Proposal for a Hydroelectric Power Plant

Columbia River, British Columbia

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For: Dr. Adel Guirgis

ENER 300

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Executive Summary

This is a proposal for a hydroelectric plant situated in Canada with an operating capacity of 3000 MW. It is a dam type hydro facility located in British Columbia on the Columbia River after it merges with Kootenay River (coordinates: 49° 9'12.71"N, 117°43'43.83"W). Technical evaluation revealed that the theoretical production capacity is 3,125 MW at 90% efficiency and 3000 cubic meters per second of flow rate.

A case study was done on the Robert-Bourassa generation complex to analyze the types of requirements and issues that may occur while building a dam. An environmental report revealed that a buildup of mercury occurred in reservoirs and downstream of the dam and caused wildlife damage, widespread flooding and the forced relocation of the village of Fort George. As the dam and the generation plant was built on First Nations reserves, agreements had to be made which included monetary payments, and its remote location required building thousands of kilometers of power lines to connect to the provincial power grid.

The environmental impacts addressed in this study focus on the upstream and downstream changes to the river ecosystem that occur post dam installation. Impacts included possible reservoir flooding and river flow regime changes beyond the natural seasonal fluctuations. Further, changes in reservoir’s chemical and physical properties are inevitable leading to the endangerment of aquatic plants and animals. The proposed solution is to release a minimum of 1000 cubic meters per second of flow depending on the inlet seasonal flow to allow for sedimentation to build downstream which minimizes the erosion of riverbeds.

Compliance with laws and regulations at the federal and provincial level must be met before choosing a location. At the federal level, the *Dominion Water Power Act* contains all the federal laws on any power generated by water. The provincial government of British Columbia has a similar legislation. *The Water Sustainability Act* and *The Land Act* are both enforced by Land and Water British Columbia Inc.

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Nomenclature

kW: kilowatt, 1000 watts

MW: megawatt, 1,000,000 watts

v: velocity in meters per second

q: volumetric flow rate in cubic meters per second

ρ: density of water in kilograms per cubic meter

A: area in square meters

g: acceleration of gravity, 9.81 meters per seconds squared

h: falling height / head, meters

TWh: terawatt hours, a measure of terawatts used in one hour

SEBJ: Société d'énergie de la Baie James, The Society of Energy of the James Bay

ROR: Run of the River

AC: Alternating Current

DC: Direct Current

kV: kilovolt, 1000 volts

GHG: Greenhouse Gases

LWBC: Land and Water British Columbia Inc.

G-res: Greenhouse Gas Reservoir

IHA: International Hydropower Association

UNESCO: United Nations Educational, Scientific and Cultural Organization

UQAM: University of Quebec at Montreal

SINTEF: Norwegian Foundation for Scientific and Industrial Research

LUKE: Natural Resources Institute of Finland

Introduction

The objective of this study is to choose a suitable location for a 3000 MW capacity hydroelectric power plant. A hydroelectric power plant is an electricity generating facility that uses the kinetic or potential energy of water to drive a turbine and produce electricity. It is a renewable source of energy by the virtue of the water cycle. The water cycle is powered by the sun which allows for the evaporation and the precipitation of water from sea levels to mountain tops - gaining potential energy. (Figure 1) [1] The flow of the water due to the gravity is what allows us to harness this energy. There are two main types of hydroelectric plants: run of the river and dams. Dams have a high reservoir that contains large amounts of water and release it to a lower reservoir. The transformation of the water's potential energy to kinetic energy drives the turbine. (Figure 4) [2] In the run of the river type plant, part of the flowing river water is diverted into a turbine and electricity is produced, no water is withheld, and no reservoir is required. (Figure 5) [2]

Currently there are only two hydroelectric plants that operate above a 3000 MW capacity in Canada; Robert-Bourassa and Churchill Falls, at 5616MW and 5428 MW, respectively. [3] Canada is one of the leading producers of hydroelectricity, producing 387 TWh per annum and accounting for 58% of annual domestic electricity generation. [4] [5] The current installed capacity is 79 GW with a technical potential of 160 GW. [6] As evident in Figure 6 [4], the majority of hydroelectric power plants are located in Quebec and British Columbia. After analyzing the technical potential of various rivers in Canada, the Columbia river was chosen as the location of the 3000 MW hydroelectric dam. Columbia river is the largest river in the Pacific Northwest Region of North America. (Figure 7) [7] It is sourced from Columbia Lake, 820 meters above sea level and originates in the Rockies and flows through Washington and Oregon before Emptying in the Pacific Ocean. [8] It has an average flow of 7500 cubic meters per second near the mouth and is 2000kilometers long. [8] It powers 14 dams, three of which are in Canada. Flow rates at the dam location vary widely. The site location, right after the Kootenay River can experience from around 800 to 4500 cubic meters per second. Actual flow rates depend on many factors including upstream runoff, storage operations and treaty discharge requirements. Visualized hydrometric data of flow rate at the exact proposed dam location can be seen at Figure 8 of the Appendix.

Dams produce electricity in situ as the water drives the turbine. Unlike in fossil fuels, burning of the fuel to create steam is not required, therefore direct transmission is possible. British Columbia 500kW transmission lines pass right through the proposed location carrying electricity from Mica and Revelstoke Dams. Figures 9 and 10 show the location of the dam and its proximity to the transmission lines. [10]

Discussion

To prepare and obtain a general sense of what would be required of the new dam, a case study was performed on a pre-existing hydroelectric generation plant - the Robert-Bourassa Generation Plant, located in Quebec.

Case Study – The Robert-Bourassa Generation Plant of Quebec

In 2016, Quebec reported that it had a generating capacity of 45,402 megawatts and generated 207.2 terawatt hours of power, of which 95% was attributed to hydro power. [3] The Robert-Bourassa Generation Plant, located east of the James Bay, is one of the eleven hydroelectric generating stations on the La Grande Watershed and produces a large portion of this total hydroelectric power at an installed capacity of 5616 megawatts. [11]

Environmental Impacts

As part of the construction and operation of the Robert-Bourassa plant and others in the La Grande Complex, a long-term survey and report was made on the mercury levels of the bodies of water around dams. The report, which compiled data gathered over 34 years from 1978 to 2012, found as follows: [12]

a. Natural Lakes: Mercury levels observed over a period of 22 to 28 years showed lower than standardized levels for Canadian fisheries and did not show any trends in changes of mercury levels during the observation period.
b. Reservoirs: A temporary increase of 2 to 8 times the natural levels of mercury were observed, but typically stabilized back to natural lake levels after 20 to 30 years.
c. Downstream: In general, mercury levels were found to be higher than natural lake levels, but the concentration decreased over distance.

