd. (KWL) to conduct an inventory of potential run-of-river hydroelectric sites in British Columbia, Canada. KWL completed the hydroelectric resource assessment using the Rapid Hydropower Assessment Model (RHAM), a Geographic Information System (GIS) program developed by KWL. KWL completed the assessment in four months; without RHAM, the assessment would have taken over a year.

Over 8,000 potential run-of-river hydroelectric sites with a potential installed capacity of over 12,000 MW and annual energy of nearly 50,000 GWh per year were identified. Figure 1 shows the location of these sites with their associated size and estimated unit energy cost range.

KWL estimated the cost for each project, which included access roads and power lines to connect to the BC Hydro/BCTC power system. Using capital cost and annual energy estimates, the unit energy cost was estimated for each project. The projects were then ranked to produce the supply curve of run-of-river hydroelectric potential for British Columbia presented as Figure 2.

RHAM, a GIS application, provides several key capabilities for hydroelectric applications. Nearly all aspects of a hydroelectric project can be spatially referenced to a geographic location, and the attributes of that project or location described using a database. RHAM can link data to a geographic location and enables engineers to develop computational models that significantly increase the speed at which large volumes of data are processed into useful information.

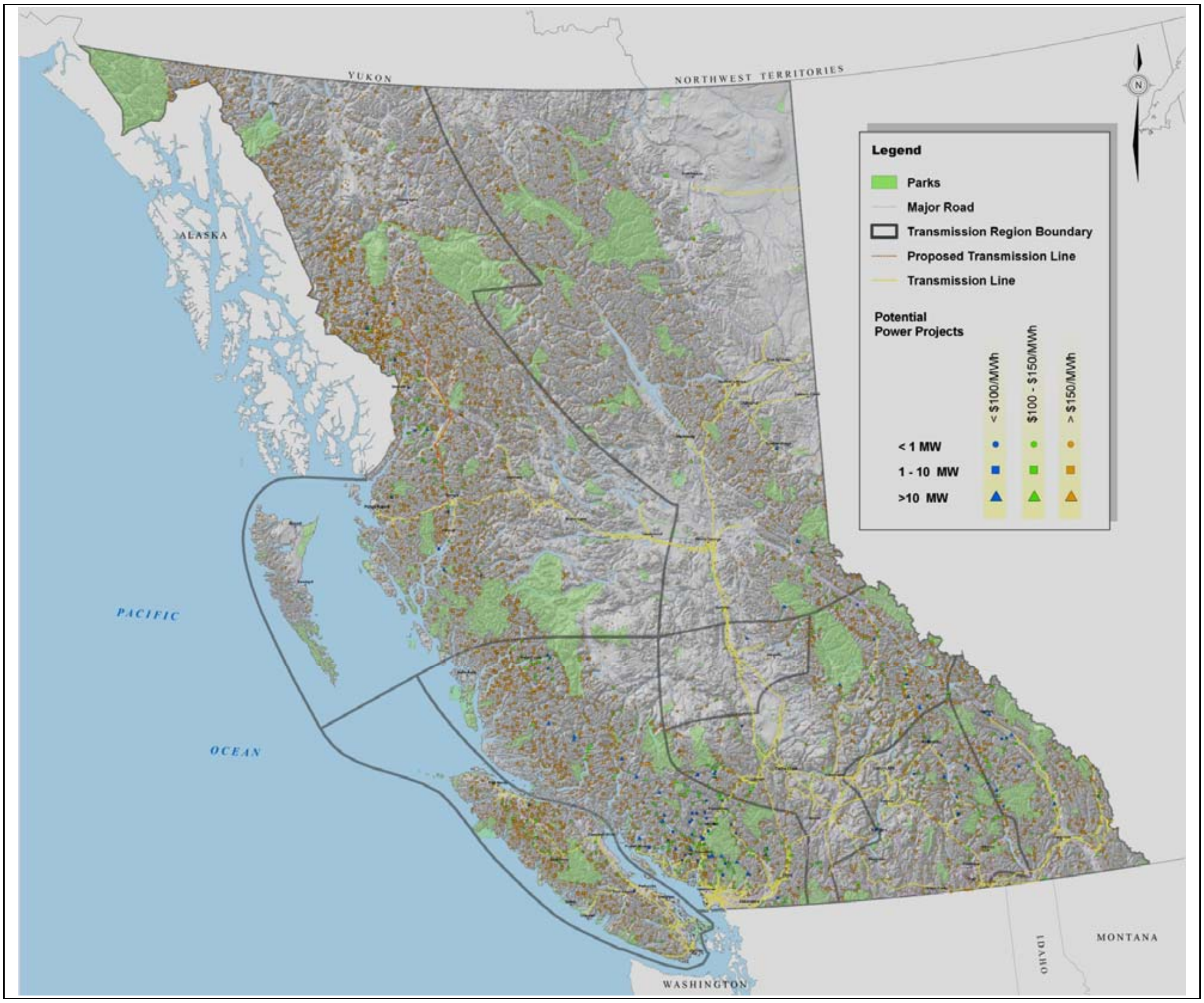

Figure 1: Run-of-River Hydroelectric Potential in British Columbia, Canada

Using RHAM, KWL analyzed every stream in 100 m sections, identifying potentially good locations for projects. This information was then used to estimate the size and cost of hydroelectric projects. Using RHAM's GIS capabilities, this information was quickly compared with ecological mapping and land use information to determine site suitability.

For linear infrastructure such as roads, penstocks and power lines, RHAM can locate optimal alignments and estimate costs by analyzing slope, geology and land cover datasets.

METHODOLOGY

Run-of-river hydroelectric facilities use the water flow and elevation drop (i.e. head) of streams to generate power. This type of hydroelectric project can be constructed with a small diversion dam (i.e. intake) to direct water from the stream channel into a penstock (i.e. pipeline) that conveys flow to a powerhouse. A turbine and generator in the powerhouse convert the potential energy into electricity, and the water is returned to the stream.

