OPERATION OF THE MULTI-INTAKE BOX CANYON RUN-OF-RIVER HYDROELECTRIC PROJECT TO MEET ENVIRONMENTAL COMMITMENTS

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ABSTRACT

The Box Canyon Hydroelectric Project is a 16 MW run-of-river facility located in the McNab Creek watershed on the north side of Howe Sound, British Columbia, Canada. The Project includes intake structures on three of the tributaries to McNab Creek (Box Canyon, Marty and Cascara Creeks) as well as six minor tributary diversions, all of which feed into a single high pressure penstock to direct water to the powerhouse. With this arrangement, it may have the most hydraulically complex design of any run-of-river hydroelectric project in North America, if not the world. The powerhouse includes a single, multi-jet Pelton turbine and water is returned to McNab Creek. The Project is connected to the BC Hydro transmission system via a 2.8 km long, 138 kV transmission line.

Knight Piésold Ltd. was retained by the owner, Box Canyon Hydro Corporation (a subsidiary of Elemental Energy) to assist with 1) concept development, environmental assessment and permitting, 2) detailed design, and 3) operational monitoring of the facility. The Project was commissioned in early 2016.

Under the Project's Water License, the Project has maximum allowable diversion rates, minimum instream flow requirements (IFR) and maximum flow ramping rates. These requirements are different for each intake and in McNab Creek, due to differences in hydrology, river morphology and fish species distribution.

The IFR requirement at each intake is controlled by the intake design to ensure that IFR is released as priority before water is able to be diverted for power generation. Similarly, the maximum diversion rate is controlled by the intake design, which passively limits the maximum amount of water that is able to enter the penstock. However, flow ramping must be controlled by plant operation.

This paper will provide an overview of the Project's key Water License commitments and how the Project was designed and is operated to meet these commitments.

Introduction

The Box Canyon Hydroelectric Project is a 16 MW run-of-river facility located in the McNab Creek watershed on the north side of Howe Sound, British Columbia, Canada. The Project is within the traditional territory of the Squamish Nation—a valued partner on the Project.

The owner, Box Canyon Hydro Corp. (a subsidiary of Elemental Energy Inc.) retained Knight Piésold Ltd. to assist with (1) concept development, optimization, environmental assessment, and permitting, (2) detailed design, and (3) operational monitoring of the facility. 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 hydrology studies, Knight Piésold revised the design to the current 16 MW arrangement.

The Project, which was commissioned in early 2016, diverts water from high elevation intakes and returns the water further downstream, resulting in a diversion section with reduced flow. Water is diverted from multiple intakes—each designed to address the unique hydrology, river morphology, and fish species distribution along McNab Creek and its tributaries—introducing challenges not typical in a run-of-river hydroelectric project with a single intake. There are intake structures on three of the tributaries to McNab Creek (Box Canyon, Marty, and Cascara Creeks) as well as six minor tributary diversions, all of which feed into a single, high-pressure penstock to direct water to the powerhouse on McNab Creek. Key details for the major components of the Project are summarized as follows:

- Rated capacity of the plant: 16 MW
- Design flow: 3.96 m^3/s
- Penstock length: 8.6 km (diameter: 665 mm to 997 mm ID)
- Gross head: 488 m
- Turbine(s): 1 x Pelton unit, 6-jet vertical axis
- Switchyard: 13.8 kV to 138 kV transformers
- Transmission line: 2.8 km of 138 kV transmission line

This complex arrangement, which is unique in British Columbia, required detailed investigation, assessment and design considerations to assure permitting agencies of its operational capabilities and address the conditions of the Water License.

Figure 1: Marty Creek intake (left) showing the Coanda screen intake and side-spill weirs. Powerhouse and substation (right) adjacent to McNab Creek.

