Run-of-River Hydroelectricity and Cumulative Effects in British Columbia:

A Case Study of the Clowhom Watershed

By

Adam Ftaya

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ABSTRACT

The expansion of run-of-river (ROR) hydroelectric operations in British Columbia has raised concerns over the potential cumulative effects arising from multiple ROR sites and additional land-uses within a watershed. While this concern has been expressed by a multitude of interest groups, cumulative effects assessments (CEAs) are still a developing concept, and ROR-centric CEAs are often hard to find or lacking in detail. A central issue is the lack of research regarding the environmental impacts of ROR operations and their associated infrastructure. To address these challenges, this study focuses on identifying the key land-use and aquatic changes that have occurred in the Clowhom River Watershed, an area that has been recently subjected to ROR development. Existing literature is first used to identify the potential impacts of each ROR project component; these impacts are then examined in a cumulative manner along with the potential impacts from additional watershed activities and climate change. Results suggest that the cumulative effect of ROR developments will be largely determined by the pre-ROR state of watershed development and infrastructure. These findings may help to identify the most suitable locations to develop ROR operations, while trying to mitigate environmental impacts.
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1. Introduction
Over the past century, hydroelectricity has proven to be a reliable and relatively inexpensive source of emission-free energy. Generated in 159 countries, hydropower accounted for over 16% of global energy production in 2008 (International Energy Agency: 2010). Whereas most of this energy is derived from large dam projects, construction of these large projects has dropped significantly over the past 25 years. Through many decades of operation, the emergence of social, environmental, and safety concerns have often resulted in an opposition to large dams, illustrating the many shortcomings associated with what is typically considered a clean energy. As alternative forms of power production have been explored, the employment of small hydro has emerged as a way to both minimize the environmental footprint associated with large hydro and utilize rivers that were otherwise unsuitable for traditional hydro projects. While these smaller projects greatly reduce the most obvious impacts associated with large hydro, they have substantial trade-offs.

1.1 Hydropower in British Columbia
In British Columbia, 90% of the province’s power production comes from hydroelectric sources (BC Hydro: 2015a). In 1962, the formation of BC Hydro allowed for significant hydroelectric expansion through the 60’s, 70’s, and early 80s. During this period, the construction of large dam projects in the Peace and Columbia Basins allowed for massive gains in energy production, currently responsible for over 80% of BC Hydro’s generating capacity (BC Hydro: 2015a). While these large dam installations have provided substantial quantities of reliable energy, the scale of their environmental impacts is also significant. The displacement of rural communities, flooding of landscapes, and alteration of streamflow regimes are only a few of the most obvious impacts associated with the creation of these projects. The completion of the Revelstoke Dam in 1984 marked the last of these large dams to be built in British Columbia, though a new project on the Peace River – Site C – is slated to be in operation by 2024.

Over the past two decades, independent power producers (IPPs) have been growing within the BC energy sector. In 2002, the implementation of the BC Energy Plan helped promote the construction of smaller, more numerous hydroelectric projects. In this plan, the provincial government specified that IPPs would be responsible for any new power generation, and that the role of BC hydro would be limited to improving efficiency at existing hydro facilities (Government of BC: 2002). A series of ‘Calls for Clean Power’ issued by BC Hydro, in conjunction with the BC Clean Energy Act further helped to promote and expedite these IPPs. One of the most popular project types for IPPs has come in the form of run-of-river (ROR) installations. Well-suited to the often steep terrain and high velocity river systems of British Columbia, the small hydro projects have sprung up in great numbers. Currently there are 55 ROR power projects in operation in BC, with an additional 15 in development, many of which consist of multiple generation sites (BC Hydro: 2015b).

1.2 Run-of-River Power
ROR projects have become an appealing alternative to large hydro projects due to their lower construction costs, seemingly minor environmental impact, and abundance of potential site locations. ROR projects use the natural flow regime of a river to generate electricity, diverting water from the river and into a downstream powerhouse (Figure 1). Under this scheme, there is no requirement for a large
dam and its associated reservoir, thus mitigating the upstream and downstream impacts associated with water impoundment and flooding.