While mercury has had less than anticipated impacts on the bodies of water affected by the construction of the dam and generation plant, mercury buildup was found to have been the cause of rotting vegetation, which in turn caused the death of approximately 10,000 caribou. Other impacts from the construction of the Robert-Bourassa dam included the flooding of approximately 11,500 square kilometers of land, which included Cree and Inuit land and homes, as well as the forced relocation of the village of Fort George upstream of the La Grande Riviere. [13]

A more general description of the environmental impacts of hydroelectric generation plants can be read on page 16, Environmental Impacts.

Social Impacts

An important aspect that was necessary to consider for the construction of this generation facility was the use of First Nations lands. The area in which the Robert-Bourassa dam and generation plant was planned to be built on was on Native reserves, mainly those of the Crees. [14] Therefore, Hydro-Quebec and the Société d’énergie de la Baie James (SEBJ) negotiated with the Cree and other relevant First Nations bands and signed several agreements in 2002 that included the following: [15]

- An establishment of funds to be used for the benefit of the Crees and other First Nations bands in the area worth approximately $73 million which will be used in concerns such as environmental remediation, wildlife management, and various training;

- Approximately $38 million dedicated to programs related to mercury buildup and its effects on the environment;
- Employ 150 Crees in permanent positions in the La Grande generation complex, which includes the Robert-Bourassa generation plant;
- Build transmission lines to the Cree and other involved First Nations communities;
- Establish a Dispute Resolution Committee to handle any disputes between Hydro-Quebec/SEBJ and the Cree.

Power Transmission

To transfer the power that is generated through the facility, transmission lines must be built connecting the generators to its intended consumers – mainly the villages, towns and cities of Quebec. The Robert-Bourassa Generation Facility is in a very remote location compared to its main consumers, being located over 900 kilometers from Montreal. This has led to the construction of thousands of kilometers' worth of power lines from the generating facilities of the Robert-Bourassa and its associated facilities in the La Grande Watershed, with multiple substations to connect the extensive power lines together and distribute them to consumers. [16]

While alternating current (AC) transmission lines are the norm for power distribution, direct current (DC) transmission lines have become increasingly more appealing to utilize due to their higher power transmission efficiency – especially over longer distances - and smaller physical footprint of transmission towers. [17] The Robert-Bourassa has one substation that utilizes both 735-kiloVolt (kV) AC lines and 450-kV DC lines, of which the DC line extends to interconnect with the US power grid for exchange of electricity. [18]

Findings of Case Studies

From our case studies, as well as from the requirements of this report, it was determined that while design, equipment and the characteristics of the river and its surroundings are crucial for determining the generating potential of the dam, there are many laws that place restrictions on the location, size and environmental impacts of the dam while social concerns and influences can attach additional costs and concerns onto the project. These factors; technical, regulatory, and environmental impacts - will be discussed in the sections that follow.

Technical

The technical study was divided into four main parts, the selection of hydroelectric facility type, hydrological, geographical and case studies. For the selection of facility type, there are two main options, dams and run of the river. Run of the river (ROR) uses the inflowing kinetic energy of the water to spin the turbine. Embankment Dams use a high reservoir to collected water at high potential energy points and release the water to convert the potential energy into kinetic energy. This kinetic energy then drives a turbine. In both cases a kinetic body of water is needed. Lakes and open bodies of waters, like oceans do not work which reduces our options to rivers. The type of facility is selected by doing a simple power calculation between the two designs.

Run of River power output is proportional to the kinetic energy of the water and is dictated by Equation 1. [19] Maximum Power output for a flow rate of 3000 cubic meters per second, 6 turbines with 6.5 meter diameter, and a penstock diameter of 8 meters, a water velocity of 9.95 meters per second, an output of 22.3 MW per turbine is resulted, with a total production capacity for all 6 turbines being 133.6 MW. This is at 90% efficiency which is typical for a hydroelectric generator. (Values kept similar to, or as close as possible to that of the Mica dam with a production capacity of 2800 MW)

Dam power output are proportional to the head of the facility and is dictated by Equation 2. [19] Maximum power output for a flow rate of 3000 cubic meters per second, and a

244 meters height (similar to the height of the Mica dam), an output of 6462MW is resulted, approximately 50 times more than that of the ROR design. Therefore, the embankment type dam is the one selected for this project.

When choosing the embankment type dam the main downside is that a reservoir will have to be created upstream of the dam to guarantee a couple things. First of all, that the hydraulic head of the dam remains relatively constant and secondly that the flow rate through the dam is kept within reasonable margins so that the power generation of the dam does not vary by much. In the case of the chosen dam, there will be a requirement to build dykes to provide much needed stability and height to the reservoir and the surrounding area and with flow rates similar what the Mica dam is receiving. The power generation this dam will attempt to produce is comparable to the Mica dam which lies on the same river. This means that the dam should have a reservoir of similar size requiring roughly 20-30 dykes to complete. This is considering that a similar project such as the Robert-Bourassa dam needed 27 dykes to complete. This will have an impact on the surrounding environment and flooded area which will be later discussed in the report. On top of that, there might be a requirement for a spillway which will ensure the reservoir never exceeds capacity by creating a way to evacuate the reservoir. [18]

Hydrological study began by exploring different Canadian river basins. Hydroelectricity is predominantly produced in BC and Quebec and has the most technical potential there as well. [3] The Saint Lawrence River, in Quebec and Ontario, has a discharge of 9850 cubic meter per seconds and is the largest river in Canada (based on discharge). Columbia river, in British Columbia, is the third largest at 7730 cubic meters per second. Columbia River is the river of choice. It powers Mica and Revelstoke dams which both have a production capacity of 2800 MW and above. [20]

The Columbia River was followed from where it originated to the American border to find a suitable location. Its elevation profiles were observed on Google Earth. The objective was to find a suitable location that would minimize the destruction of land, would have sufficient depth for the reservoir and substantial flow rate. A suitable location is found after the combination of Kootenay river, in the lower arrow lake area (coordinates: 49° 9'12.71"N, 117°43'43.83"W). There are no cities nearby and the location has a high surrounding hill height. A cross sectional elevation study of the river is conducted used Google Maps Figure 11. The geographical study reveals that the height of the dam can reach 118 meters at a width of 800 meters. The goal is to achieve the maximum height for a reasonable width to minimize damage to the environment. A study was done on Google Earth Pro to compare elevation and cross-sectional profiles (figure 2 and 3) of the Mica Dam to verify the similarities and differences. Figure 3 shows that the cross-sectional elevation allows for a substantially tall dam. The deep riverbed and elevated hill formation are a good combination for a large reservoir.

