

Pemberton Creek IPP

A FEASIBILITY REVIEW FOR THE DEVELOPMENT OF A SMALL HYDRO PROJECT ON PEMBERTON CREEK

As a component of its **2007 Strategic Plan**, the Village of Pemberton has engaged Summit Power Management Inc. to prepare the following study exploring the opportunities for developing a run-of-river small hydroelectric project on Pemberton Creek. This report was prepared under the terms of reference of a Request for Proposals issued by the Village of Pemberton in October 2007 for a "Feasibility Study for Pemberton Creek IPP"

1. Pemberton Creek Watershed

The Pemberton Creek watershed is located immediately west of the town of Pemberton, approximately 30 km north of Whistler, in the Pacific Ranges of B.C.'s Coast Mountains. The watershed encompasses an area of 51 km² ranging in elevation from 210 m at its confluence with the Lillooet River to 2438 m at the peak of Mount Ipsoot, 12.5 km west of the Village of Pemberton. The catchment area is 31.9 km² upstream of the Water Survey of Canada gauging site (08MG025) and 31.25 km² above the Village's former water intake location. The creek drains an elongate hanging valley approximately 10 km in length characterized by steep side walls and a relatively flat bottom, except where the valley narrows and steepens above the Village of Pemberton. (Cameron, 1991). Provisionally, two potential intake sites were identified in the upper reaches of the Pemberton Creek basin (Figure 1); intakes at elevations of 875 m and 1050 m would have catchment areas of 21.6 km² and 17.6 km² respectively.

Pemberton Creek flows through three biogeoclimatic zones, Alpine Tundra, Mountain Hemlock and Coastal Western Hemlock Zone with subzone variants ranging from southern dry subarctic (CWHds1) to leeward moist maritime (Mhmm2). Environment Canada classifies more than half of the watershed as old forest with only 11% as previously logged, young forest. Almost 37% of the watershed is considered alpine above tree line, including glacier, rock and chutes affected by avalanche. Less than 1% is considered urban. Pemberton Creek (Watershed Code is 119-487400, which includes One Mile Lake), exhibits a hydrologic regime predominantly driven by snowmelt; with much of the annual flow volume occurring during the period of May to August.

From the Ipsoot Glacier headwaters, Pemberton Creek flows through three distinct reaches; the deposition reach (5% grade, 4500 m long), the waterfall reach (18% grade, 4000 m long) and the alluvial fan (0.7% grade, 4500 m long) (Nichols, 2001).

The basin consists entirely of granitic rock of the Coast Plutonic Complex (Nichols, 2001). Pemberton Creek landforms, including the bedrock peaks and the lower V-shaped gullies cut through the bedrock, are due to the glaciations during the Pleistocene Epoch, of which the Fraser has left the most evidence (Stewart, 2001).

Land Use for Pemberton Creek

The Pemberton Creek watershed lies within the traditional territories of the Lil'wat First Nation, and dialogue with the Lil'wat regarding a potential small hydro development will be important to its successful advance.

Though the village of Pemberton and the attendant settlement and infrastructure occupy the lowest, "alluvial fan" sections of the basin, the upper reaches of the Pemberton Creek watershed are

largely undeveloped. The 2001 Community Watershed Assessment Plan describes land use within the Pemberton Creek watershed as follows:

“Within the upper basin, Forestry is the primary land use at this time, with an allowed annual cut of 2500 m³/yr, averaged over a five-year period. Harvesting has removed approximately 86 ha of timber in the PCCW, with another 44 ha planned for harvesting in the 2000-2004 development plan. Only blocks belonging to Talbot Logging are shown on the current development plan map; however, Category I blocks belonging to Western Forest Products and Weyerhaeuser located inside the PCCW have been included in this CWAP. Approximately 7.9 km of road has been built, with another 2.5 km planned for construction. The PCCW has relatively low recreation value at this time because of limited access. A heli-skiing operation based out of Whistler utilizes Ipsoot glacier at the Pemberton Creek headwaters.”

Timber harvesting activities are on-going within the basin.

Pemberton Creek above the Village of Pemberton is very steep and despite an easily accessible trail from town, there is thought to be little recreational value. There is a heli-skiing tenure on Ipsoot glacier, but it is relatively inaccessible for snowmobiles.

Mineral exploration and development activity within the basin is relatively minimal. There have been two mineral claims in the Pemberton Creek watershed in an area formerly used as a rifle range. Both claims have since lapsed. The claims identified two areas with elevated copper, molybdenum, lead, zinc and gold values in soils and bedrock over an area up to 70m wide and 1.5km long, north of Pemberton Creek (Cameron, 1991). A search of Mineral Titles Online BC (<http://www.mtonline.gov.bc.ca/>) indicates that there are no mineral claims registered in the Pemberton Creek watershed as of the February 2008.

Pemberton Creek watershed has high value non-timber forest products in its annual mushroom production. Species available include, but are not limited to, Pine Mushrooms (*Tricholoma magnivelare*), lobster mushroom (*Hypomyces lactifluorum*), Chicken-of-the-woods (*Laetiporus sulphureus*), Morel (*Morchella spp.*), hedgehog (*Hydnum repandum*) and white and golden chanterelles (*Cantharellus subalbidus* and *C. formosus*).

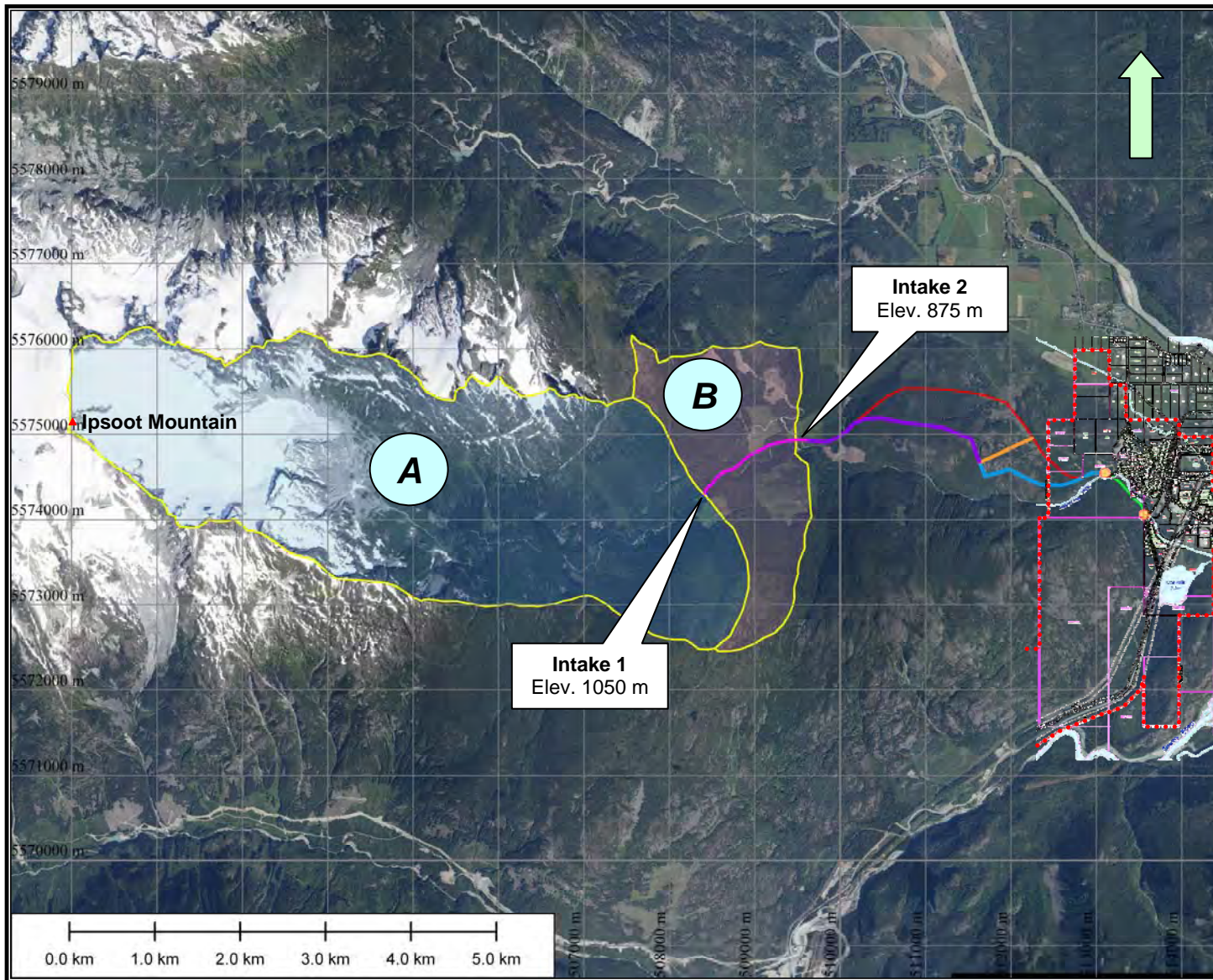
- o Consultation and communication with First Nations, commercial and recreational stakeholders, and the public in general, will be an important aspect of a successful development of a small hydro project on Pemberton Creek. Accommodation of those interests may have a significant bearing on the technical and financial viability of the project.