![Diagram of a basic ROR operation](image)

**Figure 1** – Diagram of a basic ROR operation. A portion of water is first diverted from the main channel and into the penstock. Water drops through the penstock under gravity, where it eventually reaches a powerhouse. Water spins turbines located in the powerhouse to generate electricity. The diverted water is then returned to the river (figure from NextGenerationHydro.com).

While the direct impacts of one of these installations is less than those associated with large hydro, the ability to reliably produce large amounts of power is also greatly reduced. With minimal water storage ability and placement on lower-order rivers, the quantity of energy produced by ROR installations is greatly reduced and more susceptible to changes in climate and streamflow. As such, ROR projects are often built in higher numbers, with many projects built as a series of installations on one river or in one watershed. High costs of transmission systems further promote the clustering of these projects, as common transmission systems between projects will greatly reduce costs. While the impacts of one ROR installation may be acceptable, the development of multiple generation sites along with other activities within a watershed may result in unacceptable cumulative impacts, mitigating the perceived benefits as compared to large hydro.

### 1.3 Environmental Assessment

In British Columbia, hydroelectric development may be subject to both provincial and federal environmental reviews. As specified in the *BC Environmental Assessment Act*, power plants with capacities greater than 50 MW will trigger the need for an environmental assessment and approval from the Environmental Assessment Office (EAO) prior to construction. Potential projects with capacities under this threshold still undergo an assessment through the Water License Application process, as
administered by the Ministry of Forests, Lands, and Natural Resource Operations (MFLNRO). Under the Canadian Environmental Assessment Act (CEAA), a federal assessment may also be triggered if federal money or land is involved in the project, or where federal authority is required to make decisions regarding specific ‘Law List Regulations’ within the CEAA. Simply put, these environmental assessments are underpinned by two broad principles (Cotton and Emond: 1981):

(1) early identification and evaluation of all potential environmental consequences of a proposed undertaking; and,

(2) decision making that both guarantees the adequacy of this process and reconciles, to the greatest extent possible, the proponent’s development desires with environmental protection and preservation.

1.3.1 Cumulative Effects
While formal legislation for environmental assessments in Canada has existed since the 1970s, consideration for cumulative effects is still being explored. Cumulative effects refer to the resultant changes to the environment that have arisen or may arise from the combination of past, present, and future activities. In Canada, the 1995 Environmental Assessment Act was the first piece of legislation to formally acknowledge the need for cumulative effects assessments (CEAs), making it a federal requirement in any environmental assessment.

In British Columbia, MFLNRO has sought to address cumulative effects by developing a provincial Cumulative Effects Framework (CEF), set to be implemented by April 2016. In a recent report from the Office of the Auditor General of BC (2015), it was found that both the provincial government and MFLRNO were not effectively addressing and considering cumulative effects in decision making, and that it is unclear how the new framework will support decisions regarding the province’s natural resources. In order to achieve the two goals of environmental assessment as described by Cotton and Emond (1981), it is vital that an effective CEF is established and that cumulative effects are thoroughly considered in any decision regarding the province’s natural resources and ecosystems.

1.3.2 Cumulative Effects and ROR hydropower
When conducting an environmental assessment for a potential ROR development, it is crucial that a cumulative effects assessment (CEA) is employed. While the environmental impacts of one of these facilities might be acceptable, the cumulative effects of multiple ROR sites within a watershed may compound these impacts to unacceptable levels. These impacts can be further enhanced through a variety of activities such as timber harvesting, mining, agriculture, and urban development.

Sometimes overlooked are the local impacts that may occur as a result of climate change. As acknowledged by the provincial government in the 2010 British Columbia Climate Adaptation Strategy, BC can expect a multitude of challenges arising from climate change. In the case of hydroelectric development, changes to long-term precipitation patterns could have substantial impacts for both project operations and aquatic ecosystems. The increasing magnitude and frequency of extreme events such as droughts and storms will be of particular concern for these developments. In a CEA, the impacts from these climate factors should be considered in conjunction with the direct impacts from
hydropower development and other nearby land-uses, as they have the potential to interact in a cumulative manner. As described in the 2010 *British Columbia Climate Adaptation Strategy*, one key adaptation strategy will be to “conduct climate change assessments for sectors known to be sensitive to climate change.” Water resources are particularly susceptible to climatic changes, making inclusion of climate scenarios in a ROR CEA a necessity.