Real-time Hydrometric data at the proposed location is available from Water Office Canada. Figure 8 illustrates the variation of water discharge rate and height over the course of the year (specifically 2018). [21] The mean discharge rate varies from 1000 to 4300 cubic meters per second over the course of the year. [21]

With the height and the flowrate found, the theoretical potential capacity can be estimated using Equation 2. At 4300 cubic meters per second of flow rate, and a dam height of 118m, 4479.8MW can be produced. This is the maximum production capacity of the dam. Since the flow rate varies so wildly, it is not a good indication of the actual power produced. A more useful number is the capacity factor. Capacity factor shows the energy output over a period of time and it is the best method for accommodating for temporal fluctuations. A high capacity factor shows that the facility operates close to the nameplate capacity. The analysis is done over the course of the year and the nameplate capacity for the proposed hydroelectric facility is 3000 MW. A tabular analysis is shown in Table 1. It illustrates the projected power generated accounting for the seasonal variations. The capacity factor, based on the annual production of 20 TWh and the nameplate production capacity of 3000 MW yields 0.76, a relatively high ratio when compared to other existing hydro facilities around the world. This is indicative of the fact that the proposed hydro facility will operate close to its nameplate capacity. The Mica Dam has a capacity factor of 0.29, indicating it rarely produced close to its nameplate capacity of 2805 MW. To contextualize this further, a chart of capacity factors from various sources is illustrated in Figure 12. [22] Nuclear has the highest capacity factors spanning from 0.75 to 0.95 whereas hydro ranges from 0.30 to 0.55.

Proximity to Markets

This dam is rather close to Kamloops (253 km), Kelowna (152 km) and Vernon (166 km) as it is roughly located halfway between Calgary (335 km) and Vancouver (392 km). The dam itself will most likely provide power to either Calgary or Vancouver. However, both major city centers already have established main sources of power generation, which are natural gas and other hydroelectric dams respectively. This leaves the nearby cities of Kelowna, Kamloops and Vernon who will benefit greatly from having so much power being produced nearby with excess power being sent where there is a demand. The dam itself is located near a large 500 kW power line that is already used to transfer energy from the Mica dam to the surrounding cities. [23] Ideally this dam would also hook up into that and use that to transmit the power it produces.

Base Load and Peak Load

The base load energy production of this project will occur in September when the river flow rate is at its yearly low. The power production that a flow rate of 965 cubic meters per second provides is approximately 1117 MW, which is a far cry from the goal of 3000 MW, but this power production can be controlled by using the reservoir to increase the flow rate at the cost of some hydraulic head which will lead to the production of a more acceptable amount of power. For example, if the reservoir holds something in the range of billions of cubic meters of water, just letting our flow rate increase through the dam to around 1000 m3/s will not put a huge dent in the height of the reservoir over the selected time period of a month. So, the safely estimated lowest average flow rate could be considered to be 1000 cubic meters per second over the month of September which means the base load of the dam is around 1158 MW assuming the addition of dykes and extra flow rate do not affect the hydraulic head a ton. Meanwhile the peak load of the dam will happen in the month of June which has a reported average river flow rate of 3760 m3/s which leads to the generation of 4352 MW, which is both adequate for what this dam is designed to do and is under the theoretical maximum power output of the dam. Also, trying to increase the power generation by lowering the reservoir volume at this time of year would be a fruitless endeavor as an extra volume would be needed to increase power generation in lower flow rate months to decrease the variation in power production going from month to month.

Regulations

In Canada, there are a large number of governing bodies that have a say in how and where a reservoir for hydroelectric power will be built. These bodies have acts put in place to ensure that wildlife and habitat are being preserved, as well as to ensure the safety of the workers building and the residents of the surrounding area. Compliance with these laws and regulations are crucial to the success of the dam and should be taken in to consideration before choosing a location.

Federal

At the federal level, the *Dominion Water Power Act* contains all the federal laws on any power generated by means of water. [24] This could include dams, reservoirs, waterfalls, or ocean thermal energy conversion within Canadian waters.
Outlined below are some key parts of this act that will need to be complied with to avoid consequences with the federal government.

Land Acquisition

Any water power facility falls under the *Dominion Water Power* Act if it is on public land. Pursuant to *Section 1* of the act this land is considered a property of the crown and therefore crown land use permits must be acquired. The act states that permits for water power will not be granted unless the work is “for the general advantage of Canada”. If use of crown land is required, the crown permit may be acquired from the Governor in Council appointed by her Majesty pursuant to the *Expropriation Act.*
The minister appointed by the queen can charge specific fees for the use of the crown land. These fees are at the discretion of the minister. [24]

Surveys, Records

Section 10 of the act states that the minister may order that a survey be done to assess the environmental risk to the area, as well as detailed plans for the hydropower facility. These must include geological surveys of the surrounding waters done by an expert, how much water will be diverted, how much water will be used, and which gauges will be used to measure said water. The minister appointed will have full access to all works, plans and records pertaining to the facility, as stated in *Section 11*. Permits for land use will be given based on these surveys; as such, impeccable records must be kept. [24]

Decision Making

According to *Section 15* of the act, the federal government has final say of any decisions pertaining to hydroelectric power as used on the crown land. The Minister appointed has the power to make regulations regarding storage and diversion of the water, transmission of water power, construction or operation of the facility, among other things. [24]

Provincial

In addition to the regulations set out by the federal government, the provincial government of British Columbia has similar legislation. *The Water Sustainability Act* and *The Land Act* are both enforced by Land and Water British Columbia Inc. [25] The provincial government is also responsible for most of the safety laws that surround hydro power.

Land and Water British Columbia

The purpose of LWBC is to enforce the safety regulations set out in the appropriate acts as well as give out water permits within the province. *The Water Sustainability Act* covers safety during the construction, maintenance, and operation of the dam as well as enforces contingencies that must be in place in case of dam failure. Both acts that are governed by LWBC go into great detail about safety and land concerns. These regulations should be reviewed very carefully before a permit application is submitted, as they will require detailed plans and contingencies as pursuant to these acts.

Consequences for failure to comply can be found in *Division 4, Section 28* of the *Water Sustainability Act.* [25]

BC Hydro

As the majority of electricity in British Columbia is hydroelectricity, BC hydro is the governing body that deals with the production and transmission of electricity. Permits and agreements must be obtained for BC hydro prior to construction of the facility. More specifically a purchase agreement with is required from BC Hydro as well as a Transmission Service Agreement [26]

Environmental

The environmental legislation surrounding dams and reservoirs is mostly the responsibility of the Federal government, more specifically the Department of Oceans and Fisheries. According to *The Fisheries Act Section 20-4,* No person shall obstruct a fish way. This is something that needs to be taken into consideration as the building of a reservoir on a very large river system is sure to obstruct fish migrations.
In order to be able to build the reservoir on the Columbia River, the department will need to be consulted. They will provide an environmental survey and determine whether this river is a viable place to build. Their main concern will be to limit the destruction and disruption of the local flora and fauna. [27]

Other Permits and Licenses

In addition to the Acts set out above, there are many other laws that need to be considered. Permits must be acquired and permission from different companies and governments need to be obtained prior to constructing a dam.

