Design and Operation of the Multi-Intake 16 MW Box Canyon Run-of-River Hydroelectric Project

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Abstract

The 16 MW Box Canyon Hydroelectric facility, located in southwest British Columbia, Canada was commissioned in early 2016. Knight Piésold Ltd. was retained by Box Canyon Hydro Corporation (a subsidiary of Elemental Energy) for the development phase, detail design and construction phases of the facility. The facility is comprised of three main water intakes, and six small tributary intakes. The water conveyance system includes approximately 7 km of pipeline connecting all intakes to a single 1 km (0.6 mile) long buried high-pressure steel penstock diverting generation flows of up to 3.96 m3/s. The facility operates under a gross head of 516.90 m.

Long-term (>20 years) synthetic stream flow datasets were developed for each creek, based on stream flow monitoring and a concurrent long-term regional discharge dataset. Detailed hydraulic analyses at varying discharge conditions for each creek was required to design a balanced water conveyance system, while also determining the available gross head, net head and hydraulic transient conditions during the operations of the facility.

Hydraulic analyses were completed using fluid dynamics principles and with KYPIPE analysis software. This allowed for comparison of the results and impacts of the theoretical considerations including friction losses and minor losses of the pipelines and penstock. Head losses and hydraulic transient conditions were detailed to define the operation ranges of the facility and to design and select the facility's equipment.

Penstock and pipelines materials were optimized in order to improve performance and lower the overall capital costs of the facility. Valves, instrumentation and generating equipment required careful selection for optimum operation at all design flow conditions, operation pressures and maximum efficiency.

This paper and presentation will provide an overview of the key design challenges and innovative solutions conceived in the development of this multi-intake high-head run-of-river hydroelectric facility.

Intro

The Box Canyon Hydroelectric project, owned, developed and operated by Box Canyon Hydro Corporation (a subsidiary of Elemental Energy) was fully commissioned in early 2016. Knight Piésold Limited assisted the Owner, with concept development, optimization studies, environmental assessment, and permitting, which continued through to detailed design and operational monitoring.

The development of the project started in 2005, when a single water intake and powerhouse project arrangement sized for 5.6 MW on Box Canyon Creek was conceptualised. Through project optimization, inclusion of multiple intakes and tributary stream diversions were assessed and by 2010, the current concept of a multi-intake project was advanced. In 2010, the Owner received a 40-year Electricity Purchase Agreements with BC Hydro (electric utility in the province of British Columbia) and in 2013, the Owner was granted a water license for energy production.

Located in the McNab Creek watershed in southwest British Columbia, approximately 40 km northwest of Vancouver, Canada, the site is relatively hard to access, as it is only accessible by boat. The project has a total installed capacity of 16 MW and will generate on average 46 GWh per year of renewable energy, enough to power approximately 4,500 homes.

The project consists of a network of three run-of-river water intakes and six smaller tributary stream diversions. The water intakes are connected by buried high-density polyethylene pipe and steel penstocks diverting the combined generation flows to the surface powerhouse developing a gross head of 516.9 m. The powerhouse has one 6-jet Pelton turbine and can divert a total of 3.96 m^3/s of water from the intakes. The project is connected to the provincial grid by 138 kV transmission line.

The Box Canyon water intake is located approximately 2.5 km from the powerhouse on Box Canyon Creek, two tributary streams are diverted to the intake headpond. The Marty water intake is located approximately 4.2 km from the powerhouse on Marty Creek, three tributary streams are diverted to the intake headpond and one tributary stream is diverted directly to the penstock. The Cascara water intake is located approximately 2.9 km from the Marty intake. The Cascara water intake connects with the Marty low pressure penstock by an inverted syphon water conveyance pipeline. The Box Canyon penstock and Marty penstock are both connected to a single high pressure penstock that connects to the powerhouse in the lower reach of the McNab Creek. A schematic longitudinal profile of the project is shown in Figure 1.