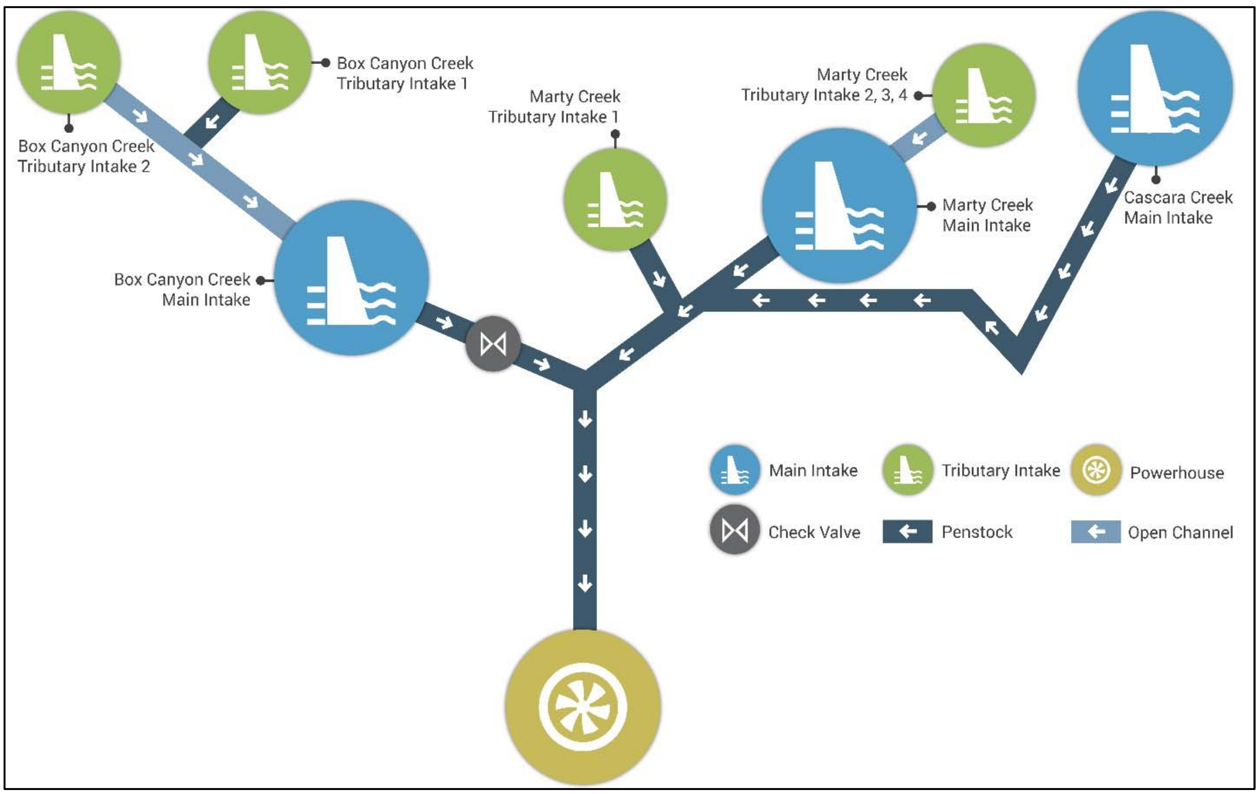

Figure 2: Project Schematic

Key Water License Conditions

The Project's Water License is one of the key permits required to allow operation of a hydroelectric facility in British Columbia (BC). It is regulated by the BC Ministry of Forests, Lands and Natural Resources Operations (FLNRO), in consultation with other Provincial and Federal agencies. There are three primary water license conditions that affect how the Project can operate, namely instream flow requirement (IFR), maximum diversion rate and ramping rates. These conditions are determined through the environmental assessment and permitting process to avoid environmental impact, while allowing beneficial use of the Provinces water resources.

The Box Canyon Project is a run-of-river, flow-diversion, hydroelectric facility. Water is diverted from each of the intakes, into the penstock and returned to the Creek at the powerhouse. When the plant is diverting water, instream flow is reduced through the diversion section. The IFR was determined following the BC Instream Flow Methodology (Lewis et. al., 2007). Much of the Projects diversion section is non-fish bearing, although the lower reaches include resident and anadromous salmon and trout. The assessment considered connectivity and geomorphic processes throughout the diversion section and hydraulic habitat assessment (PHABSIM) in fish bearing reaches. The licensed IFRs vary by intake and month, to meet the varied physical and biologic conditions in each stream, and range from 0.035 m^3/s to 0.35 m^3/s. Mean annual discharge in Box Canyon, Marty, Cascara Creek intakes are 0.88 m^3/s, 0.77 m^3/s and 0.63 m^3/s, respectively. While the mean annual discharge in McNab Creek at the powerhouse is 6.7 m^3/s.