- Canadian Environmental Assessment Act Decision
- British Columbia Environmental Assessment Act Certificate
- Coast Guard Decision if the reservoir interferes with any navigable water. [26]
- Permission from the Ministry of Forests if any trees are to be disturbed or removed.

- Permission from the Ministry of Transportation for the use of roads for transporting equipment and supplies
- Permit from the British Columbia Utilities Commission [28]
- Approval from the Canadian Dam Association [29]

Environmental Impacts

Hydroelectric power plant installation does not come without adverse costs to human and wildlife if not implemented responsibly. The two main sets of environmental impacts of dams are those which are intrinsic to dam construction and those which are due to the mode of operation of each dam. The most significant consequence having a dam is isolating populations of species living up and downstream of the dam and cutting off migrations and other species movements. The elimination of the benefits provided by natural flooding may be the single most ecologically damaging impact of a dam. The disintegration of river ecosystems can result in a massive reduction in the number of species in the watersheds.

A dam reservoir can provide numerous benefits, including water supply, irrigation, hydropower and flood control. Reservoirs also enable other activities such as fisheries, recreation, and provide surface areas for other forms of energy generation such as floating solar panels. Some of the environmental effects of dams can also benefit some species. For example, holding a reservoir will form a habitat for lake fish, while warm water can increase the abundance of fish species which are unable to survive in the cool river.

Despite the added benefits that come with a reservoir, it can result in increased flooding possibility, and river flow regime changes which can lead to changes in food security and increased water-related diseases.
To reduce flooding occurrence, spillways can be built to provide sustained release of flows from a dam into a downstream area, usually the riverbed of the dammed river (Figure 12) [30]

Fluctuations in temperature, dissolved oxygen levels and physical properties of a reservoir are often not compatible to the aquatic plants and animals that developed with a given river scheme. In addition, reservoirs frequently host non-native and hostile species such as algae and snails that further destabilize the river's natural populations of plants and animals. As a result, an increase in decaying organic material can occur, driving up the release of methane, which is a greenhouse gas with a global warming potential. [30]

There has, however, been a lack of scientific certainty on how to measure hydropower’s greenhouse gas (GHG) footprint, and this uncertainty has proven to be a significant difficulty for policy and decision makers, especially regarding the potential financing of projects and the designation of ‘sustainable’ or ‘climate friendly’ labels to certain projects. [31]

To combat and monitor methane emission, a GHG Reservoir (G-res) Tool was created through a multi-stakeholder research project led by the International Hydropower Association (IHA) and the UNESCO Chair for Global Environmental Change. The tool uses a conceptual framework created with scientists from the University of Quebec at Montreal (UQAM), the Norwegian Foundation for Scientific and Industrial Research (SINTEF) and the Natural Resources Institute of Finland (LUKE). [32]

The G-res Tool was created to guide hydropower companies to gauge and report the net greenhouse gas emissions of a reservoir. The G-res tool could have a significant impact on the decision-making process around new freshwater reservoirs.
Reporting results gained using the G-res Tool gives investors, regulators and local communities greater confidence in a reservoir’s carbon footprint.
Methane and Carbon Dioxide emissions tend to decrease with the capacity of the dam constructed but slightly increase with the head of the dam. Hence an optimization analysis is to be conducted to keep emissions within tolerable levels. Figures 13 and 14 show the data obtained from a life cycle of greenhouse gas emissions estimation for small hydropower schemes in India. [33]

Another concern is the holding back of sediments by a dam that would naturally replenish downstream ecosystems. The Columbia River used to drop its sediment load in the original Arrow Lakes. Now those sediments are left in the reservoirs, resulting in abnormally clear water for such a large river. [34] When a river is robbed of its sediment load, it obtains it by eroding the downstream river bed and banks which can destabilize bridges and other riverbank structures. Riverbeds downstream of dams are typically eroded by several meters within a decade of first closing a dam; the damage can extend for tens or even hundreds of kilometers below a dam.

To reduce the likelihood of this occurrence, there will be a minimum flow of 1,000 cubic feet per second released from the dam. The minimum flow is proposed to benefit production in the river from the bottom to the top of the fish food chain by supplying an amount of continuously wetted river habitat. There will be more small fish, which sustain larger fish, which in turn are food for top predators.

Historically, construction of dams on the Columbia River, has reduced the available salmon habitat to 13% of the river. Fall Chinook salmon currently use only 85 km of the 2,000 km river as breeding grounds. In order to not aggravate this issue, the proposed solution is to include fish ladders which allow the salmon to travel through the dams. [34]

Conclusion and Recommendations

The purpose of this report was to install a hydroelectric power plant with a capacity of 3000 MW, anywhere in Canada. This was successfully executed by proposing a dam location in British Columbia on Columbia River after its merging with Kootenay River, in the Lower Arrow Lake region (49° 9'12.71"N, 117°43'43.83"W). 500 kW transmission lines located nearby will be used to power Kamloops, Kelowna and Vernon. The theoretical production capacity is 3,125 MW with a 3000 cubic meters per second flow rate at a head of 118 meters. The main environmental impacts include salmon migration, flooding and lack of sedimentation. These are to be resolved by installing fish ladders, spillways and allowing flow release downstream, respectively.

To further enhance the chance of finding a more suitable location, one can research whether the dam fits in with a farm plan for water availability and distribution. The station could also be located in a place where the land or the rock structure on which the dam will be built on is strong enough to hold the weight and the force of the water in the dam. In order to obtain a more accurate analysis of hydrometric, riverbed, hill formation, and topography data, a more advanced software tool can be implemented besides Google Earth pro to ensure picking the most suitable location for a dam without legal and environmental consequences. A software such as Rapid Hydropower Assessment Mode can identify hydroelectric sites using Geographic Information Systems. However, it requires a license to access.