As the province grows and the demand for electricity increases, it is possible that ROR operations will continue to expand as BC Hydro maintains its ‘Standing Offer Program’ for small, clean energy projects. As such, it is increasingly important to determine the types of cumulative impacts that may be anticipated from further ROR development. While ROR proposals in BC have been subject to CEA in the past, they can be lacking detail and considerations for climate change are often not included. In this study, I will seek to perform a cumulative effects assessment for a ROR hydroelectric development in British Columbia. Using the Clowhom River in southwestern BC as a case study, an assessment will be performed to identify the cumulative effects that may arise from both existing ROR operations and any additional land-uses in the watershed. In addition, the CEA will incorporate current climate trends that may have the ability to affect project operations and enhance project impacts. As a watershed that has been exposed to resource and hydropower development for many decades, the temporal scope of this study will be narrowed to explore the changes that have occurred from the watershed’s physical state immediately prior to the first ROR installation in 2010.

2. Case Study Background

2.1 Study area

The Clowhom River Watershed is located approximately 60 km northwest of Vancouver and 25 km west of Squamish (Figure 2). Ranging in elevation from sea level to 2600 m, the terrain varies from dense coniferous forest to glacial alpine areas. Tributaries originating from these glaciers converge with the Clowhom River, which then empties the 385 km$^2$ watershed into Salmon Inlet. From its headwaters at Phantom Lake, the Clowhom River travels 18 km to the Clowhom Lake reservoir. Over the course of this section, the river drops approximately 900 m from its headwaters, resulting in a fairly steep overall stream gradient of 5%. Water is held in the 10 km long reservoir before being passed through the Clowhom Dam and directly into Salmon Inlet.

Located in the Coastal Western Hemlock Biogeoclimatic Zone, climate is typically wet and mild in the Clowhom Watershed. Moist pacific air masses drop heavy precipitation as they travel through the region and encounter the Coast Mountains. In winter this results in heavy snow at higher elevations, and a mix of rain and snow at lower elevations. Summers are typically cooler than the rest of BC, but hot and dry periods are not uncommon (Pojar et al: 1991). The proximity to the ocean tends to moderate year-round temperatures in the watershed, with average winter temperatures just above 0°C and average summer temperatures just under 20°C (BC Hydro: 2005).
2.2 History of Development

Beginning with the harvest of red cedar in 1906, logging operations have continued for over 100 years in the Clowhom Watershed. While harvesting for shingle production began in 1906, the first major sawmill in the region did not open until 1948 (Keller and Leslie: 2011). Logging operations continue today.

Constructed in 1952, the Clowhom Dam impounded the lower Clowhom River immediately prior to its confluence with Salmon Inlet. The 33 MW facility flooded a total area of 856 ha, resulting in a loss of three lakes with 17 km of shoreline, and an additional 9 km of mainstem and tributary channels (Raphals: 2004). The facility is still in operation today.

The Clowhom Watershed has since been subject to ROR development both on its mainstem and on the Bear Creek tributary (Figure 3). Beginning operation in 2010, the Upper and Lower Clowhom generating stations combine for a capacity of 22 MW. Downstream of these operations, Bear Creek joins the mainstem at the Clowhom Dam Reservoir. An additional two ROR operations with a combined capacity of 20 MW were installed on Bear Creek in 2012.

Figure 2 – Map of the Clowhom Watershed (Adapted from BC Hydro: 2015)
A search of mining operations through the BC Ministry of Energy and Mines found no history of mining in the Clowhom watershed, with no active or exploratory operations today. The remote location and limited accessibility by barge only has also meant that urban development and recreational activity is almost non-existent.