Pemberton Community Watershed

Pemberton Creek is the “named source” of the **Pemberton Community Watershed** (Community Watershed Code 119.004), officially designated 15 June 1995 under the provisions of the B.C. *Forest Practices Code*. A search of the Water Stewardship Division of the B.C. Ministry of Environment “Water Licences Web Query” (http://a100.gov.bc.ca/pub/wtrwhse/water_licences.input) identifies the following existing water licences for Pemberton Creek:

Table 1 – Water Licences on Pemberton Creek

Purpose	Quantity	Licensee	Licence No.	Priority Date (yyyymmdd)
Waterworks Local Auth	25,550,000 gal / yr	Village of Pemberton	C026463	19590414
Waterworks Local Auth	36,500,000 gal / yr	Squamish- Lillooet Regional District	C029836	19631231
Land Improvement	2 ft ³ / s	Village of Pemberton	C061785	19850418



**PEMBERTON CREEK
SMALL HYDRO PROJECT**

**Pemberton Creek
Basin**

Area	A	17.55 km ²
Area	B	4.08 km ²
Combined:		21.63 km ²


 Village of Pemberton Boundary (approx.)

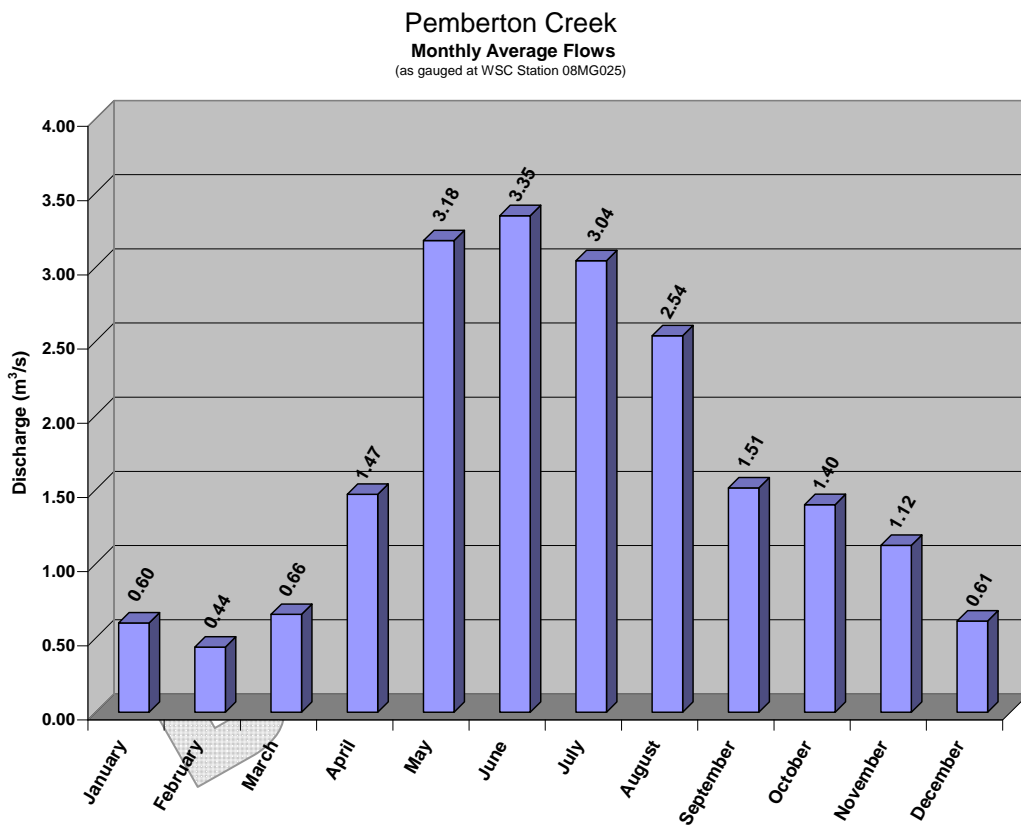
Figure 1

Imagery courtesy of: Ryan River Hydro Joint Venture

Pemberton Creek served the community of Pemberton as the main supply of drinking water until 1993, at which time a sub-surface water supply source was developed by the Village of Pemberton. Neither of the authorized surface water extractions is presently being utilized, although there remains an interest in maintaining Pemberton Creek as a back-up water source for the Village. The diversion and intake facilities at the original point of diversion are not functional at present.

Climate and Hydrological Data

The British Columbia Forest Service maintained a climate station on Pemberton Creek (#1086083) between 1964 and 1989 but data collection was sporadic. The Water Survey of Canada collected hydrometric data for Pemberton Creek during 1987 to 2006. Station 08MG025 (situated at 50° 19' 02" N, 122° 48' 05" W) was equipped with a continuous data recorder and, provides a good basis for hydrological analysis for the Pemberton Creek basin. Unfortunately, the station was decommissioned completely in 2007.



As is common with many southwest B.C. coastal streams, the hydrology of Pemberton Creek is driven largely by snow and ice melt during the spring and summer periods, with low flows encountered during the colder winter months when precipitation falls as snow over most of the watershed.

- During the course of development of a potential small hydroelectric project on Pemberton Creek, it would be advisable to conduct additional streamflow data collection and analysis in order to refine the hydrological model for the basin. This will be important to developing a comprehensive energy production model, to environmental analysis determining appropriate flow releases, and to better inform the design process (ex. in determining flood flow return frequency).

2. Access to the proposed project site

Road Access

Access to the upper (deposition) reach of Pemberton creek is via a private road along the south side of Miller Creek controlled by the Talbot family of Pemberton.

The Talbot family is currently harvesting timber from within their licensed tenures in the upper reach. A mainline forest access road exists that could serve the development of the upper sections of a Pemberton Creek hydro project, including the intake works.

Construction access to middle and lower sections of a Pemberton creek hydro project would require refurbishment of old logging roads, and some new temporary access road construction.

At the proposed powerhouse locations, construction of short sections of new permanent forestry-type roads would be required.

Project Interconnection

Access to the B.C. Hydro electrical grid is also an important to the development of a small hydro project. Typically, a development of the scale contemplated for Pemberton Creek would seek to connect at a “distribution” level voltage (25 kV) by tapping to a local B.C. Hydro electrical sub-station¹.

However, preliminary enquiries indicate that the Pemberton sub-station may be near capacity in its present configuration. *When it was operating at full output, an additional small hydro project connecting to the sub-station could overload the existing transformer²*

- It would be a priority for the development of a small hydro project on Pemberton Creek to secure and maintain access opportunities throughout the project area. Additionally, it will be important to continue discussions with B.C. Hydro and B.C. Transmission Corp., as well as other prospective Independent Power Producers in the region to ensure that opportunities for interconnection of the project to the electrical grid are preserved.

¹ Lower voltage equipment (ex. circuit breakers, powerlines, transformers) is less expensive, and less technically demanding, than high voltage equipment, making a 25 kV interconnection alternative more economical than, for instance, a connection to the 230 kV transmission system.

² When operating at full capacity, the output from the existing generation entering the Pemberton sub-station significantly exceeds the local load demand. That “surplus” energy is transformed through the Pemberton sub-station from 25 kV to 230 kV and is delivered via the main transmission system to B.C. Hydro’s customers elsewhere in the province. In order to deliver *more* electricity to the transmission system (i.e. the energy from an additional power generating facility), a larger transformer (as well as additional circuit breakers, buss work, etc.) would be required.

3. Preliminary fisheries & wildlife habitat assessment

Pemberton Creek is part of the Lillooet-Harrison sub-basin of the Fraser River. The main anadromous species present is coho salmon (*Oncorhynchus kisutch*) although sockeye salmon (*Oncorhynchus nerka*) are known to have utilized both One Mile Lake and Pemberton Creek to spawn. Chinook (*Oncorhynchus tshawytscha*), pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) are found downstream in the Lillooet River. As Pemberton Creek is a designated Community Watershed, it is automatically classified as a fish bearing stream, for its entire length, in keeping with BC *Forest Practice Code* guidelines. Though designated as an **S2** fish bearing stream over its entire length for riparian management purposes, it is generally considered that there are no fish present above the "alluvial fan" reaches of Pemberton Creek due to excessively steep gradient.