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Appendices

Figure 1 - Water Cycle
[1]

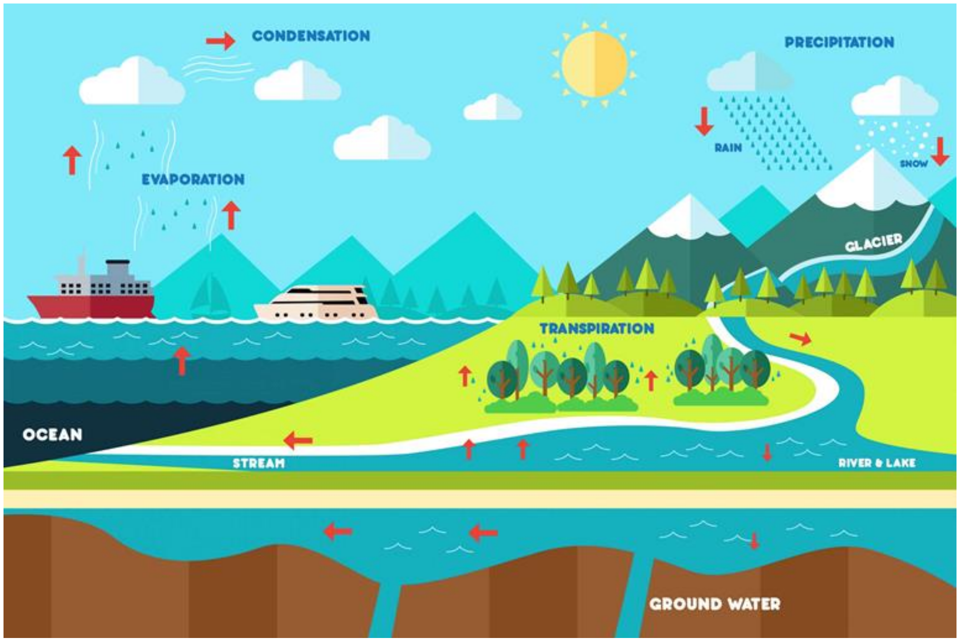


Figure 2 - Google Earth Pro Imaging of Longitudinal elevation profile of the Mica Dam revealing a height upwards of 200m

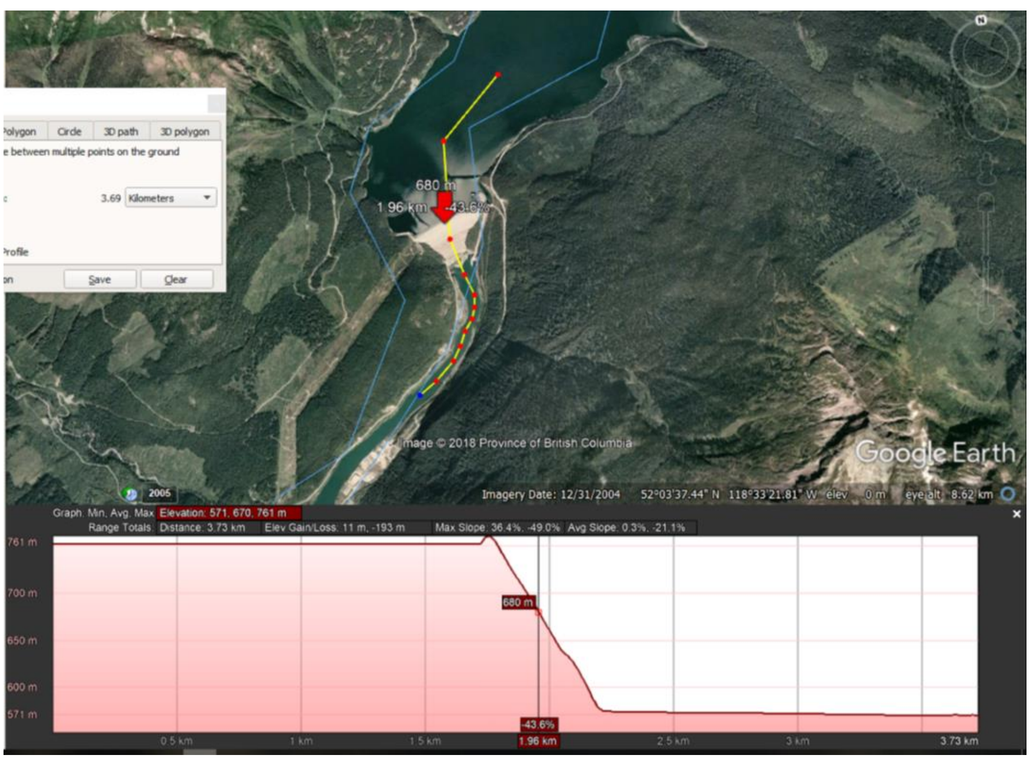


Figure 3 - Google Earth Pro Imaging of Cross sectional elevation analysis of the river bed and hill formation to determine the heights and widths that make for a suitable dam. Reveals 175m dam height can be achieved

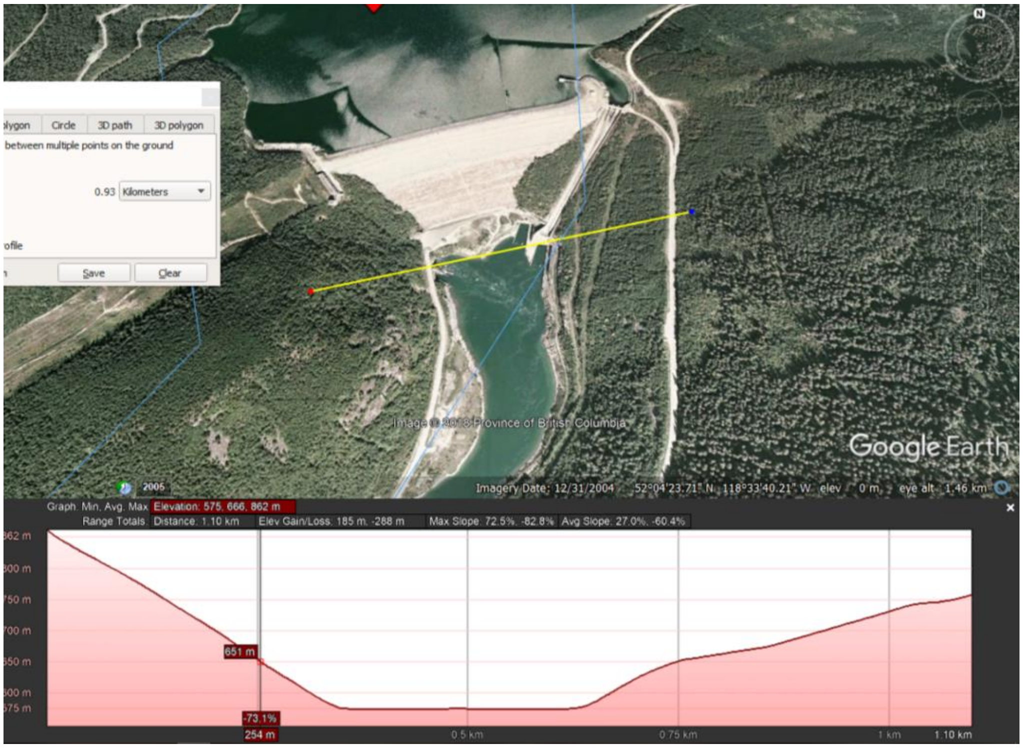


Figure 4 - Dam Type Hydroelectric Generator [2]