The maximum diversion rate limits the amount of water that is able to enter the penstock and also affects the magnitude and timing of water within the diversion section. This parameter is guided by the design optimization, as an oversized diversion rate is not economic, and also guided by environmental requirements to supplement IFR releases and provide high flows for sediment mobilization and geomorphic processes. The licensed maximum diversion rate is specified for each intake and ranges from 1.25 m^3/s to 1.4 m^3/s at the main intakes and 0.065 m^3/s to 0.125 m^3/s at the tributary intakes.

Flow ramping is the progressive alteration of discharge in a stream channel resulting from the operation of a hydroelectric project and may present risk to the environment or people. When the Project starts up, flows within the diversion section are reduced and flows downstream of the tailrace are increased. The opposite response occurs during a shutdown; increasing flow in the diversion section and decreasing flow downstream of the tailrace. Rapid reductions in water level have the potential to strand and kill fish. In order to avoid this, the Project must limit stage (water level) change to meet guideline ramping rates. The BC guidelines specify that the stage change at ramping sensitive sites must be less than 2.5 cm/hr during critical times of the year (for example, fry present periods) and 5 cm/hr at all other times (Knight Piésold, 2005). In order to meet these criteria, the plant must provide unique rates in Box Canyon and Marty Creeks during start-up and McNab Creek during shutdown. To meet the guideline criteria in McNab Creek, the plant diversion rate can vary by approximately 0.5 $m^3/s/hr$ and 1 $m^3/s/hr$, to meet the 2.5 cm/hr and 5 cm/hr criteria. Because stage and discharge are not linearly related, the plant flow change rate varies depending on streamflow, which changes as the plant shuts down. Hence a shutdown from full design flow to zero flow, can take many hours. Similarly for a start-up, where the plant diversion rate can vary by approximately 0.1 m^3/s/hr and 0.2 m^3/s/hr, to meet the 2.5 cm/hr and 5 cm/hr criteria. However, as the compliance criteria relate to instream stage change rates, there are some mitigating factors that generally reduce the required start-up and shutdown times.

Operation to meet IFR and Maximum Diversion Rates

The intakes on Box Canyon, Marty and Cascara Creeks consist of concrete and earthfill weirs, which provides controlled entry into the penstock. Water flows over the weir and into the collection channel via a Coanda screen. IFRs are released from the headpond via an IFR release pipe. The inlet to the IFR release pipe is located to avoid blockage from ice and debris and ensure that IFRs are released as priority before water is diverted for energy production. A knife gate on the release pipe allows the IFR to be adjusted seasonally and instream flow is measured continuously downstream of each main intake via a streamflow gauging station and associated rating curves.

Maximum diversion rate is limited in two ways at the Box Canyon, Marty Creek and Cascara Creek intakes. Firstly, the Coanda screen intake has a limited capacity, specified per unit length of screen. However, Coanda capacity is greater than the allowable maximum diversion rate to account for partial blockage that can occur from snow, ice and debris (typically, tree leaves and needles). This is a common intake design approach in BC. Typically, these projects then limit the maximum diversion rate with turbine control. Due to the intake and penstock arrangement at the Box Canyon Project, maximum diversion flow at each intake cannot be limited by turbine control, so the maximum diversion rate at each intake must be passively controlled. A weir at the inlet to each penstock (internal weir) and side spill weirs that discharge the creek downstream of the intake are used. The side spill weir at the Marty Creek intake is shown on Figure 1 and in detail on Figure 3. The maximum diversion rate is controlled by the relative elevation of the internal weir and side spill weir crest elevations. Stop-log slots allow adjustment of the side spill weir elevation and therefore adjustment of the maximum diversion flow. Maximum diversion rate will be verified by concurrent flow measurements upstream and downstream of the intake.

