# Design of the Box Canyon scheme

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The article outlines the innovation and challenges involved in the hydraulic design of the Box Canyon run-of-river hydro project in Canada, which is equipped with nine intakes on different waterways.

The 16 MW Box Canyon hydroelectric project ranks among the most hydraulically complex of any run-of-river hydro project in North America, if not the world. The project, which is located in the McNab Creek watershed, 40 km northwest of Vancouver, British Columbia, has nine intake structures on different creeks and tributaries. All nine feed into a single, high-pressure penstock that directs water to the powerhouse containing a single six-jet vertical axis Pelton generating unit.

The owner, Box Canyon Hydro Corp (a subsidiary of Elemental Energy Inc.) retained Knight Piésold Ltd to assist with:

- concept development, optimization, environmental assessment, and permitting;
- detailed design; and,
- operational monitoring of the facility.

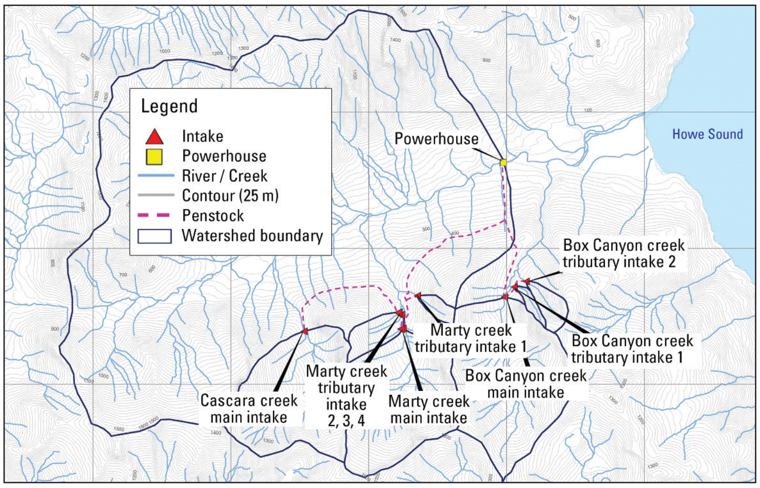


*Fig. 1. General arrangement of the Box Canyon scheme showing its complexity.*

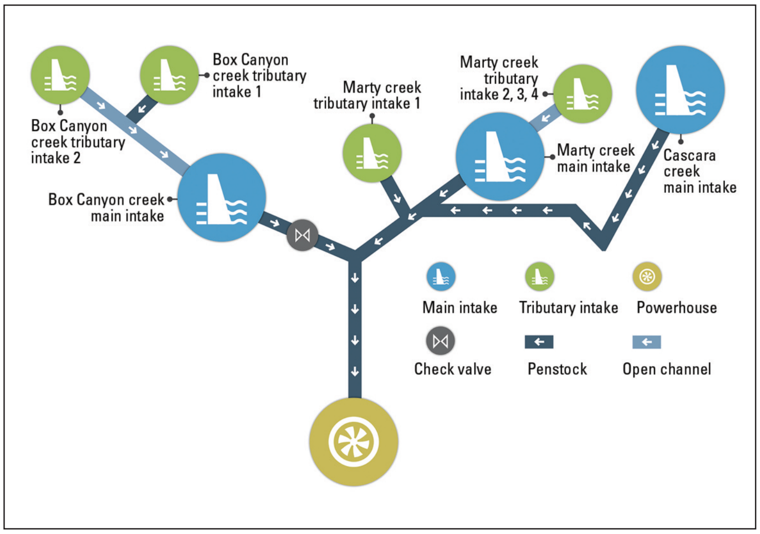


*Fig. 2. Schematic highlighting the complexity of the Box Canyon project.*

| Main features of the project | |
|---|---|
| Rated capacity of the plant (MW) | 16 |
| Intakes (No and type) | 3 main and 6 tributary |
| Design flow ($m^3/s$) | 3.96 |
| Penstock length (km) | 8.6 |
| Penstock inside diameter (mm) | 665 to 967 |
| Gross head (m) | 516.9 |
| Turbine type | Pelton unit, 6-jet vertical axis |
| Transformers (kV) | 13.8 to 138 |
| Transmission line: | 2.8 km of 138 kV |

Initial investigations began in 2004, at which time the project concept was a 7 MW facility with a single intake on Box Canyon creek. Through optimization studies, which included site investigations and detailed hydrological studies, Knight Piésold revised the design to the current 16 MW arrangement. The design required addressing hydraulic, waterhammer and environmental flow release complexities, which are not typical for a single intake, run-of-river hydro project.