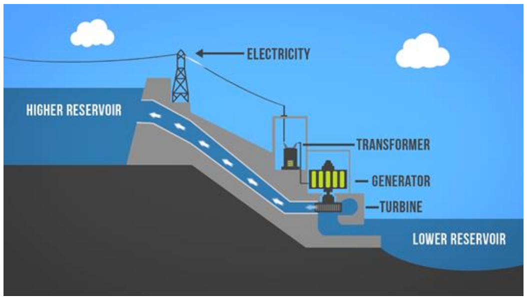


Figure 5 - Run of River [2]

Figure 6 - Canadian Electricity Capacity [3]

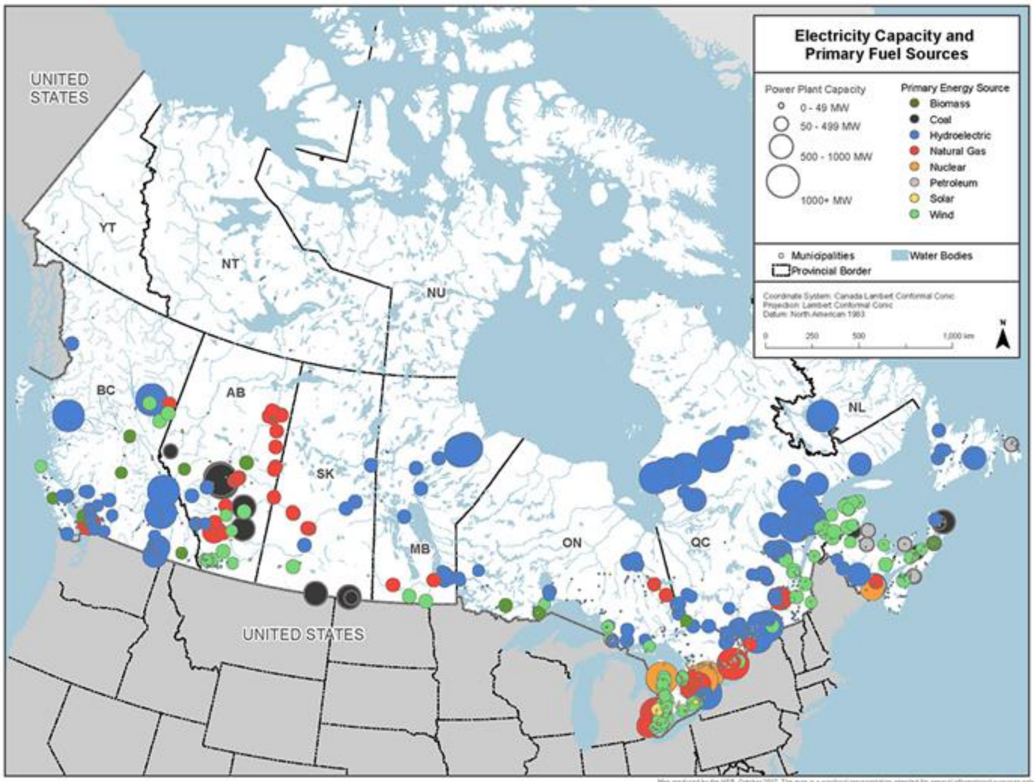


Figure 7 - Columbia River Basin
15% of the basin exists in Canada. [7]

Figure 8 - Hydrometric Data Graph for COLUMBIA RIVER AT BIRCHBANK (Measuring station: 08NE049) [BC] Year 2018 [20]

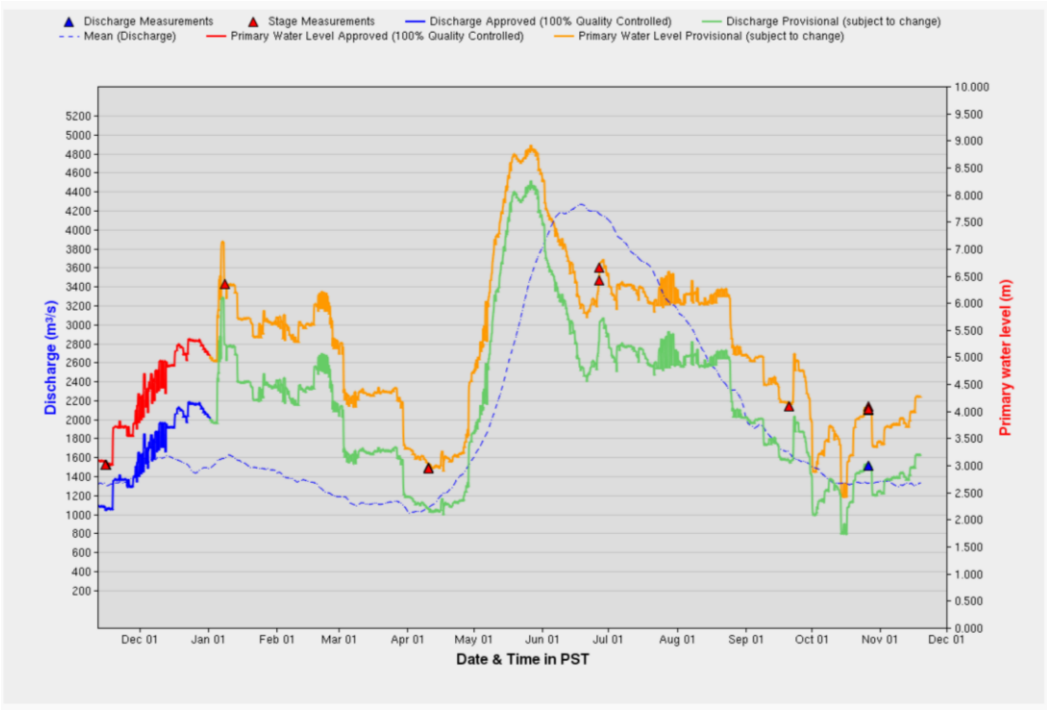


Figure 9 - Transmission Lines [10]

Figure 10 - Transmission Lines [10]

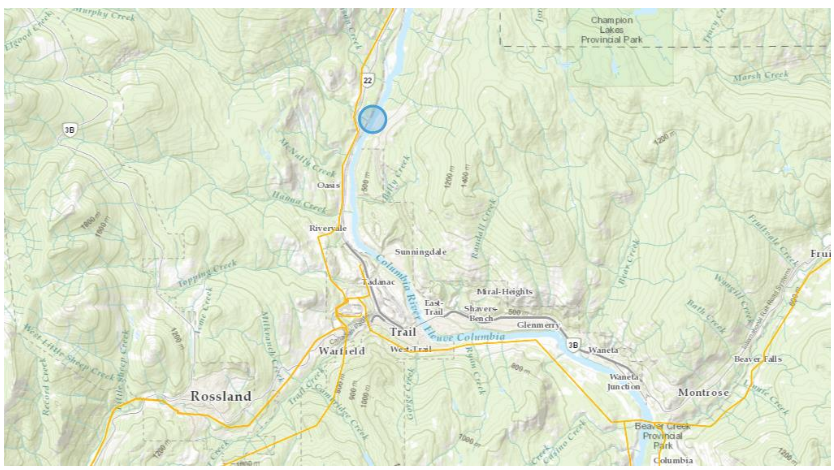


Figure 11 - Cross Sectional study of proposed location using Google Maps. The yellow is where the elevational cross section is taken