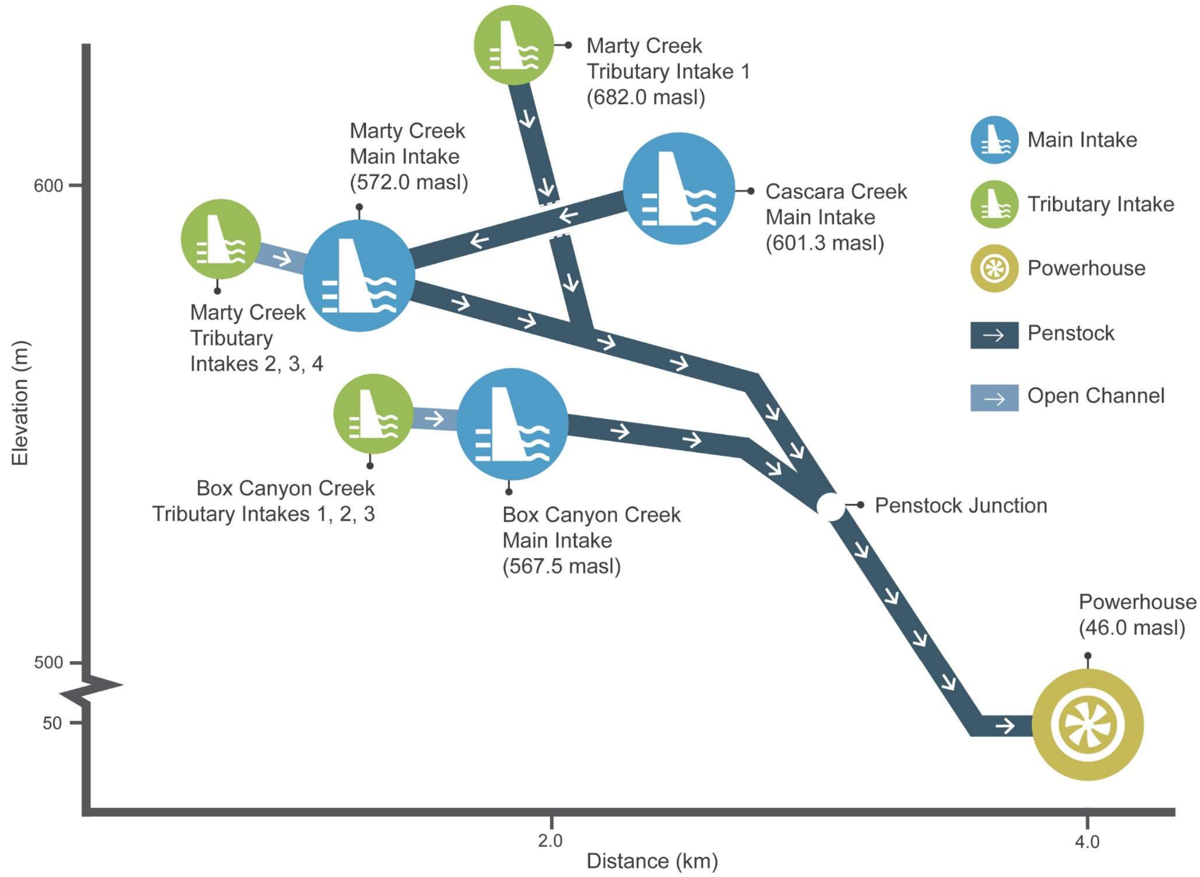

Figure 1: Longitudinal profile of the project. Headpond elevations and turbine centreline elevation are indicated.

The project will generate electricity mostly during late fall and early winter (October - December) as a result of rain and immature snowmelt from snowpack and in the spring and summer (May - July) as a result of freshet and late winter snow and rain events. The watersheds maximum elevations are 1,380 m (Box Canyon Creek watershed) and 1,640 m (Marty Creek and Cascara Creek watersheds) resulting in greater unit runoff and a greater proportion of annual precipitation occurring as snowfall. A schematic plan view of the project and its catchments is shown in Figure 2.