Figure 3 – Map of existing and potential ROR operations in the Clowhom Watershed. (Each existing site consists of a headworks, powerhouse, and penstock)
The long history of timber harvest makes the Clowhom Watershed an appropriate location for this case study. As many remote BC watersheds have been primarily subjected to logging operations, the Clowhom Watershed may be a suitable representation of similar watersheds that are being targeted for ROR development. In addition to the four existing ROR sites, there are seven active applications for hydropower within the watershed. The potential for further ROR expansion also makes this watershed a suitable case study, as many groups have expressed that the key concern over ROR development pertains to the cumulative risk of multiple ROR sites within a watershed (Watershed Watch Salmon Society: 2007) (Helston: 2012) (BC Sustainable Energy Association: 2015) (Anderson et al: 2015).

2.3 Study Objectives
In this study, I will first explore how each component of a ROR project may impact a watershed. ROR power generation in the Clowhom watershed will then be examined to determine which of these impacts are most likely or unlikely to occur given the specific land-use changes and stream conditions in the watershed. These impacts will then be examined to illustrate how they may interact in a cumulative manner with climate change and potential development in the watershed such as hydropower, logging, and recreation. This analysis will hopefully give more insight into the potential effects of ROR projects and in what scenario they may or may not be most suitable to both provide reliable emission-free energy and mitigate environmental impacts.

2.4 Study Outline
The study will be broken down into the following sections:

Section 3 – Investigation of the potential impacts of ROR development, based on existing literature.

Section 4 – Identification of the key land-use and hydrological changes and that have occurred in the Clowhom watershed as a result of ROR development, and the potential impacts these changes may have.

Section 5 – Examination of the current and potential status of resource development and additional land-use changes in the watershed.

Section 6 – Exploration of climatic and hydrological data to determine the extent to which climate change may impact the watershed.

Section 7 – Examination of how the mechanisms and impacts in sections 2, 3, 4, may act in a cumulative manner to affect the watershed.

Section 8 – A discussion of the key results of the analysis and how they may be used to better improve ROR development in British Columbia.
3. Environmental Effects of ROR Hydropower Development

In this section, I provide a detailed overview of the potential impacts from ROR hydropower development. Impacts attributed to each project component are divided into those that will primarily affect either aquatic or terrestrial ecosystems. Table 1 provides a summary of the project components and their major impacts as described in this section.

### Table 1. ROR project components and associated impacts. ‘X’ indicates that project component will impact corresponding indicator.

<p>| Project Component | Direct Impacts |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |</p>
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<th></th>
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<th>Terrestrial</th>
<th>Aquatic</th>
<th>Other</th>
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<td>X X X X X</td>
<td>X X</td>
<td>X</td>
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<tr>
<td>Footworks</td>
<td>X X X X X</td>
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<td>Penstock</td>
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<td>Transmission Lines</td>
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<td>Roads</td>
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<tr>
<td>Weir, Intake and Water Diversion</td>
<td>X X X X</td>
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3.1 Headworks and Footworks

The headworks and footworks consist of all structures respectively located at either the upstream intake or downstream terminus of the project. This includes the control building, powerhouse, substation, service buildings, and helipads.

3.1.1 Terrestrial Impacts

Building infrastructure first requires extensive clearing of vegetation, resulting in habitat loss and potential wildlife fragmentation. Without vegetation, organic soil inputs are reduced, and soil properties such as structure, stability, and permeability can be altered. Deforestation and the presence of impermeable infrastructure and bare soil surfaces can have its greatest impact of surface runoff, increasing the quantity and speed at which water is delivered to nearby waterbodies (Sahin and Hall: 1996). Bare soil surfaces may also be more erodible than the previously vegetated landscapes, allowing for greater transport of sediment with surface runoff (Gholami: 2013). Noise from plant operations such as the powerhouse can further act to disturb local ecosystems and reduce suitable wildlife habitat.

3.1.2 Aquatic Impacts

The most significant aquatic impacts pertain to the aforementioned changes in surface runoff. Depending on both the size of the stream and the extent of land-use change, changes in the influx of water and sediment to adjacent waterbodies can directly affect water quality and streamflow timing.
3.2 Weir, Intake and Water Diversion

The weir and intake are the key components of water diversion in a ROR project. A concrete barrier or weir is often used to create a small reservoir or headpond at the project headworks. The weir then works to divert water through an intake and into the penstock. During times of high streamflow, the weir is also designed to pass flood flows and debris into the downstream channel. Adjacent to the weir, a sluiceway is sometimes constructed to flush sediment and pass woody debris from the headpond. Water intakes are located within the stream channel, and can have an impact on both terrestrial and riparian habitat.