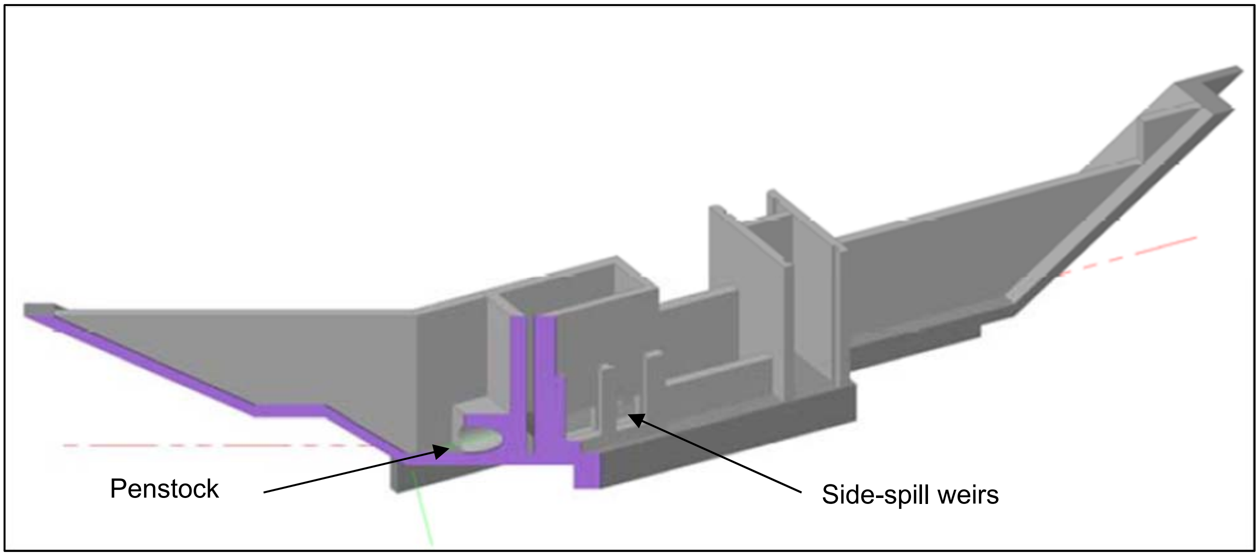

Figure 3: Isometric view of Marty Creek intake concrete works showing the side-spill weirs, which are used to control the maximum diversion rate.

Operation to meet Ramping Rates

The three main intakes are connected to a single high pressure penstock and the intakes are at different elevations. Consequently, the start-up or shutdown procedure is limited by the ramping rates at each intake during different portions of the procedure. The Project is shown schematically on Figure 4. The following sections describe a start-up and shutdown scenario.