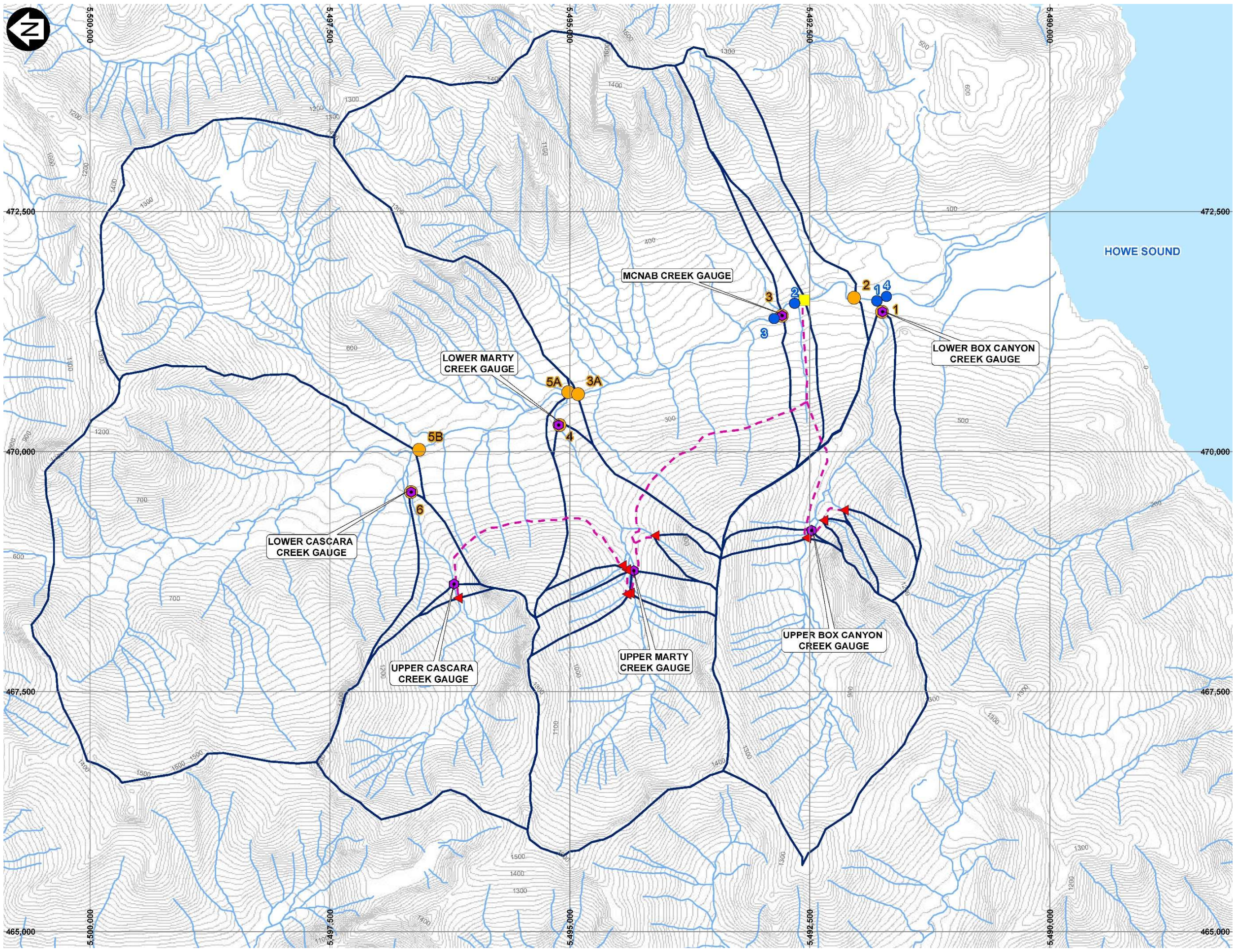

Figure 2: Plan view of the watershed catchments. The water intakes are shown (triangle) and the water conveyance system is shown (dash line).