In the lowest reaches of Pemberton Creek, One Mile Lake is important spawning and rearing habitat for coho salmon and cutthroat trout and high value wetland habitat for waterfowl and transitional riparian bird species. An intake weir was built in 1993 to allow flow from Pemberton Creek into One Mile Lake to improve fisheries and recreational values. As part of that project, coho fry from the Birkenhead Hatchery were released in One Mile Lake 1993-1997. The intake weir is currently not functioning in full capacity due to sediment build-up since it was last excavated in 2003. Increased beaver activity has redirected portions of the diversion channel away from One Mile Lake. Habitat improvement projects to address these issues are planned by Fisheries and Oceans Canada in August 2008.

2005 and 2006 were particularly dismal years for coho returns, not only in Pemberton Creek but for the Lillooet watershed as a whole, although there was a small escapement of approximately 700 smolts from One Mile outlet in early June 2007. Spawning in early December 2007 was adversely affected by a frazil ice wet avalanche that blocked Pemberton Creek at the Highway 99 bridge, causing the creek to flow overland into One Mile Lake. Spawning adults, eggs and resident trout were found stranded in the resulting ice mass.

Rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarki*), dolly varden (*Salvelinus malma*), bull trout (*Salvelinus confluentus*), largescale sucker (*Catostomus macrocheilus*), redbelt shiner (*Richardsonius balteatus*) and coastrange sculpin (*Cottus aleuticus*) all inhabit Pemberton Creek.

There was a fisheries habitat improvement project completed upstream and downstream of the CN Railway crossing. Logs and rootwads were cabled to the dyke on the left bank looking downstream. The project was completed by Fisheries and Oceans Canada as a mitigation for the overflow channel built behind the Squamish-Lillooet Regional District office. The project provided minimal improvement to fish habitat because the woody debris was installed both parallel to the flow and above the normal water depths. Large woody debris is only effective when it can work with the natural action of the water to provide variations in flow, energy dissipation contributing to the formation of natural features such as pools, refuge areas and gravel deposition.

Water Quality

Baseflow water chemistry data is limited on Pemberton Creek. The Village of Pemberton tests their drinking water for *Escherichia coli*, total and fecal coliform. Further water chemistry needs to be completed for low-level macronutrient levels, alkalinity and conductivity.

Wildlife

There are no Wildlife Habitat Areas (WHA's) designated within Pemberton Creek Watershed, however the watershed boundary borders WHA Rutherford Creek (2-190) and WHA Miller Creek (2-261). WHA's designate critical habitats in which activities are managed to limit their impact on the identified wildlife, in these cases, grizzly bear (*Ursus arctos*) (BCM WALP, 2004).

There is no Ungulate Winter Range habitat identified by the Forest and Range Practices Act in the Pemberton Creek watershed but again, it is bordered by designated ranges in both the Rutherford and Miller drainages.

Species and Ecosystems at Risk

The BC Species and Ecosystem Explorer indicate nine ecological communities at risk within the CWH zone which could occur within Pemberton Creek watershed and no ecological communities at risk within the MH zone. The following is a list of species that have been listed provincially as extirpated, endangered, or threatened (red) and species of special concern to become endangered or threatened (blue) (Table 2). All the following species could reasonably occur within the Pemberton Creek watershed. Of particular concern within this project boundary are wolverine, fisher, grizzly bear, coastal tailed frog, bull trout, dolly varden and cutthroat trout.

Table 2. Listed species potentially occurring within Pemberton Creek watershed.

Scientific Name	English Name	Status
<i>laytonia washingtoniana</i>	Washington springbeauty	Red
<i>Corynorhinus townsendii</i>	Townsend's Big-eared Bat	Blue
<i>Epilobium glaberrimum</i> ssp. <i>fastigiatum</i>	smooth willowherb	Blue
<i>Falco peregrinus anatum</i>	Peregrine Falcon, <i>anatum</i> subspecies	Red
<i>Falco peregrinus pealei</i>	Peregrine Falcon, <i>pealei</i> subspecies	Blue
<i>Gulo gulo luscus</i>	Wolverine, <i>luscus</i> subspecies	Blue
<i>Hirundo rustica</i>	Barn Swallow	Blue
<i>Martes pennanti</i>	Fisher	Blue
<i>geyeri</i> var. <i>tenerum</i>	Geyer's onion	Blue
<i>Ardea herodias fannini</i>	Great Blue Heron, <i>fannini</i> subspecies	Blue
<i>Ascaphus truei</i>	Coastal Tailed Frog	Blue
<i>Botrychium simplex</i>	least moonwort	Blue
<i>Butorides virescens</i>	Green Heron	Blue
<i>Cheilanthes gracillima</i>	lace fern	Blue
<i>Cicuta maculata</i> var. <i>maculata</i>	spotted cowbane	Red
<i>Megascops kennicottii kennicottii</i>	Western Screech-Owl, <i>kennicottii</i> subspecies	Blue
<i>Myotis keenii</i>	Keen's Myotis	Unknown
<i>Nothochelone nemorosa</i>	woodland penstemon	Blue
<i>Oenothera pallida</i> ssp. <i>pallida</i>	pale evening-primrose	Red
<i>Oncorhynchus clarkii clarkii</i>	Cutthroat Trout, <i>clarkii</i> subspecies	Blue
<i>Patagioenas fasciata</i>	Band-tailed Pigeon	Blue
<i>Pinicola enucleator carlottae</i>	Pine Grosbeak, <i>carlottae</i> subspecies	Blue

Scientific Name	English Name	Status
<i>Pleuropogon refractus</i>	nodding semaphoregrass	Blue
<i>Rana aurora</i>	Red-legged Frog	Blue
<i>Salvelinus confluentus</i>	Bull Trout	Blue
<i>Salvelinus malma</i>	Dolly Varden	Blue
<i>Schoenoplectus americanus</i>	Olney's bulrush	Red
<i>Sidalcea hendersonii</i>	Henderson's checker-mallow	Blue
<i>Strix occidentalis</i>	Spotted Owl	Red
<i>Ursus arctos</i>	Grizzly Bear	Blue
<i>Carex lenticularis</i> var. <i>dolia</i>	Enander's sedge	Blue
<i>Castilleja rupicola</i>	cliff paintbrush	Red
<i>Pleuropogon refractus</i>	nodding semaphoregrass	Blue

Project Siting and additional habitat assessments

- o In identifying and refining a conceptual small hydro project layout, it will be necessary to conduct a more thorough program of fisheries habitat identification and impact assessment. However, it appears as though a small hydro installation on Pemberton Creek could readily be developed in a manner consistent with Fisheries & Oceans Canada Requirements and Guidance for Run-of-River Hydro Projects objectives:
 - o “Optimally, the intake and tailrace should be located upstream of fish populations”, and,
 - o “Where fish habitat exists within the proposed project area, diverted water should be returned to the stream upstream of anadromous salmonid, critical trout or endangered species habitat. In addition, the project should avoid impacts to resident fish and their habitats”.

Similarly, wildlife habitat assessment would be required, and the small hydro project would need to be designed, constructed and operated so as to minimize impacts to wildlife.

These assessment would typically be addressed through the course of a comprehensive regulatory review of the small hydro project, and involve a multi-agency review conducted jointly by the Water Stewardship Division of the B.C. Ministry of Environment and the Integrated Land Management Bureau of the B.C. Ministry of Agriculture & Lands.

4. Infrastructure Options

In developing a model for the conceptual location and layout of a small hydro development for Pemberton Creek, it is essential that the project be sensitive to environmental and community values:

- The development must minimize its environmental footprint through a considered approach to project design, construction and operation;
- Visual aesthetics is of vital concern to the community's residents, and it will be important for community acceptance that the development respect and maintain natural viewsapes
- The development should not infringe upon the immediate community – as much as possible, the development must seek to address issues of noise control, visual and architectural consistency within its setting, safety and security, and public access.
- The development is situated within a growing community and should be integrated as fully as possible with existing and planned infrastructure for the Village of Pemberton.