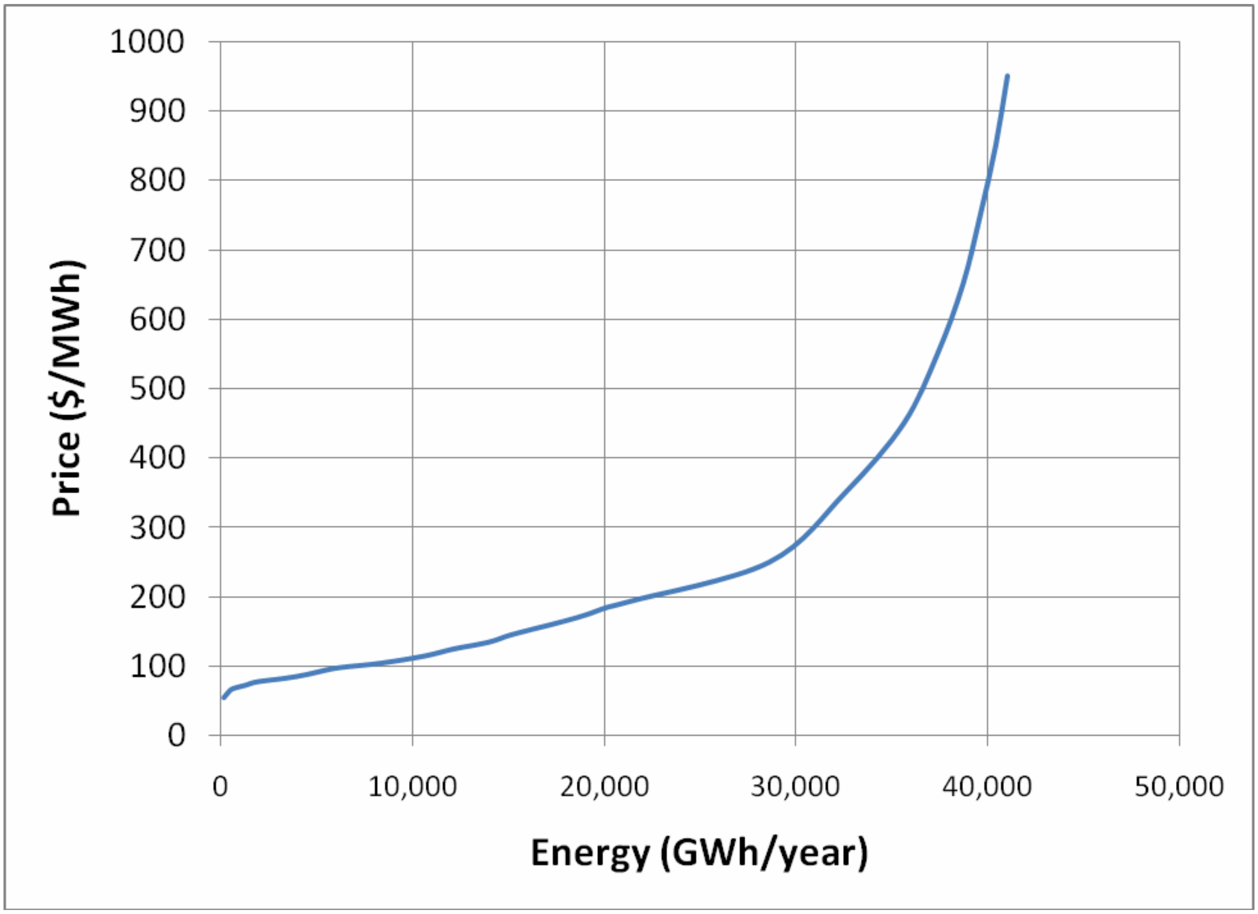

Figure 2: Run-of-River Hydroelectric Supply Curve for British Columbia, Canada

Several steps are involved in assessing hydroelectric projects. These include: estimating flow, head and power; screening to identify feasible project locations; and estimating capital, operating and unit energy costs.

FLOW

The mean annual discharge (MAD) at any given site was estimated using GIS tools, which were applied to a Digital Elevation Model (DEM) to calculate drainage area for any given stream location. The resulting area accumulation was then combined with a runoff surface to estimate MAD. The model results were then validated by comparing them to hydrological statistics from Water Survey of Canada (WSC) stream flow gauges.

The distribution of water flow, and hence power generation, was estimated from historical daily WSC records. The available WSC records were subdivided into the 29 hydrologic zones for British Columbia identified by Obedkoff[1]. Annual energy production for a normal year (annual

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[1] British Columbia Streamflow Inventory,
Coulson, C. H., Obedkoff, W, British Columbia. Ministry of Environment, Lands and Parks., British Columbia. Resources Inventory Branch. Water Inventory Section.
Victoria, B.C., Ministry of Environment, Lands and Parks, Resources Inventory Branch, Water Inventory Section, 1998.

energy), annual energy production for a low-flow year (firm energy), and the power that can be relied upon during high demand periods (dependable capacity) were estimated for potential project sites.

To develop an estimate of energy production, a regional hydrology analysis was carried out. This involved statistical analysis of WSC hydrologic data and use of GIS capabilities to distribute the resulting statistics to the potential project locations. Minimum flow releases to the diverted portion of the stream were assumed to be the lesser of actual flow or 15% of mean annual flow. Historical daily data to 2005 for all the WSC gauges in British Columbia were used, and the data was divided into zones of similar hydrologic characteristics as defined by Obedkoff to estimate regional stream flow characteristics.