Design Flow Optimization

During the prefeasibility and feasibility studies of the project, a synthetic daily average flow dataset was created for Box Canyon, Marty and Cascara Creek by regression with data from a nearby Water Survey of Canada (WSC) hydrometric data station. The WSC station had 41-year of reliable discharge records. The Owner installed flow monitoring data loggers at the site of all three intakes and in the lower reaches of the three creeks. Flows were verified by stream gauging.

To comply with federal and provincial permits, the project included the design of instream flow release points (environmental flow) and intake weirs and side openings with elevations designed to hydraulically control the maximum diversion flow. Minimum instream flow releases were set for each month at each intakes, between 0.035 m^3/s and 0.35 m^3/s. Additional releases of any non-diverted flows, in excess of the maximum diversion flows, are released at all intake sites during operation to minimize the effects of changes in downstream water levels of the intakes, reducing the risk of fish stranding.

Once diverted flows available for generation were defined, an economic viability assessment was completed through use of a financial model, that includes energy estimation and estimated project development costs developed for run-of-river hydroelectric projects in British Columbia. Once both hydrologic and financial models were created the installed capacity was optimized by combining the diverted flows of the additional intakes site on the Marty Creek and the Cascara Creek and to include the additional six tributary stream diversions.

Project Optimizations and Overall Hydraulic Design

The design of the project required innovative design solutions and equipment selection, key components include:

- The water intakes are designed to operate with Box Canyon intake as the turbine controlling intake (water level controlled by plant PLC) while Marty Creek and Cascara are operated as passive non-instrumented intakes. Both are located at higher elevation than Box Canyon intake and provide generation flows up to the design capacity of the intakes. The plant's PLC is used to limit generator hunting by controlling the water level at the Box Canyon intake and control ramping events at the intakes.
- A tilting disk check valve was designed on the Box Canyon penstock to prevent back water to the Box Canyon headpond when the water conveyance system is experiencing water levels above the Box Canyon intake elevation (typically at low flow operation from Marty intake or when the plant is in not operating). Valve stroke cushioning was required to reduce the transient conditions during the valve closing and opening strokes to acceptable levels.
- The water intakes were designed with Coanda screen spillways to divert the generating flows while excluding debris and fine sediments, which can decrease the life of water conveyance and generating equipment.
- The water conveyance system and low pressure penstock sections were designed with butt fused high-density polyethylene (HDPE) pipe where allowable to simplify and reduce the cost of installation. The high pressure penstock sections were designed as butt welded steel penstock lined with fast-set, single-coat, 100% solid polyurethane coating and lining allowing the work after welding to be completed relatively quickly by eliminating the need for second pass coating and lining.
- Generation flows are regulated by the 6-jet Pelton turbine and generator. The Pelton turbine allow for low minimum turbinable flow and controlled ramp-down of the generation flows.

Head Loss Estimates

During normal plant start-up, generation flows are diverted from the Marty and Cascara intakes until the net head level of the Marty penstock is equal to the Box Canyon intake water level, at which point, Box Canyon's intake flows are combined with Marty and Cascara intake flows. Figure 3 shows the theoretical head losses at design flow and the measured flows at the turbine flow, under a variety of conditions. Theoretical power generated at rated discharge is illustrated in Figure 4.