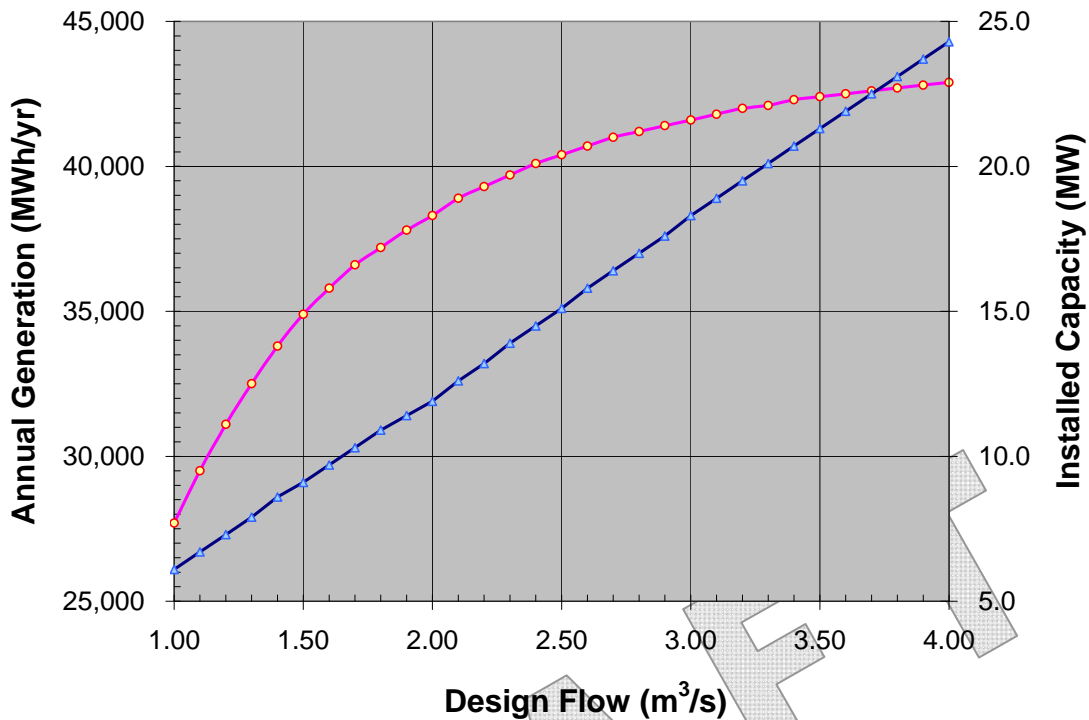
Geotechnical considerations

A review of various reports prepared with regard to the assessment of the Community Watershed (Cameron, 1991; MoF/MoELP, 1997; Nichols, 2001; Stewart, H. 2001) indicates that a small hydro development on Pemberton Creek would be required to address slope stability issues common to most natural resource developments in mountainous terrain in southwestern B.C. However, prudent location and design of the project facilities should mitigate geotechnical risk exposure. The principal areas of concern would be traversing high-angle slopes with roads and penstock corridors, and designing the diversion and intake facilities, as well as creek crossings, to withstand flood events.

Project sizing

In order to evolve a conceptual layout for the project, it was first necessary to select an appropriate design flow rate for the generating facility. Utilizing the daily flow records for the Water Survey of Canada *Pemberton Creek* gauging station (prorated to estimate the flows available at an intake situated at an elevation of 1050 m and allowing for an instream flow release of 10% of mean annual discharge at that point), an EXCEL spreadsheet model was constructed to provide a preliminary evaluation of annual energy output of a hypothetical generating plant (located at an elevation of 260 m) utilizing a broad range of design flows (Figure 2).

Figure 2 **Output vs. Design Flow**



The analysis suggests that the optimal design flow for a run-of-river generating facility on Pemberton Creek (for with an upstream catchment area of approximately 17.6 km²) would probably be in the range of 2.0 to 3.0 m³/s. It is evident by the steep slope of the pink “annual generation” curve below 2.0 m³/s that incremental increases in the design flow would result in substantial increases in energy generation. Inherently, the additional costs associated with increasing the size of the generating facility (notably, the penstock and generating equipment) appear well warranted up to this point. Between 2.0 and 3.0 m³/s, the incremental value of additional design flow capacity begins to diminish, and beyond a 3.0 m³/s design flow, additional design flow capacity yields only marginally higher annual energy output.

This preliminary evaluation would be valid for a project configuration with the intake situated farther downstream. For the lower elevation *Alternate 2* intake site (see discussion below) with a catchment area of 21.6 km², the optimal flow range would be proportionally larger (i.e. 21.6 / 17.6 = 1.23 times larger), or between 2.5 and 3.7 m³/s.

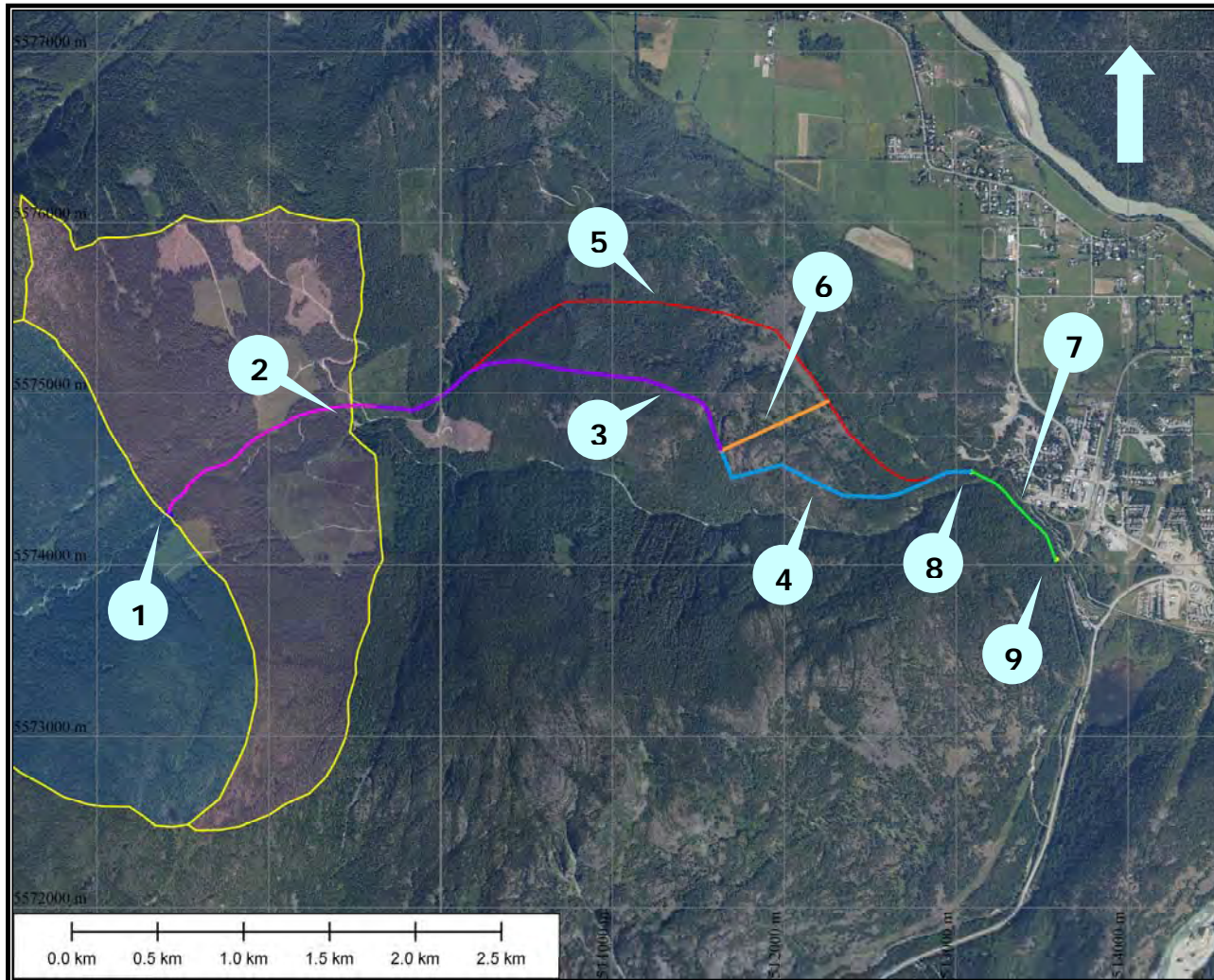
Project Configuration

For the purposes of developing concepts for the configuration of a small hydro project on Pemberton Creek, two powerhouse sites and three alternative penstock routes were considered. An intake site in the upper basin, selected on the basis of topographic mapping and aerial imagery, was located at a point on the stream near the head of the steepest gradient reaches so as to maximize the head developed while minimizing the length of the penstock. An alternative intake site, somewhat lower in elevation but situated to capture more of the basin run-off (and requiring an appreciably shorter penstock), was also identified. As a run-of-river project; there would be no water storage constructed to support the development at either of the alternative intake sites.