HEAD

Head is estimated by using the spatial statistics functions in ArcGIS. These functions perform a search around a given point and return the minimum elevation. The search was conducted in 500 m increments, from 500 m to 5,000 m. An algorithm was developed to prevent the search from identifying a minimum elevation in a neighbouring watershed. Head was estimated by subtracting the minimum elevation identified from the elevation of the DEM cell at the intake. The search distance formed the basis for estimating the penstock length. ArcGIS was used to multiply the head and flow and to store information for each location, including head, flow and in-stream power. This resulted in approximately 10 million data points.

IN-STREAM POWER

In-stream power potential is the product of head (H), flow (Q) and fluid weight, as described by the following equation:

$$P_{in\text{-}stream} = \gamma_w Q H_s$$

where,

$P_{in\text{-}stream}$ = in-stream power (kW)
γ_w = 9.81 kN/m3 (constant)
Q = mean annual flow (m^3/s)
H_s = static head from intake to powerhouse (m)

SCREENING

To identify sites that are technically feasible for development, screening was applied to physical parameters as shown in Table 1.

Table 1: Screening of Projects Based on Flow, Head and Power

Parameter	Valid Range
Mean Annual Discharge	0.1 – 200 m^3/s
Head	30 – 1,000 m
In-Stream Power	> 500 kW

The minimum flow, head and power conditions represent practical limits to generating power from an economic standpoint. The maximum flow condition establishes a limit for medium-sized hydroelectric facilities. The maximum head condition represents a maximum practicable pressure rating for penstocks and generating units.

Further screening was done to eliminate potential sites on glaciers, within parks, within stream reaches with salmon, and where hydroelectric projects have already been developed.

For small watersheds, the project with the highest ratio of stream power to penstock length was selected. For large watersheds (i.e. >100 km^2), more than one project was permitted by creating a 5 km buffer around the first location, and then the location with the next-highest power-to-penstock distance ratio was selected. After completing the optimization process, a total of 8,242 sites were identified.

NET POWER

To estimate penstock costs and power generation, the diameter, slope, length and wall thickness of the penstock for each project is determined. After sizing the penstock, the net power is calculated according to the following equation:

$P_{net} = \gamma_w Q(H_s - H_f)\eta$, where:

P_{net} = plant design capacity (kW)
γ_w = 9.81 kN/m^3 (constant)
Q = design flow = mean annual flow (m^3/s)
H_s = static head from intake to powerhouse (m)
H_f = friction losses in penstock (m)
η = power plant efficiency, assume 0.85

CAPITAL COSTS

Capital costs were developed for all projects. Research was conducted on existing or proposed hydroelectric projects in British Columbia that were small or medium developments and had been constructed, were under construction, or were proposed between 2002 and 2007. Fourteen such projects were found ranging in size from 1 to 125 MW, and sufficient information for model calibration and validation of cost estimates was collected.

The estimated cost breakdown of the energy equipment, substation, transformer, powerhouse, intake and miscellaneous civil was completed using RETScreen[2] and calibrated with project cost data from the fourteen B.C. projects. All other component costs were estimated using conventional means.

Project infrastructure requirements were applied to the project costing routine in RETScreen. This element was used to produce a cost table with a capital cost for each major component of the projects (e.g. energy equipment). Statistics Canada price indexes (both for general construction and specific sectors) were used to adjust costs to 2007 dollars.

The conventional analysis method of cost estimation utilizes information from past project costs, recent contractor bids, consultant knowledge and individual experience with equipment, and crew and productivity rates. Conventional means were used to estimate unit costs for construction of the power line, access roads, penstock, camps, and for equipment and crews. RHAM was used to identify the least expensive route for access roads and power lines from a proposed hydroelectric project to an existing public or resource road and power line.

The main factors in estimating power line voltage are capacity and length as shown in Table 2. Power lines were sized based on serving each project independently, with the capacity of the power line set equal to the capacity of the project. RHAM then identifies the least-cost route based on slope and land cover.