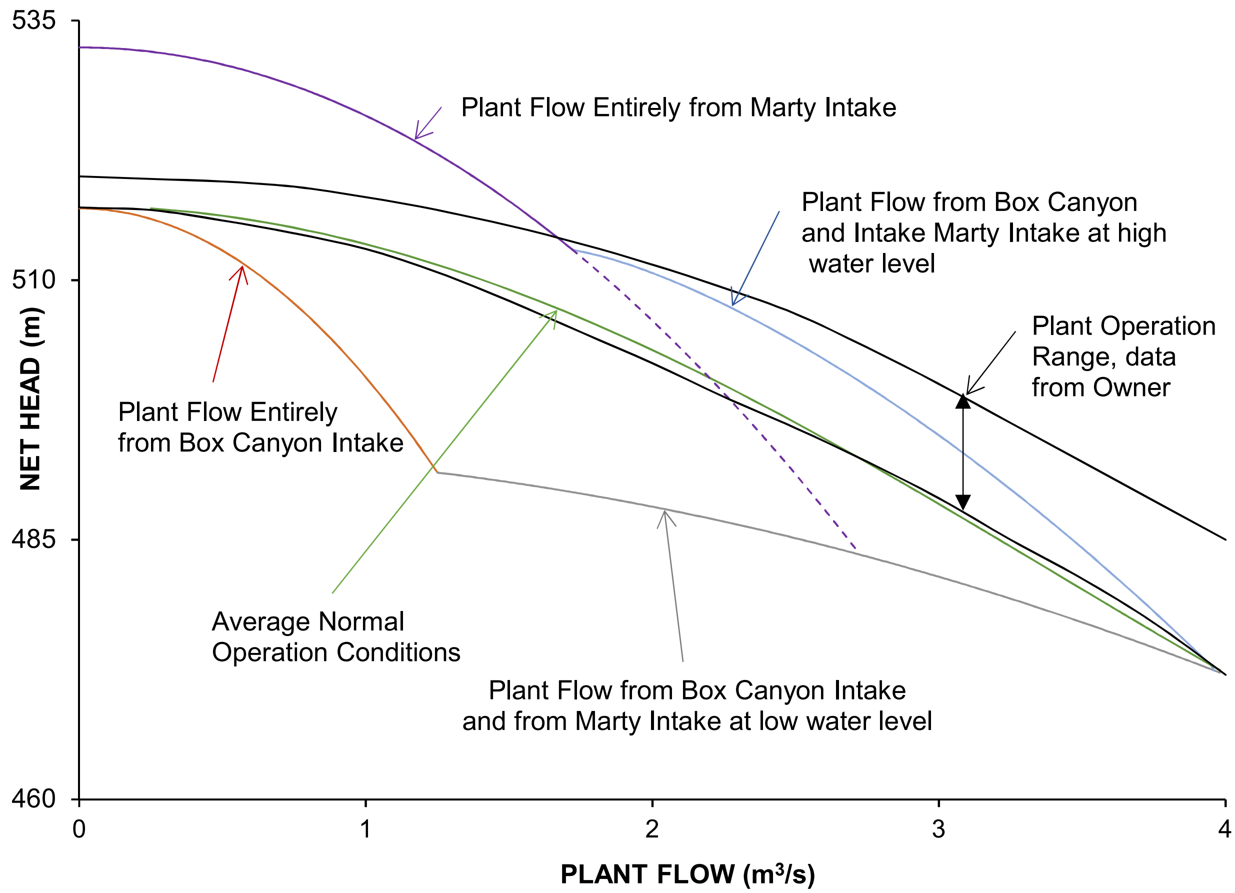

Figure 3: Head loss at the turbine. During the design phase, each possible flow condition was analysed with the synthetic streamflow data to define the required turbine operational range. Plant operation data range for August 2016 to March 2017.