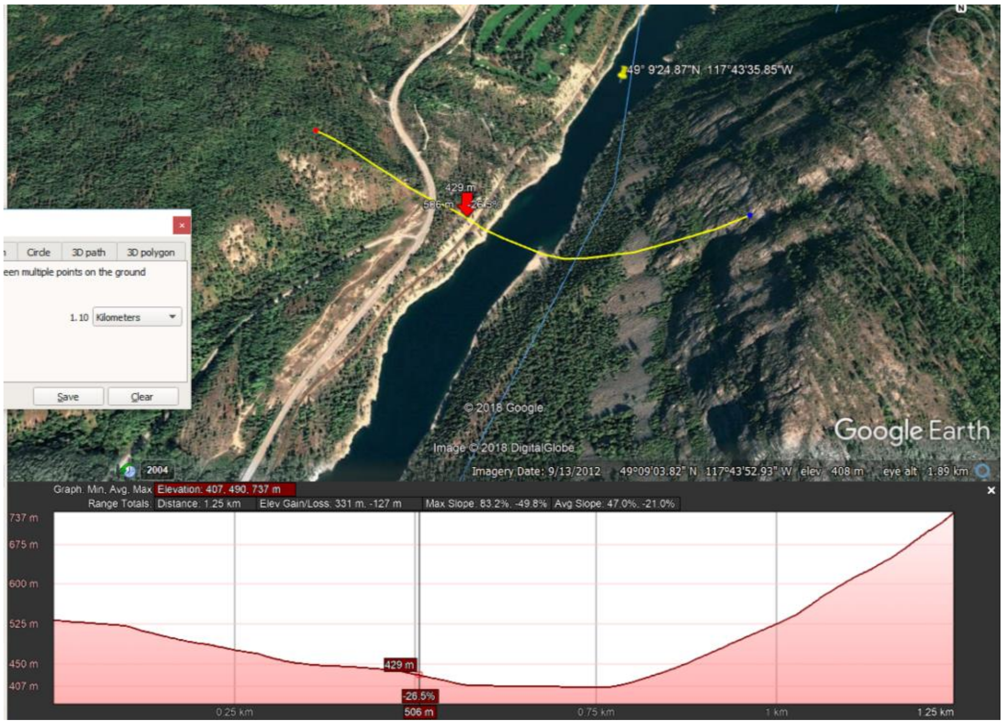
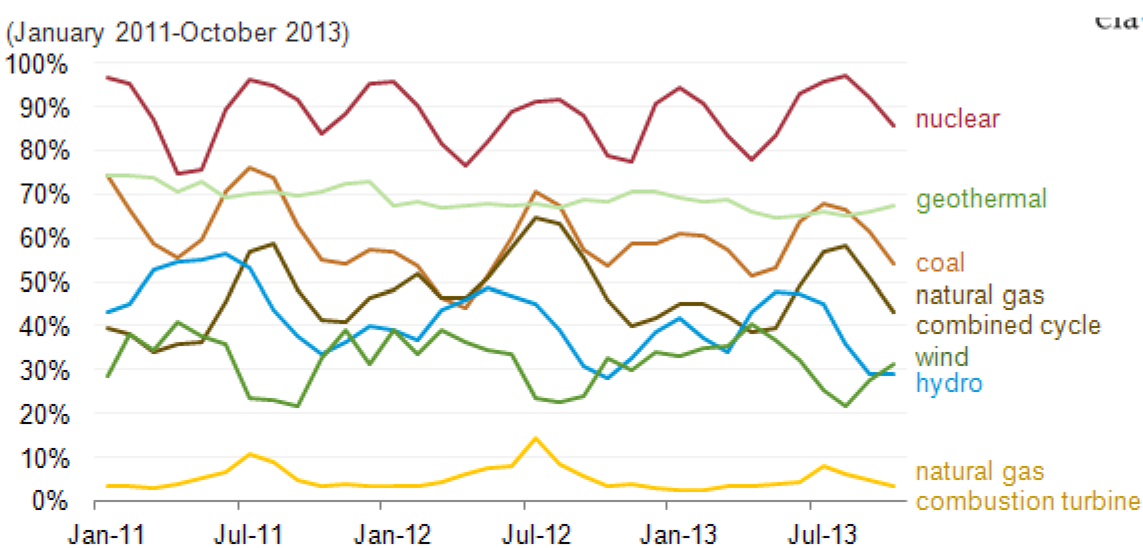


Figure 12 - Capacity Factors for Various Energy Technologies



(https://upload.wikimedia.org/wikipedia/commons/2/21/US_EIA_monthly_capacity_factors_2011-2013.png)

Figure 13 - Cross section of typical spillway with Tainter Gates
[28]