Based on this preliminary technical assessment of the site, the Project would consist of three distinct parts. Depicted on Figure 3, they are:

- An intake structure on upper Pemberton Creek at an elevation of approximately 875 m. The intake structure would divert power flows to the water conveyance system. It would also be designed to pass the required riparian flow and excess flows to the natural Pemberton Creek water course. An alternative intake location at a slightly higher elevation was also considered.
- A water conveyance system that would be between 4,000 m and 6,100 m in length, depending on selected configuration, and nominally, 1.1 m to 1.3 m in diameter. It would be in two sections; a low pressure conduit and a high pressure penstock. Alternatives involving a “low route” (possibly with lesser visual impact) and an underground shaft/tunnel combination to connect the low pressure conduit and the high pressure penstock section were also investigated.
- A powerhouse (at an elevation between 225 and 260 m), tailrace and sub-station located on lower Pemberton Creek. A “baseline” configuration for the powerhouse would contain two 8.0 MW Pelton-type turbine generator units, as well as ancillary protection and control equipment. A tailrace would return water from the turbines to the creek. A sub-station adjacent to the powerhouse would contain a transformer to step the power up to the 25 kV level to enable interconnection with the B.C. Hydro system.

D R A F T



**PEMBERTON CREEK
SMALL HYDRO PROJECT**

General Layout

- 1 - Intake – Alternative 1
- 2 - Intake – Alternative 2
- 3 - low pressure penstock
- 4 - high pressure penstock
- 5 - penstock “low route” alternative
- 6 - penstock “shaft - tunnel” alternative
- 7 - high pressure extension
- 8 - Powerhouse – Alt. 1
- 9 - Powerhouse – Alt. 2

Figure 3

Imagery courtesy of: Ryan River Hydro Joint Venture

Pemberton Creek Intake Structure

Intake - Alternative 1 -- A diversion weir and intake structure would be located on Pemberton Creek at an elevation of approximately 1050 m – near the break in stream gradient between the upper “deposition” reach and the top of the “waterfall” reach. The diversion weir would create a small headpond and would be integrated with an intake structure to divert power flows to the water conveyance system. The intake would allow for the passage of the required riparian flow (“instream flow release”) and excess flows to Pemberton Creek (see Figure 4 – following text).

A concrete overflow weir with Coanda-style intake arrangement (see Appendix A) is commonly recommended for an application such as Pemberton Creek. The weir crest would be approximately 15 m in width and the height of the structure, 1.5 m. The entire system would be designed to convey design flows in the range of 2.0 to 3.0 m³/s to the inlet of the penstock at maximum flow.

The concrete weir would extend across Pemberton Creek and would have a crest elevation of approximately 1050 m. Typically, Coanda type intakes utilize only a small head pond to moderate approach flows; the volume of water impounded is nominal. The weir would incorporate a spillway section (to pass flood flows), a mechanism to provide the required instream flow release, and a sluiceway to dewater the weir and intake for routine maintenance and service.

A headwater level sensor would be installed at the intake to provide input to the powerhouse control system to regulate power flows through the intake. Telemetry from the intake would typically be conveyed to the powerhouse over a communications cable buried beside the penstock.

Intake - Alternative 2 -- An alternative intake site is located near the present logging road crossing of Pemberton Creek, at an elevation of approximately 875 m. This site would only be practical if a downhill penstock grade could be developed between the intake and a “saddle” breaching the ridge immediately north of Pemberton. The *Alternative 2* intake is 175 m lower in elevation than *Alternative 1* (resulting in approximately 20% less head available to the project), but would capture approximately 23% more of the basin (and accordingly, additional flows). The physical structure of the *Alternative 2* intake would be very similar to that of the higher elevation *Alternative 1* intake, though it would be designed to flows in the range of 2.5 to 3.7 m³/s to the penstock.

- The larger catchment area of the lower elevation intake site off-sets the loss in head in moving downstream from the higher intake site. While the penstock diameter would be marginally larger for the *Alternate 2 intake* configuration, the penstock length is considerably shorter, with a commensurate cost savings. Fundamentally, the energy that could be produced from a project configuration using either intake site would be similar – however, the shorter penstock requirement favours the lower *Alternative 2* intake site.
- A third potential intake site, located approximately 1 km downstream of the logging road crossing bears further investigation. Development of the site would appear to be more complicated and the penstock route would be required to traverse the steeper terrain south of the ridge. However, the same advantages that suggest *Intake - Alternative 2* over *Alternative 1*, may apply to the third site.

Water Conveyance

From the intake structure, water would be conveyed to the powerhouse by way of a *penstock*. The specifications for the penstock would ultimately be determined through the course of a detailed engineering and economic analysis³, in which particular consideration would need to be given to social values (i.e. visual aesthetics) versus cost. However, for design flows in the range of 2.0 to 3.0 m³/s, a penstock with a nominal diameter of 1.0 to 1.2 m (36” to 48”) would be a typical for this application. For the higher volumes from the *Alternative 2* intake, pipe diameters could be increased into the 1.30 m (52”) size range.

High Route Alternative -- The water conveyance system would be a single pipeline comprising two distinct sections. The upper section would be a low pressure conduit that would extend from the intake structure to a point near the top of a distinctive west-northwesterly trending ridge situated

³ An optimization exercise would typically evaluate the benefits of decreasing the diameter (and thus, the expense) of the penstock against the “costs” of increased head losses (simply, a smaller pipe delivers less water, and ultimately, less energy). Also, a significant portion of a water conveyance system costs are the “fixed” expenditures for installation of the penstock – it may be advantageous to select a slightly larger diameter pipe as the incremental costs may be insignificant. Selection of materials, particularly for the lower pressure sections of the penstock would also be a common variable to consider in the overall costing and design of the conveyance system.

immediately west of the Village of Pemberton. Depending on the location of the intake, the low pressure conduit would be approximately 2,300 to 3,700 m long and have an inside diameter of 1.1 m. It could be made from either HDPE (high-density polyethylene), ductile iron, fibreglass, or steel – or a combination of these materials -- depending on a more detailed cost-benefit-analysis. Generally, a buried penstock is favourable from both a technical and aesthetic perspective.

The lower pressure conduit would be built along a newly constructed road which would skirt the northern flanks of the ridge near its crest. This route would offer the ability to minimize the potential visual impacts from the valley bottom. Based on a preliminary aerial imagery and terrain analysis, a route on the southern flanks of the ridge (which would be considerably shorter and have no visual impact from the Pemberton valley), appears to be considerably more challenging (steeper terrain, potential geotechnical hazards) from a construction and maintenance standpoint. However, the merits of this alternative low pressure conduit route should be considered more thoroughly as access conditions permits.

At its downstream end, the low pressure conduit would transition to a high pressure penstock section. In this zone, the penstock would typically be coated and lined, high-pressure welded steel pipe. To extend to the higher, *Powerhouse 1* location, it would be approximately 1,600 m long and have an internal diameter of 1.1 m. The penstock would follow the fall-line downhill from the transition point to the powerhouse, a drop of 565 m at an average slope of 35%. Particularly over its lower sections, the high pressure penstock routing would need to be carefully coordinated with the *Benchlands Neighbourhood Plan*. An anchor block upstream of the powerhouse would anchor the pipe at the bifurcation point.

This *high-route* alternative penstock configuration would be the most common approach to designing a water conveyance system. By routing the penstock at a higher elevation for as long a distance as possible, a longer length of lighter (and thus, less costly) pipe may be utilized for the lower pressure conduit. While less expensive, it is anticipated that this routing could have a greater visual impact than the other alternatives.

Low Route Alternative -- A *low-route* penstock alternative, which would descend more quickly to the lower flanks of the ridge, would offer a lower likelihood of visual impact from a valley bottom viewpoint. As the route is longer, and would require a heavier-wall pipe to contain the higher pressures over much of its length, the costs for this alternative would be appreciably higher than the *high-route*. The low-route would also traverse more of the Benchlands neighbourhood.

Shaft-Tunnel Alternative -- A third alternative was considered in evolving a conceptual layout for the hydro project. The *shaft-tunnel* scheme would see the development of an adit, driven southwestward for approximately 500 m, from an elevation of 330 m in the upper Benchlands area. A shaft would then be bored upwards 500 m from the end of the adit to connect to surface at the end of the lower pressure conduit route. The penstock would be installed inside the tunnel and connected to a surface penstock at the adit portal for the final 1,000 m distance to the upper *Powerhouse 1* location.