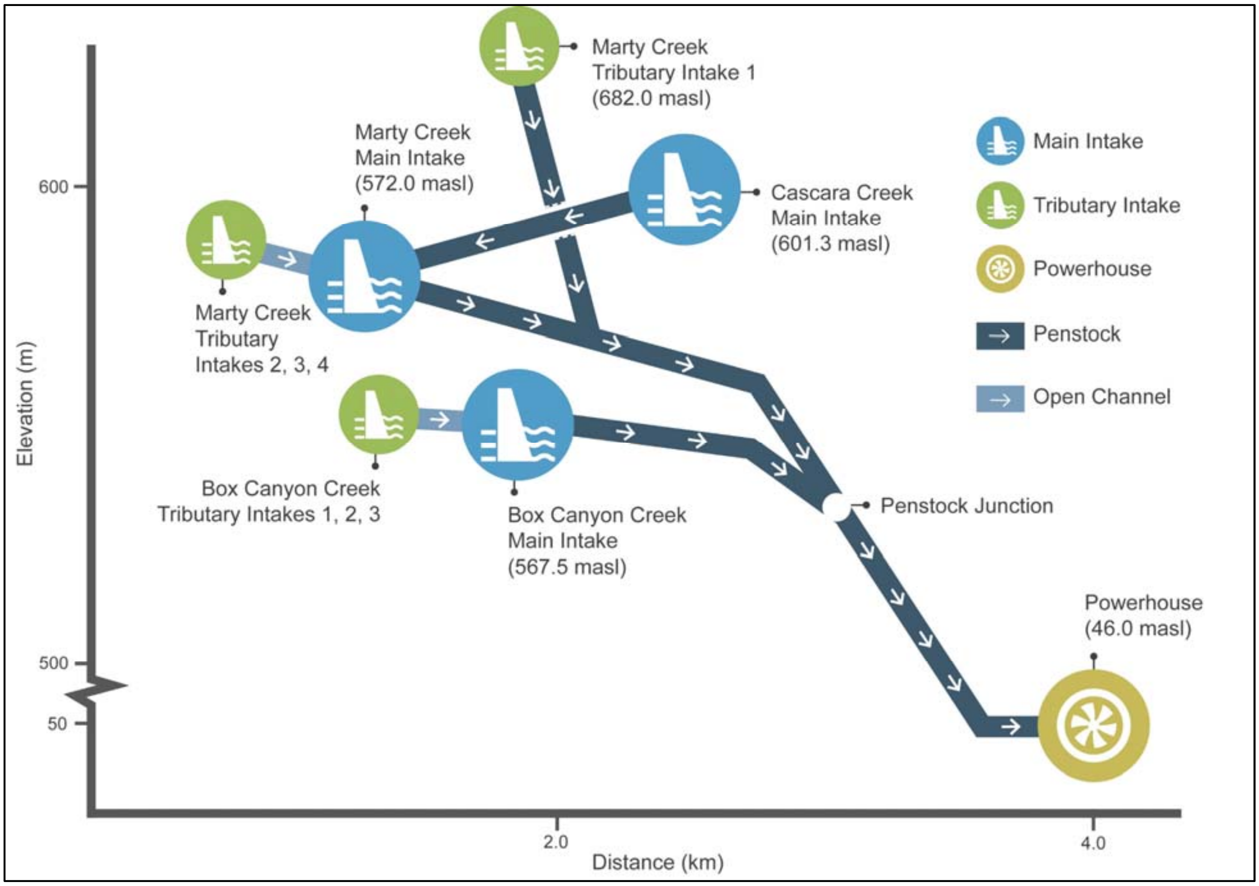

Figure 4: Intake elevation and penstock length schematic.

Ramping During Start-Up

During a start-up, flows are reduced in the diversion section and ramping is limited by the rates specified for Cascara, Marty and Box Canyon Creeks. For the purpose of this example, let's assume that available flow (defined as instream flow less IFR) in all creeks is approximately 50% of the maximum diversion rate.

If the plant is not operating, the check-valve is closed the Box and Marty penstocks are full. Water is spilling over the Box Canyon and Marty Creek intakes. Water is being diverted from the Cascara intake to Marty intake and spilling into Marty Creek downstream of the intake. As the plant starts up, water is taken from Marty Creek and the plant must be controlled to meet the Marty Creek ramping rates. The plant does not cause ramping in Cascara Creek. The plant continues to take more water until it is taking all available flow from Marty and Cascara Creek. At this point the Marty penstock branch begins to dewater and the full-pipe level begins to drop. During this period the plant does not cause ramping in any streams. This continues until the net head in the Marty penstock is less the Box Canyon branch and the check value opens, at which point the plant begins to take water from Box Canyon Creek and plant flow change is controlled by Box Canyon Creek ramping rates.

Once operating, any fluctuations in plant flow must be controlled to meet Box Canyon ramping rates. Head and penstock water level during a start-up are shown on Figure 5.

Ramping During Shutdown

During a shutdown, the plant flows causes streamflow to reduce downstream of the powerhouse and ramping is limited by the rates specified for McNab Creek. If the shutdown is due to an unscheduled outage (e.g. transmission line trip), the Pelton turbine deflectors move into place rapidly and the turbine and generator can be stopped, but penstock flow is reduced slowly to meet ramping rates.

As shutdown commences, flows spill from the Box Canyon intake and the full penstock water level in the Marty penstock increases until the check valve closes. Following this, the Marty penstock fills until flows begin to spill from the Marty intake.

Given the long duration that may be required for a full shutdown and subsequent start-up, the turbine and generator feature a hot resync feature that allows the turbine to be reengaged partway through a shutdown, while maintaining ramping requirements.