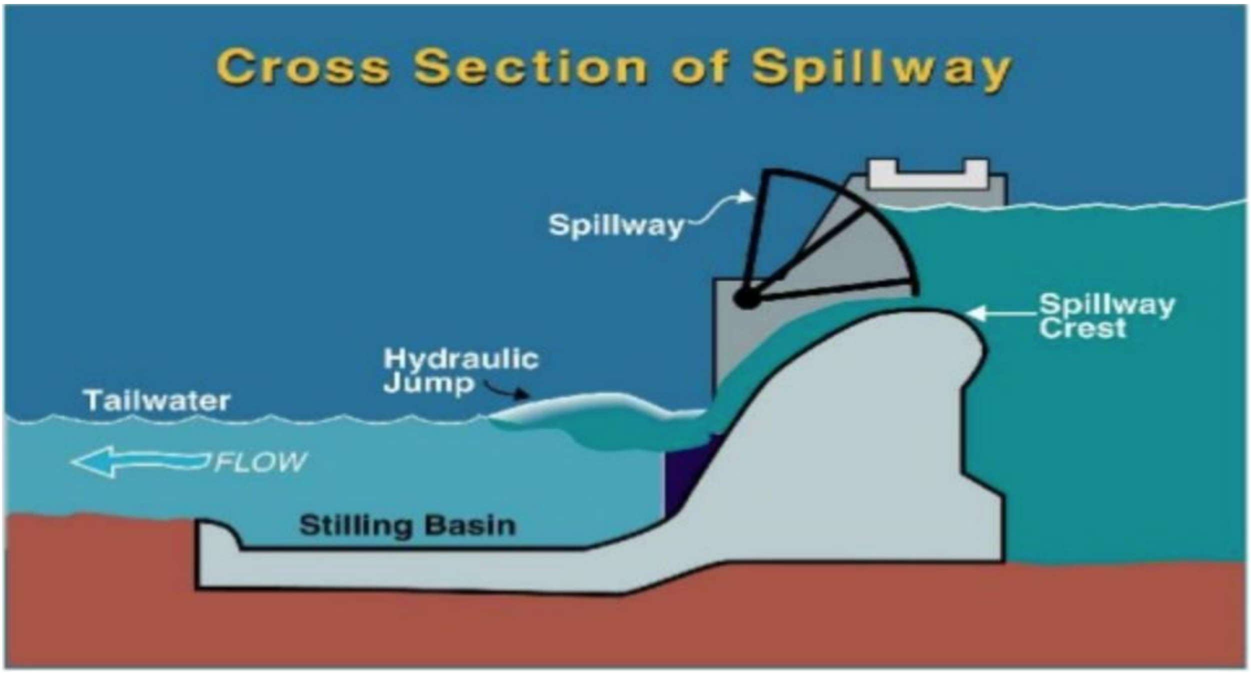


Figure 14 - Variation of GHG Emissions with Capacity for Run-of River for a Small Hydropower Scheme
[33]

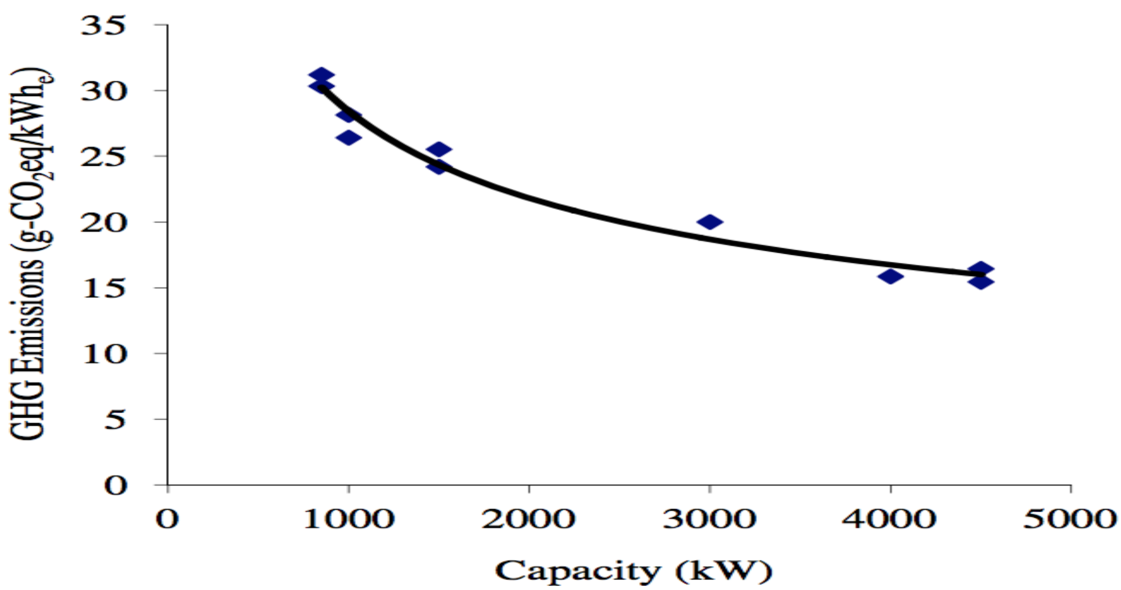


Figure 15 - Variation of GHG Emissions / Capacity with Head for Run-of River for Small Hydropower Schemes [33]

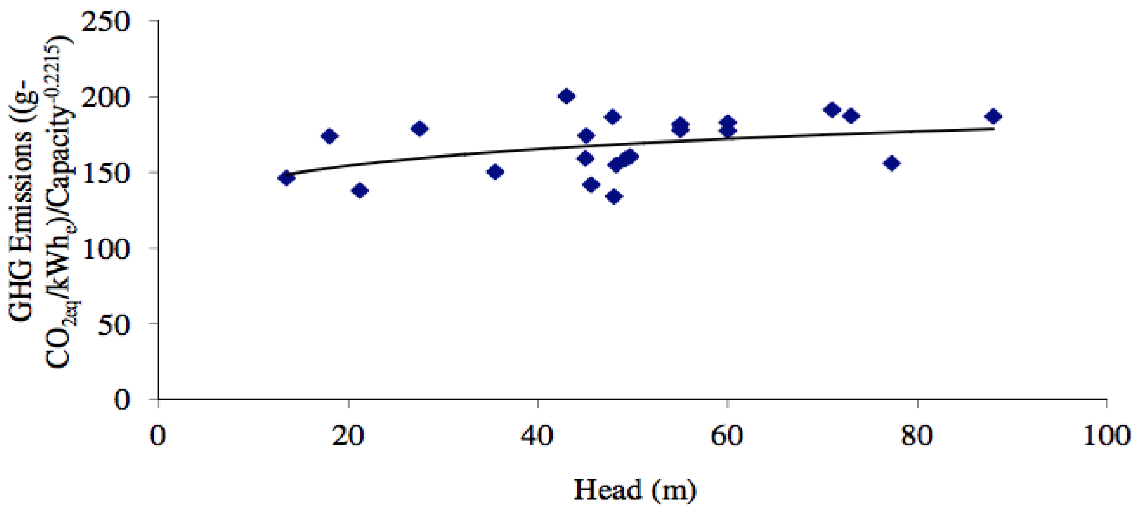


Table 1 - Calculation of Annual Power Output based of 2017 Flow Data

2017	Monthly Mean Flow Rate (m3/s)	Power (MWh)
Jan	3,060	2,295,342
Feb	1,650	1,237,685
Mar	1,480	1,110,166
Apr	2,070	1,552,732
May	3,250	2,437,863
Jun	3,760	2,820,421
Jul	2,810	2,107,814
Aug	2,310	1,732,758
Oct	2,150	1,612,740
Sept	965	723,858
Nov	1,270	952,642
Dec	1,960	1,470,219
	per year	20,054,240

Equation 1 - Calculation of Maximum Power [19]

$P_{max} = ½ \eta \rho Q v^2$ (3)

where :
v = the velocity of the water flow
Q = the volume of water flowing through the turbine per second
ρ = the density of water (10^3 kg/m^3)
but $Q = Av$, where A is the swept area of the turbine blades.

Equation 2 - Calculation of Theoretical Power [19]

$P_{th} = \rho\ q\ g\ h$ *(1)*

where

P_{th} = *power theoretically available (W)*

ρ = *density (kg/m^3) (~ 1000 kg/m^3 for water)*

q = *water flow (m^3/s)*

g = *acceleration of gravity (9.81 m/s^2)*

h = *falling height, head (m)*