The shaft-tunnel alternative would have no impact on visual aesthetics. However, the development of the adit and the shaft represent a substantial construction risk due to uncertainties in geological structure and stability and as such, a substantial financial exposure.⁴

High Pressure extension – should it prove advantageous to develop a lower elevation powerhouse site, it would be necessary to extend the penstock beyond the Benchlands area to the top of the lower “alluvial” fan reaches of Pemberton Creek. As this section of penstock would be required to withstand the highest pressures, the pipe thickness would be substantial (and accordingly, the materials unit costs would be considerably higher⁵). Particularly as there is relatively little head gained by extending the penstock, while the cost is substantial, a detailed optimization of this high-pressure extension would probably seek to keep the length of this penstock zone as short as possible.

⁴ Fracturing and faulting of the rock mass may require various means of support ranging from localized rock bolting to steel and concrete lining. While the Coast Plutonic Complex granodiorites generally present favourable geotechnical conditions for underground development, it would be very difficult to quantify the construction and financial risks of this alternative.

⁵ The cost supply cost for pipe in this high pressure zone is estimated to be nearly five times that of the similar diameter pipe for the low pressure zone.

Powerhouse and Tailrace

The powerhouse would consist of a building approximately 15 m by 20 m housing a turbine and synchronous generator system, turbine isolation valves, the control system, electrical switchgear, transformers, and powerhouse utilities (cooling and lubrication systems, heating and ventilation, lighting and service power, non-potable water supply and sanitary waste). Design of the powerhouse would require particular attention to noise emissions (commonly, ventilation systems emanate as much noise as the turbine-generator units), and site aesthetics.

Within the high head ranges under consideration, a Pelton-type impulse machine, similar in design and operation to those installed at the nearby Miller Creek and Rutherford Creek hydro sites, would be the natural choice of turbine in this application.

A detailed cost-benefit analysis would typically be conducted as the project concepts were evolved in order to determine an optimal turbine-generator size and configuration. The selection of single vs. multiple turbines, the machine orientation (a vertical-axis vs. horizontal axis) and the number of “jets” per turbine (two to six) would generally derive from detailed discussions between the project designers and turbine-generator equipment suppliers. In the current economic climate, escalating commodity prices (notably steel and copper) have driven equipment suppliers to minimize the size of the machinery – in general, there has been a trend towards the supply of smaller turbines rotating at higher speeds⁶. There are additional economies possible in designing and constructing multiple identical units for a particular application. Also, there are a greater number of suppliers in the smaller equipment marketplace, and pricing would be inclined to be more competitive.

Civil construction costs and operational flexibility must also be factored into the equipment selection process. A horizontal-axis equipment orientation would typically involve a modestly lower construction cost due to simpler foundation requirements, although a vertical-axis turbine would operate more efficiently across a broader range of flows. For the purposes of this initial evaluation, a twin 2-jet horizontal-axis Pelton-type turbine-generator arrangement was considered as a “base case”, as it would offer good operating flexibility at a lower cost. A typical two-unit horizontal axis Pelton-type powerhouse configuration is depicted in Figure 5 (following text)

As is common with contemporary generating facilities, the generating system would be designed for unattended operation. An operations manager residing in the immediate area would be available to attend the plant on a part-time basis, and would be alerted by the plant SCADA (Supervisory Control and Data Acquisition) system in the event of an alarm condition (i.e. mechanical or electrical equipment malfunction, intrusion or smoke alarm, water level or flow conditions outside of routine operating ranges, etc.). Monitoring and adjustments to the operational characteristics of the plant could be effected remotely by way of a security protected computer network, typically connected to the plant SCADA system by way of a broadband internet link. The operations manager would also be responsible for routine inspections of the headworks including the intake and diversion weir, and general site security.

The powerhouse site development would include a short tailrace through which the discharged water would be returned to Pemberton Creek.

Two alternative locations were considered for the powerhouse site; a higher elevation site in the lower Benchlands area and a lower elevation location close the railway bridge crossing. A more thorough examination of the specific site conditions (including discussions with stakeholders), in conjunction with a detailed technical and economic analysis, would be required to select an optimal powerhouse site. However, the two locations selected would represent the two end-points within a range of powerhouse siting alternatives. Assuming similar foundation conditions, the basic design and layout of the powerhouse would be virtually identical, regardless of final location.

Powerhouse 1 would be situated at an elevation of approximately 260 m in the vicinity of the southeastern corner of the Benchlands neighbourhood area. Obviously, a development at this site would need to be highly cognizant of its setting with the future neighbourhood – and such considerations may ultimately compel the selection of another site. However, in the absence of socioeconomic constraints (such as proximity to planned and existing residential areas, acoustics, aesthetics), the *Powerhouse 1* site would otherwise score favourably in an economic analysis as it would be the site that develops the most head with the least length of penstock.

The lower elevation **Powerhouse 2** site was identified through field reconnaissance at a location approximately 50 m west of the railway bridge crossing of Pemberton Creek. The lowest of a number of suitable powerhouse sites within this area, *Powerhouse 2* is situated on the right (south)

⁶ With a higher rotational speed, the size of the generator can be minimized, thus significantly reducing the costs for rotor and stator materials, and copper windings.

bank of Pemberton Creek at an elevation of approximately 225 m and would develop the highest head practically available to the project. The site would be near the break in slope at the base of an undeveloped mountain side immediately south of the Village – providing the advantages of being somewhat removed from existing residential and commercial development. Development of access (possibly through the re-establishment of an old logging road) and a creek crossing (by way of either a pipe bridge or a combination road/pipe bridge) would also be required. Neither of these elements should be overly problematic from a technical or economic perspective.

Sub-Station and Transmission Line

The powerhouse sub-station would consist of a step up transformer, a high voltage circuit breaker, disconnect switches, and lightning protectors, as well as current and voltage measuring equipment to monitor line stability and power generation. These facilities would be located within a fenced yard adjoining the powerhouse. The transmission line would typically be a standard 25 kV wood pole line following existing roads from the project sub-station to the B.C. Hydro interconnection point. However, for the relative short distances, and given the project's "suburban" setting, it would be practical to consider at least partial burial of the powerline.

As there is some question regarding the ability of the existing BC Hydro/BC Transmission Corp. Pemberton sub-station to accommodate additional electrical input from another IPP, it will be important to coordinate project development plans both with the electrical utilities and with other prospective IPP's contemplating projects in the region.

Project access

There would be two access routes to the site from Pemberton. Access to the intake site would be by way of an active logging road network which departs the Lillooet valley floor near Miller Creek. As it proceeds along Miller Creek, the road traverses privately owned property. Approximately 1.5 km of new road would be required to connect the existing logging road to the upper intake site; the lower intake alternative is situated near the present logging road crossing of Pemberton Creek.

Access to the lower portions of the penstock route and the powerhouse sites would extend from the Village of Pemberton road network to the intake works of the Village's water storage facilities. A section of new road to access the lower powerhouse alternative could be extended to the right (south) bank of Pemberton Creek should it prove desirable to develop the "full head" scheme – various access alternatives are available.