Table 2: Power Line Voltage Selection

Distance to Existing Transmission System	Power Line Capacity		
	10 MW	40 MW	100 MW
0 - 50 km	25 kV	69 kV	138 kV
51 - 100 km	69 kV	69 kV	138 kV
> 100 km	138 kV	138 kV	138 kV

[2] RETScreen International Clean Energy Project Analysis Software is a decision support tool developed by Natural Resources Canada

The 25 kV lines were assumed to connect to the nearest 25 kV system or to a substation on the transmission system. The 69 kV lines were assumed to connect to the nearest 69 or 138 kV (with step up transformer) line or substation. Power line costs were adjusted when rerouting was required to avoid parks, large water bodies, permanent snow/ice or slopes exceeding 75%. Cost discounts were made for single-pole 25 and 69 kV lines following forest roads due to the reduction in clearing costs.

To account for site variations due to regional factors and remoteness (proximity to towns or city centres), costs for construction camps were required, and transportation of people and equipment were added to estimates. Four site categories were used to indicate remoteness of location. Category A sites were located within a 50 km radius of a major town or city centre (population of 25,000 or more). Category B and C sites were located within 200 and 400 km from a centre, respectively, and category D sites were located anywhere outside a 400 km radius from a centre. It was assumed that all category C and D projects would include a camp.

The construction period required for a potential project varied depending on size. One year was used for project capacities of less than 1 MW, two years for 1 through 10 MW, and three years for greater than 10 MW. Camp and Transportation cost estimates for the construction periods are shown in Table 3.

Table 3: Total Camp and Transportation Costs ($)

Project Capacity	Site A	Site B	Site C	Site D
Less than 1 MW	105,000	210,000	755,500	881,500
1 to 10 MW	210,000	420,000	1,230,500	1,482,500
Greater than 10 MW	315,000	630,000	1,705,500	2,083,500

Estimating project-specific costs, such as those for engineering or environmental management, require detailed site information. For inventory-level costing, typical allowances expressed as a percentage of total capital cost are given. Allowances for each site category are shown in Table 4.

Table 4: Cost Allowances (% of Capital Cost) for Site Categories

Site Category	Mobilization / Demobilization Equipment & Materials	Bonding & Insurance	Environmental	Engineering
A	6%	2%	5%	15%
B	10%	2%	5%	15%
C	18%	2%	5%	15%
D	24%	2%	5%	15%

The following considerations and assumptions were used to determine costs for the project components:

1. Penstocks were to be constructed of steel, and diameter, pressure and slope were considered in estimating the cost.
2. Powerhouse, intake and miscellaneous civil costs were dependent on head, flow and number of turbines. It was assumed that blasting was required for construction at intake site.
3. The size of the powerhouse was directly related to capacity and head of plant.
4. The cost of generation equipment is dependent on head, flow, number and type (Pelton, Francis or Kaplan) of turbine(s). Installation was estimated at 15% of equipment cost.
5. Transformer and switchyard costs were dependent on the number of turbines, capacity and power line voltage. Installation of transformer and switchyard was estimated at 15% of equipment cost.
6. For access roads the cost considered the availability of materials, terrain and difficulty of construction. The roads were assumed to be 6 m wide forestry type construction with 0.3 m gravel topping. It was assumed a portion of cut volume requires blasting and slope ranged from 0 to 30%.

Application to acquire tenure is required in the case of land held by the Crown. In cases where land is privately held, negotiations are necessary to potentially purchase or acquire permission to use the land. The cost to acquire land from the Crown, First Nations or private land owners was not included in this study. An allowance for these costs will be applied to RHAM in the future.