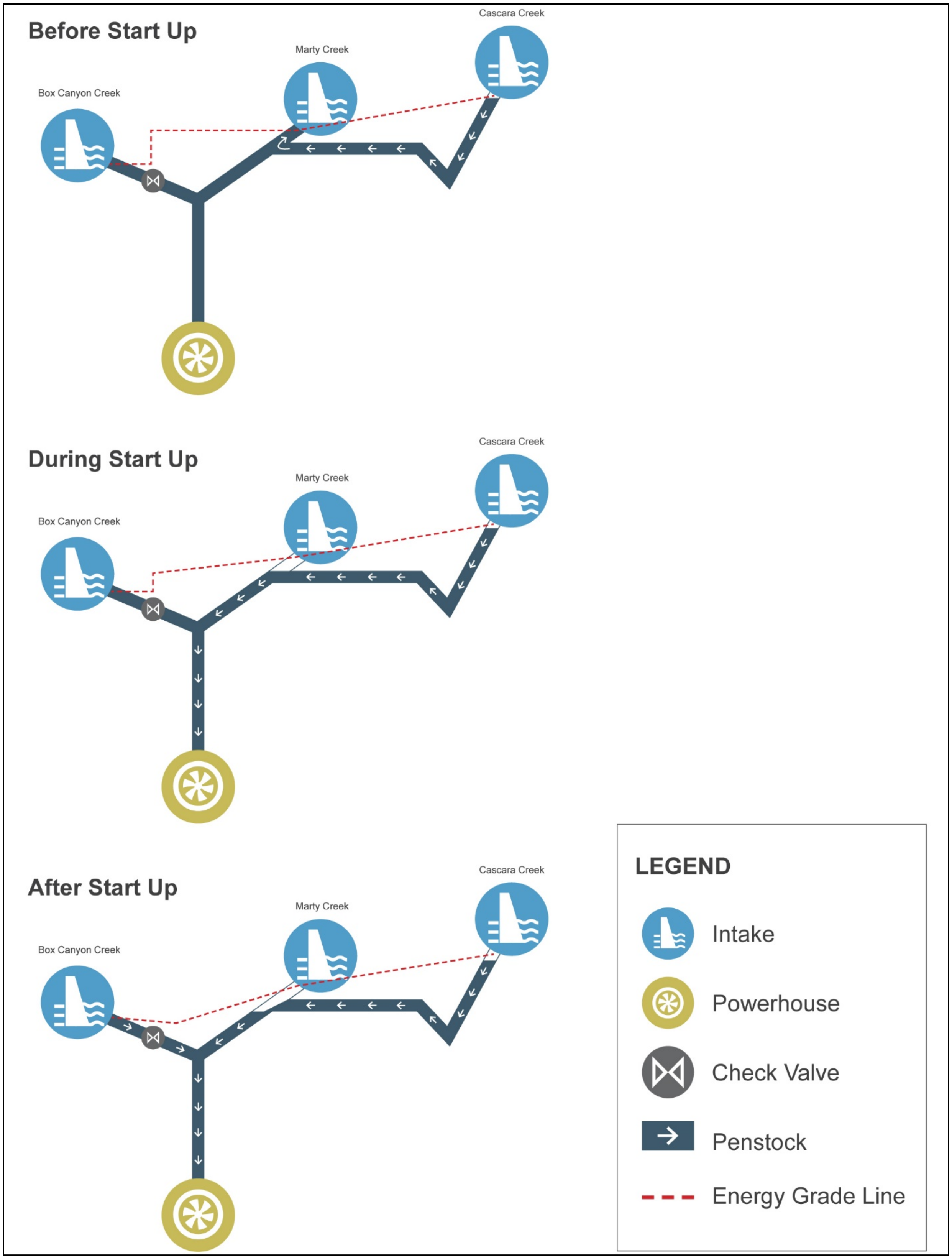

Figure 5: Head and penstock water level before, during and after start up.

Operational Experience

The plant has been successfully operating since April 2016 and the IFR, maximum diversion and ramping rate control scenarios as described are generally applicable. However, the descriptions provided above describe the gradually varied hydraulic conditions and certain operational scenarios have been more complex. For example, during higher flow conditions, when all intakes are operating at the maximum diversion rate, the Marty penstock does not dewater (gross head in the Marty and Box penstocks are balanced) and ramping can occur simultaneously at the Box Canyon and Marty intakes. Despite this, through diligent operation and monitoring, these complexities are able to be managed by the control systems put in place to meet Water License conditions.

References

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