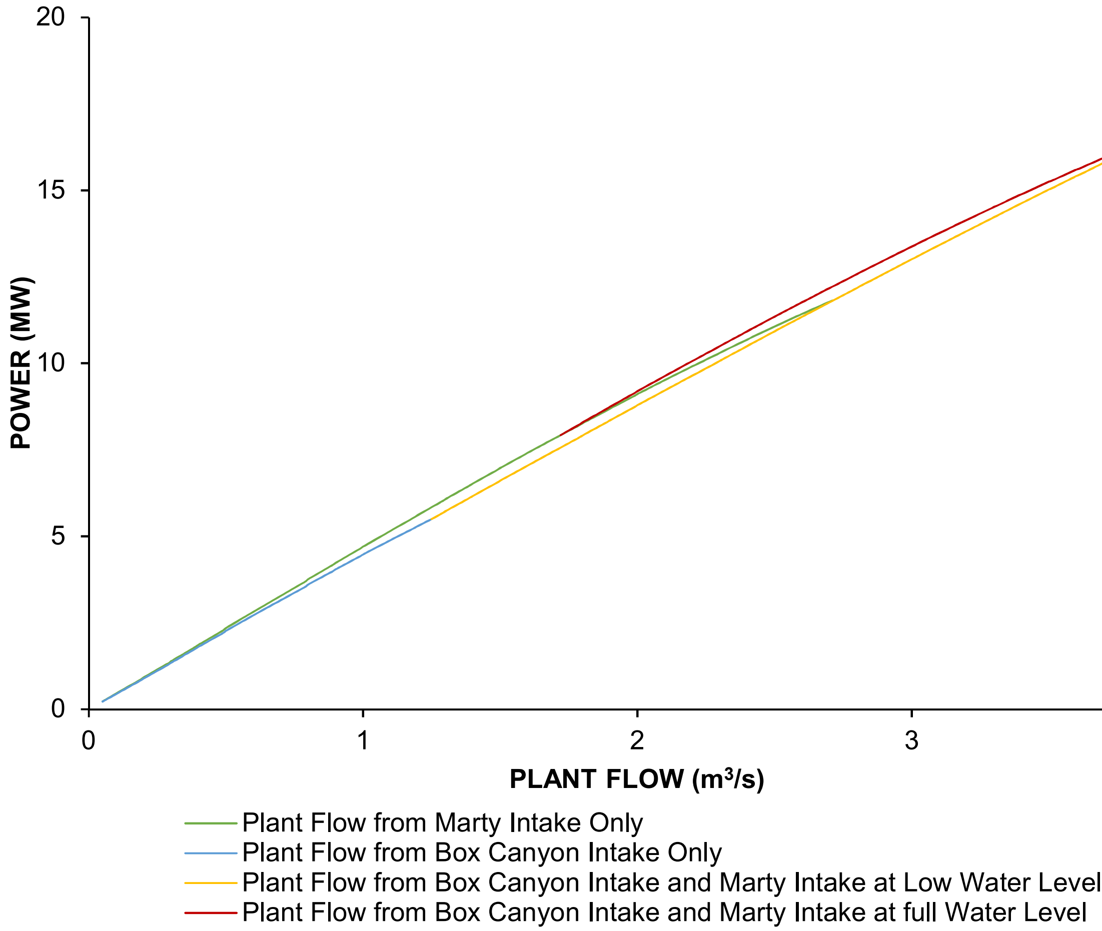

Figure 4: Theoretical power generated at plant discharge with the net head and plant discharge as shown in Figure 3.

A good understanding of the net head at different generation flow conditions was required to define the terms of the water-to-wire contract (turbine design criteria and generating unit performance guarantee), estimate the annual generated energy required for the financial analysis and comply with the terms of the Electricity Purchase Agreement. The turbine manufacturer was requested to design and demonstrate that the turbine and generator are capable of reliable, smooth, stable and vibration-free operation over the entire range of flows and operating heads shown in Figure 3.

Head losses were estimated for the water conveyance system by the classic equation developed by Darcy-Weisbach for energy loss and theory of pipes network in series. Experience with the hydraulic design of long penstocks for run-of-river facilities allow the designer to select friction factors and minor loss coefficients based on experience comparing theoretical values to measured values of other penstocks. The optimal water conveyance system head loss was determined to be approximately 12% with very little financial benefit achieved with further reduction of the head losses.

Hydraulic design of the system was then verified with KYPIPE Pipe 2010 and Surge software package to review the diverted flows as a result of the specified multi-intake conditions. Results from the Pipe 2010 software were in general accordance with the theoretical calculated head losses. The maximum and minimum transient pressures of the water conveyance system due to the operation conditions were also verified with the Surge software.

Conclusion

Understanding the hydraulic operation parameters of a multi-intake hydroelectric facility is important to analyse generation capacity and for optimal equipment selection. Validation of classic theory can be achieved by utilizing numerical hydraulic modeling software for pipes systems in series and through experience to better understand the implications of equipment selection and head loss effects.

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