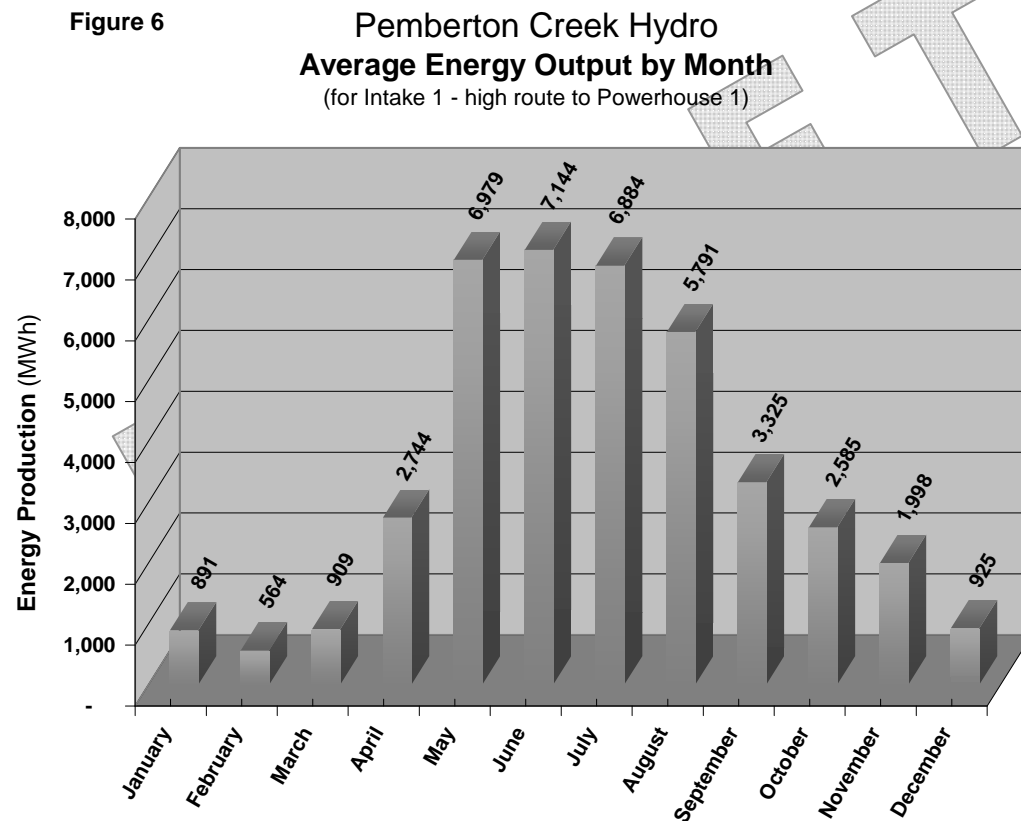
D R A F T

5. Energy Potential

A power generation model was constructed to evaluate the energy production potential for each of the various project configurations. As with the Project Sizing analysis, a synthetic hydrograph was created by prorating the daily discharge records (based simply on the relative catchment areas) for the Water Survey of Canada Station 08MG025 - *Pemberton Creek near Pemberton* to estimate the flows available at the two alternative intake sites.⁷ Allowing for a minimum instream flow release (necessary to ensure preservation of fish habitat) of 10% of mean annual discharge at the respective points of diversion, the EXCEL model then calculates the daily energy production for a hypothetical generating facility, based on;

- estimated head losses within the water conveyance system;
- estimated turbine and generator efficiencies, based on suppliers' efficiency curves;
- electrical losses associated with generator, station service, transformer, and transmission; and
- an allowance for forced and scheduled equipment outages.

Daily average energy output is then summarized on a monthly and annual basis for the period of record. The energy potential calculations are utilized to simulate a long-term proforma cash flow model and economic analysis for the project, based on the historical streamflow record. Table 3 summarizes the result of this analysis. Figure 6 depicts the seasonal energy production profile.



⁷ Ex. at the upper intake catchment is 17.55 km² vs. 31.9 km² for the basin at WSC 08MG025. For the measured flow of 3.60 m³/s at the Pemberton Creek gauging station on 01 August 2005, a flow of 17.55 / 31.9 x 3.60 = 1.89 m³/s is estimated to occur at the *Intake – Alternative 1* site.

- o With 15 complete years, plus four more partial years, of hydrological data for 1987 through present, WSC 08MG025 provides a reasonably good basis for estimating energy potential for an IPP development on Pemberton Creek. However, it would be prudent to establish an independent gauging station in the upper Pemberton Creek basin (which would be used to verify the modeled correlation between high- and low-elevation streamflow for the watershed).

Table 3
Pemberton Creek IPP Study
Project Configuration Summary

Conveyance alternative	Intake 1			Intake 2	
	elevation (m): 1,050			elevation (m): 875	
	catchment (km ²): 17.55			catchment (km ²): 21.63	
	MAD (m ³ /s): 0.93			MAD (m ³ /s): 1.15	
	<i>Hi route - 44" pipe</i>	<i>Lo route - 44" pipe</i>	<i>shaft - 44"</i>	<i>Hi route - 44" pipe</i>	<i>Hi route - 48" pipe</i>
Powerhouse 1 elevation (m): 260					
generating capacity (MW):	16.0	15.9	15.9	12.4	15.3
annual energy (MWh):	40,740	40,700	40,720	37,640	39,090
gross head (m):	790	790	790	615	615
design flow (m ³ /s):	2.65	2.65	2.65	2.65	3.25
penstock length (m):	5,380	5,550	5,454	3,940	3,940
penstock diameter (m):	1.10	1.10	1.10	1.10	1.20
L to H ratio:	6.81	7.03	6.90	6.41	6.41
Cost Index:	1.000	1.034	1.067	0.953	0.982
Powerhouse 2 elevation (m): 225					
generating capacity (MW):	16.7	16.6	16.6	13.1	16.2
annual energy (MWh):	42,550	42,510	42,530	39,800	41,320
gross head (m):	825	825	825	650	650
design flow (m ³ /s):	2.65	2.65	2.65	2.65	3.25
penstock length (m):	6,110	6,276	6,180	4,670	4,670
penstock diameter (m):	1.10	1.10	1.10	1.10	1.20
L to H ratio:	7.41	7.61	7.49	7.18	7.18
Cost Index:	1.032	1.065	1.095	0.981	1.013

Discussion:

A preliminary technical evaluation of the alternative project configurations indicates that, using design flows in the middle of what is considered the “optimal” flow range, a run-of-river small hydro development on Pemberton Creek would be sized at approximately 16 MW, and would generate and average of 40,000 to 43,000 MWh per year. As the costs to supply and install the steel pipe will be a key determinant of the project economics, a project configuration which would develop the most head with the least length of penstock (the lowest “**L to H ratio**”) would be the most economic. As indicated by the lower “cost index” values (a measure of the estimated capital cost of the project relative to its energy generation potential), the *Intake – Alternative 2* configurations appear to be more a more economic development alternative.

Similarly, the shortest, lightest “high route” penstock alternative shows an economic advantage over the longer “low route” option, although the cost difference between the two is not considered “prohibitive”. There would clearly be a cost premium to routing the penstock so as to mitigate potential visual impacts – however, a detailed cost-benefit analysis of these attributes would require additional review and discussion between the project owners and stakeholders.

With escalating construction costs over the past few years, small-hydro capital costs are typically reaching the \$2,500/kW level – a 16 MW generating facility could reasonably be expected to cost \$40 million. Annual sales revenues for a IPP project of the size contemplated would be on the order of \$4.5 to \$5.5 million.

D R A F T

6. Conclusion

Conceptually, a run-of-river small hydroelectric development on Pemberton Creek would appear to be of merit. The proximity to existing BC Hydro's principal load centre, and to transmission and transportation infrastructure, as well as the availability of local labour and materials, are attributes would contribute significantly to an economic development. By the same token, the project would need to address the very legitimate concerns of stakeholders over visual and acoustic aesthetics, environmental impacts, and continued access to existing commercial and recreational resources. However, if prudently planned, developed and operated, a small hydro project on Pemberton Creek appears well positioned to become a valuable economic contributor while maintaining the sustainability objectives of the community.

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Acknowledgements:

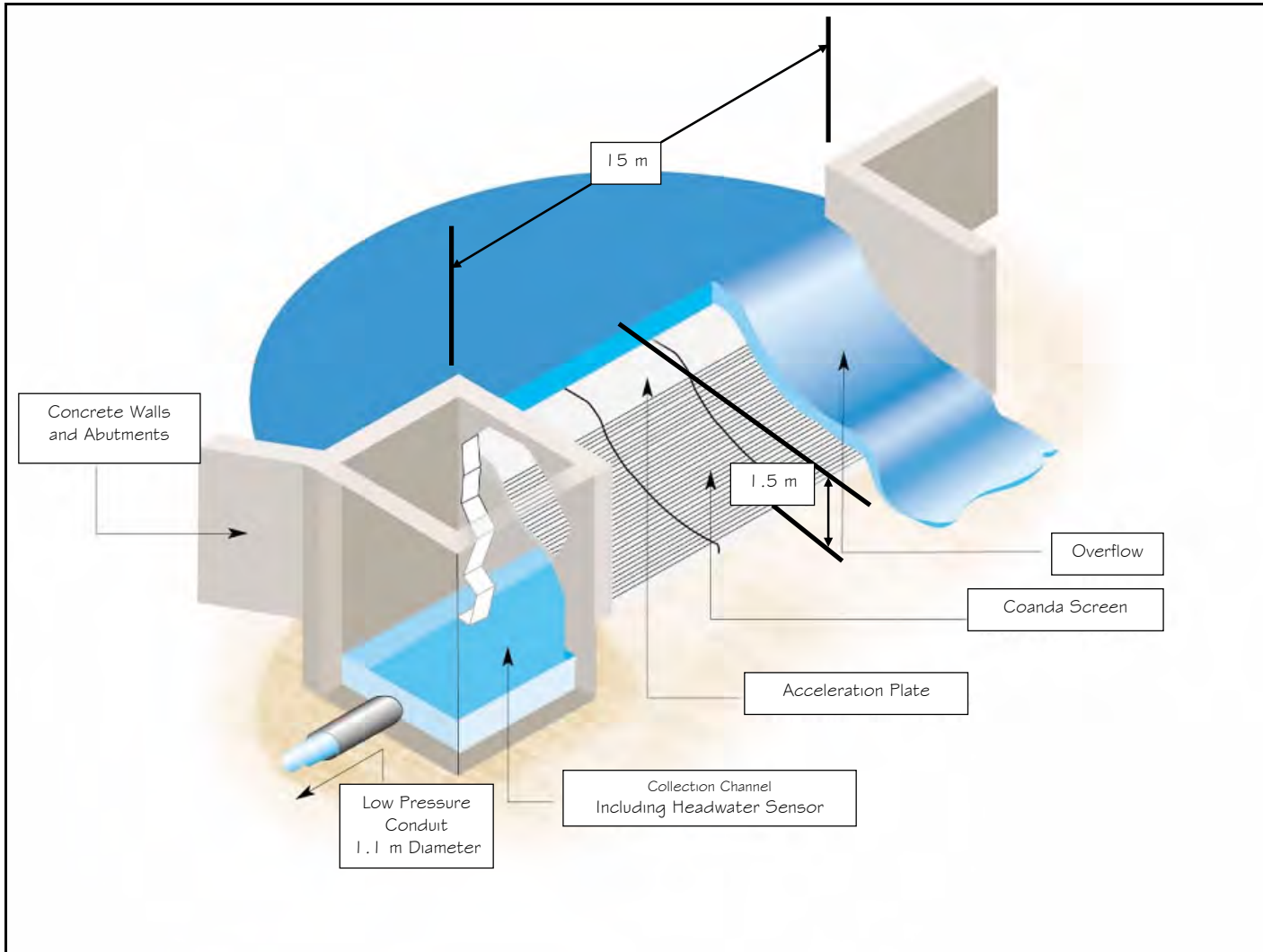
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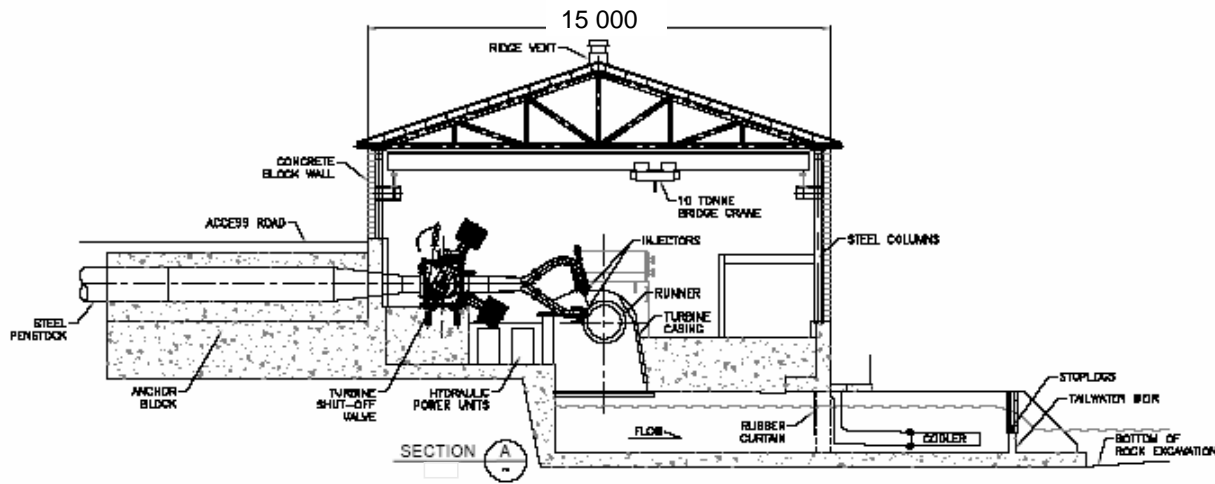
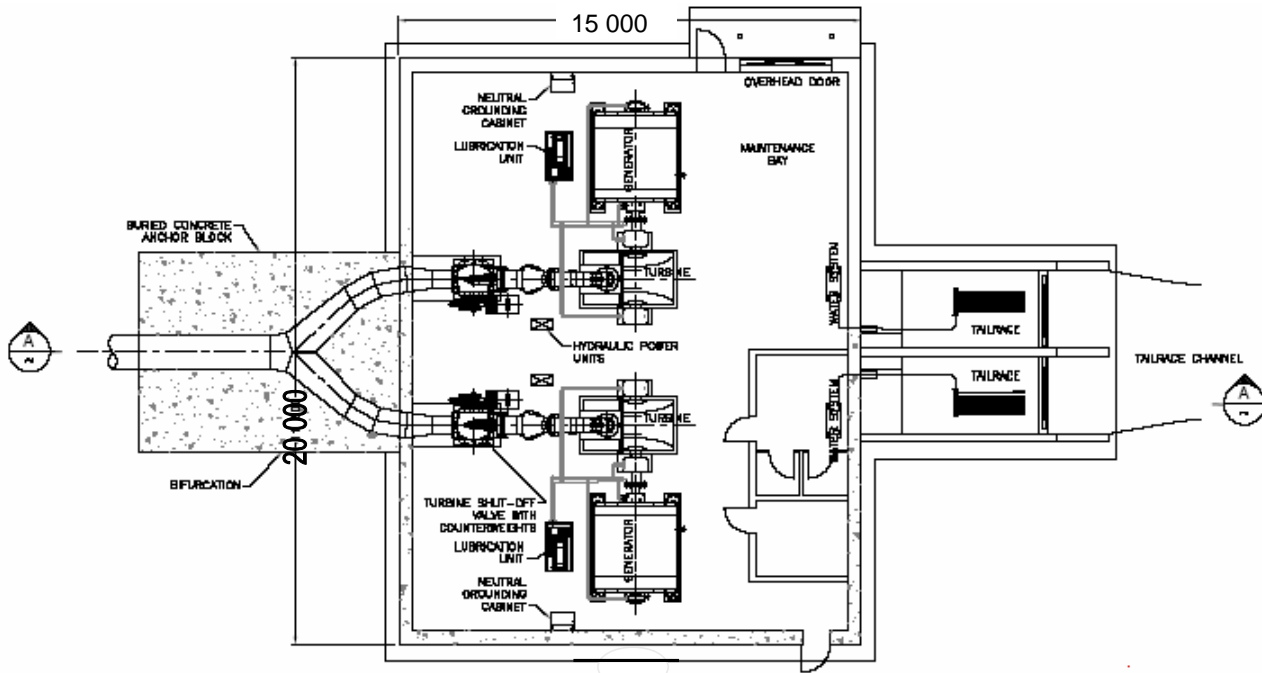
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Village of Pemberton.	
Pemberton Creek Small Hydro Project	
REPRESENTATIVE	
COANDA INTAKE	
Vicinity of Pemberton, B.C.	
Scale: Not to Scale	
Date: February 2008	Figure 4



Village of Pemberton .	
Pemberton Creek Small Hydro Project	
Powerhouse Concept	
Twin 7.5 MW Pelton unit arrangement	
Scale: approx 1: 200	Dimensions in mm
Date: February 2008	Figure 5

Appendix A – Coanda Intake background

A Coanda type intake uses a profiled-wire screen which employs the “Coanda effect” -- the tendency of a jet of water to follow a surface contour -- to draw water through the screen. On a Coanda type intake, the screen is in the shape of an ogee spillway-type configuration with the profiled wires placed horizontally, or perpendicular, to the direction of water flow.

As the water flows over the intake and down the ogee shaped downstream slope, at each wedgewire a thin film of the flow is drawn in through the screen. Only water and particles less than the effective opening size are drawn through the screen – debris such as leaves, branches and coarse sand, pebbles and cobble pass over the screen.

Observations and modelling on operating Coanda intakes indicate that the effective opening size is about one half of the open space between the individual wedgewires. Also, because of the high flow velocity down the ogee shaped downstream slope, the flow becomes laminar, which tends to concentrate any particles in the water in the centre of the flow, so that the film which is drawn through the screens tends to be the cleaner water. Coanda intakes have operated successfully during winter conditions and require relatively little maintenance.

The Coanda screen would be a stainless steel wedgewire screen with 1.0mm open gap. The upstream acceleration section would be a stainless steel plate. The complete screen with the upstream acceleration section is reinforced on the underside and would be attached at the upstream end to an upstream concrete wall and attached at the downstream end to a downstream concrete wall.

Coanda screens have been successfully installed at several small hydro facilities in southwestern B.C. over the past decade, including McNair Creek, South Sutton Creek, Marion Creek, and Brandywine Creek.

Norris Screen & Manufacturing Inc., is well known supplier of Coanda-type screens, and is represented locally. Norris's website is a useful resource for additional background:

<http://www.norrisscreen.com/index.htm>



Run of River Power Inc.'s *Brandywine Creek Hydro* Coanda-type intake (photo from <http://www.norrisscreen.com/products/hydroelectric.htm>)