OPERATING COSTS

Operations and maintenance costs were estimated to be 2% of total capital costs, including road and power line costs, which correspond with project data and the previous study of hydroelectric potential for British Columbia[3]. Rates for water rentals for general power generation in BC include costs for authorized power capacity and energy produced. The 2007 rates given by the Ministry of Environment Water Stewardship Division, which are incorporated into the annual costs in this study, are the sum of the following: $3.676 per kilowatt authorized capacity plus $1.103 per megawatt-hour per year up to 160,000 megawatt-hours, and $5.147 per each additional megawatt-hour per year. Land tax rates were estimated to be 3% of the assessed property value, which was assumed to be 80% of the capital cost of the site infrastructure.

[3] Green Energy Study for British Columbia Phase 2: Mainland - Small Hydro (external link to BC Hydro site) (October 2002).

UNIT ENERGY COST

Unit energy costs were calculated by amortizing the total capital cost for each project at a 6% real discount rate over 40 years, adding the annual costs and dividing by the annual energy estimate for the site. A discount rate of 8% was also considered. A rate higher than 8% would better reflect independent power producers' cost of capital.

JOB CREATION AND LAND AREA IMPACTED

A quantitative assessment included an estimate of the number of operations and construction jobs that could be created, and the amount of land area that would be affected. Construction jobs were estimated based on the capital cost (2.5 jobs per $1 million of capital works), while operations jobs were based on the size of the project. The operations jobs were estimated to be 0.5 full-time equivalents (FTE) for projects less than 1 MW, 1.0 FTE for projects 1-10 MW, and one additional FTE for each additional 10 MW above 10 MW.

Impacted area calculations included the estimated rights-of-way for penstocks, access roads and power lines. A 10 m-wide right-of-way was assumed for roads, power lines and penstocks.

STORAGE

KWL recently added the analysis of storage hydroelectric to RHAM. This module estimates instream storage. A GIS algorithm creates a 'virtual reservoir' by generating a line representing a dam crest at an evaluation point along a river and 'flooding' the DEM surface. This process essentially converts the DEM into a bathymetric surface, which is used to estimate storage volume of the reservoir. Dam volume is estimated based on the dam crest line, which is used to extract a cross-section profile from the DEM. The profile is converted to a volume that can be specified as either concrete or earth-fill and used for costing.

The storage output from the model can be optimized using several parameters including the inundated area, stored volume, design flows and dam volume. This is useful for identifying locations that minimize land impacts and cost while achieving storage volume targets. KWL plans to conduct a storage hydro assessment for BC in the near future.

CONCLUSIONS

There is large potential for run-of-river hydroelectric development in British Columbia. KWL's inventory study conducted using RHAM has been useful in helping power developers locate potential projects sites.

The methodology used to develop the inventory for British Columbia can be applied to any region of the world where GIS information is available or can be cost effectively developed. The quick, methodical evaluation of the hydroelectric power will help in the effort to reduce carbon fuel dependence and help ensure a sustainable energy future for the world.

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AUTHORS

Ron Monk leads Kerr Wood Leidal's Energy, Industrial and Mining Sector. Ron's expertise includes feasibility, design and construction of small hydroelectric projects. Projects include Kitasoo Hydro (1.7 MW), Tyson Creek Hydro (9.3 MW) and the assessment of run-of-river hydroelectric potential for BC Hydro and BCTC. Prior to returning to KWL in 2007, Ron's key accomplishments at BC Hydro included leading the 2004 Integrated Electricity Plan, co-initiating the hydrogen program and co-developing BC Hydro's sustainability vision.

Stefan Joyce is a hydrotechnical engineer with over 10 years' experience in modeling, analysis, design, project management, construction and contract administration. His expertise includes creek and river hazard assessment and protection, hydrologic studies, hydroelectric feasibility and design, dam safety and decommissioning, storm water management, and the application of GIS tools for hydroelectric and water resources projects.

Mike Homenuke specializes in GIS-based infrastructure analysis and planning. He has developed several computer models, capital plans and feasibility studies for various clients. Mike is involved in the development of GIS applications for engineering services, including asset management, hydroelectric resource assessment and infrastructure planning.