The project is within the traditional territory of the Squamish Nation, a valued partner on the project, and includes intake structures on three main tributaries to McNab Creek (Box Canyon, Marty, and Cascara Creeks) as well as six minor tributary diversions. Each intake is designed to meet unique water licence conditions that are intended to address the various hydrology, river morphology, and fish species distributions along the creeks and tributaries. The general arrangement and a schematic of the project are shown in Figs. 1 and 2. Key components of the project are highlighted in the photographs, and details for the major components of the project are summarized in the Table.

## Project optimizations and overall hydraulic design of the scheme

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

- The water intakes are designed to operate with the 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 elevations

*The Marty Creek intake.*

*Nine intake structures feed into this high-pressure penstock.*

than the 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 water backing up the Box Canyon penstock to the headpond when the water conveyance system is experiencing net head levels above the Box Canyon intake elevation. The check valve prevents the backing up of water during events such as start-up, operation below design flow, or when the plant is in not operating. Valve stroke cushioning was required to reduce the transient conditions during the valve closure 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 could decrease the life of the water conveyance and generating equipment.

• Generation flows are regulated by the six-jet Pelton turbine and generator. The Pelton unit can operate at low minimum turbinable flows and provide controlled ramp-down of the generation flows.

## Head loss estimates

Although the hydrology at each intake is relatively similar, there are differences in the timing and magnitude of flows available for generation at each intake. This, combined with differences in the penstock length, diameter and material in each penstock branch, mean that a unique net head versus plant flow relationship cannot be defined for the facility. 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) and estimate potential energy generation. 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.

*Aerial view of the powerhouse and substation.*

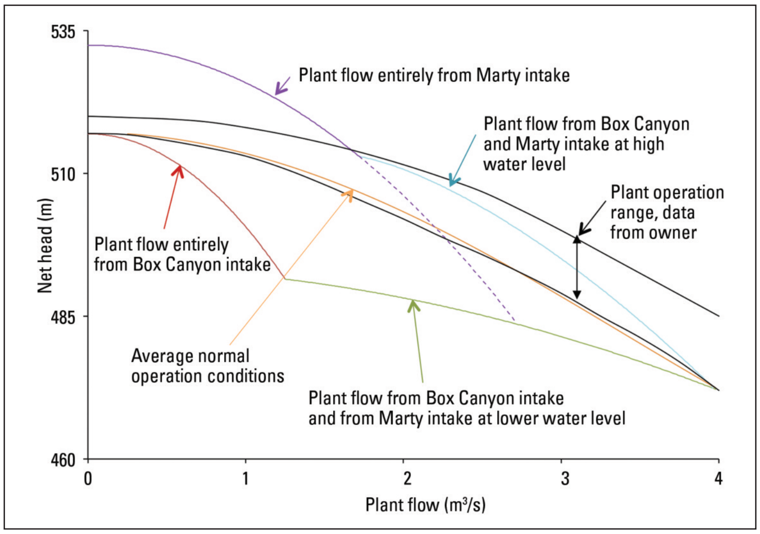


*Fig. 3. Net head at the turbine. During the design phase, each possible flow condition was analysed with the synthetic streamflow data to define the required turbine operational range. Measured operations data were provided for August 2016 to March 2017.*

The theoretical range of net head versus turbine flow, under numerous possible operating conditions, is shown in Fig. 3. Head losses were estimated for the water conveyance system using the classic equation developed by Darcy-Weisbach for energy loss 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. Hydraulic design of the system was then verified with KYPIPE Pipe 2010 and Surge software packages.

The project has been operational since April 2016. Nine months of measured operational head and plant flow data were compared with the predicted conditions, and as shown in Fig. 3, there is generally good agreement. At higher flows, the predicted net head tends to underestimate measured conditions.

## Conclusion

The Box Canyon hydro project is a unique and hydraulically complex facility. Knight Piésold combined proven approaches with unique solutions to design this facility. A comprehensive understanding of the hydraulic operation parameters of a multi-intake hydroelectric facility was important to determine generation capacity and for optimal equipment selection. Validation of classic theory was achieved using numerical hydraulic modelling software for pipe systems in series, and through experience to better understand the implications of equipment selection and head loss effects. The plant has been successfully operating since April 2016. ◊


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