3.2.1 Aquatic Impacts

The process of inhibiting streamflow and diverting water is one of the most significant threats to water quality and aquatic ecosystems associated with an ROR project. Lewis (2005) outlined six broad categories into which the aquatic impacts of a hydroelectric project can be grouped. Each category is explored in the context of a ROR hydropower operation:

**Backwater effects**:

The impoundment of a river or stream through the use of a weir will result in some degree of upstream flooding or ponding. In this case, upstream flow velocity is reduced and depth is increased, potentially converting the area to an unsuitable habitat for some aquatic species (Lewis: 2005). Alternatively, the deeper, slower-moving water may prove to be beneficial for other aquatic species (Lewis: 2005).

Measures of water quality such as sediment concentration, temperature, and dissolved oxygen can also be impacted by impoundment. Key changes may result from the reduction of water velocity, leading sediment to drop out of suspension and aggregate behind the impoundment structure (Mahmoud: 1987). Though the impacts of impoundment are not completely mitigated with a ROR scheme, the direct impacts are greatly reduced when compared to the need for the large reservoirs associated with traditional hydroelectric projects.

**Dewatering**:

Dewatering refers to the reduction of streamflow caused through the diversion of water. In an ROR scheme, the area between the penstock intake and powerhouse outfall is known is the ‘depleted reach.’ By removing a portion of the natural streamflow, a reduction in water depth and velocity may alter stream connectivity and habitat suitability for aquatic species (Lewis: 2005). Dewatering will alter the natural streamflow regime while potentially elevating water temperatures, both of which are important elements for aquatic species with sensitive life cycles and habitat requirements.

**Downstream Effects**

Downstream effects refer to the stream segment located downstream of where diverted water has been returned to the main channel. In theory, ROR projects should have little or no influence on the downstream flow regime of a river as all diverted water is returned to the stream. Still, Lewis (2005) points out that operational errors and malfunctions may briefly affect downstream flows and dewater aquatic ecosystems.
Sediment impoundment at the headpond may also decrease the amount of sediment and nutrients flowing to the downstream reach, having implications for aquatic communities and stream morphology. Changes to water temperature experienced in the depleted reach may also continue to affect areas downstream of the footworks.

**Fish Passage – upstream blockage**

In streams containing migrating fish species, the presence of a weir or small dam can inhibit their upstream passage. Water diversion may also act to inhibit fish passage, as conditions such as stream connectivity and temperature may be unfavourably altered. Many operations employ the use of fish ladders to assist in upstream migration. In non-fish bearing streams or in those without migratory fish species, these precautions may not be necessary.

**Fish passage – entrainment**

Fish located in the headpond or moving downstream are at risk due to entrainment in the diversion infrastructure. If passed through the intake, fish can be killed for a variety of reasons. Cada and Amaral (2011) describes that turbines are often responsible for crushing or striking fish, while also creating fatal changes in water pressure. This risk can be reduced through the use of screens at the intakes or through deterrent systems such as strobe lights or bubble curtains.

**Habitat alteration**

The construction of the weir and sluiceway will result in a loss of habitat, as riparian vegetation, gravel, and sediment is replaced by concrete and metal infrastructure (Lewis: 2005). Water diversion will also decrease the depth and width of wetted area in the depleted reach, shrinking suitable habitat area.

**3.3 Penstock**

The penstock consists of a series of large diameter pipes used to carry water from the intake at the headpond, to the powerhouse. The penstock can be either buried or kept above ground between the two locations.

**3.3.1 Terrestrial**

Terrestrial impacts arising from the presence of a penstock will largely depend on whether the penstock is buried or elevated. While both types will require an initial clearing of vegetation, buried penstocks require less maintenance and brush clearing, possibly decreasing the total amount of habitat loss. Buried penstocks also preserve aesthetic value and reduce the potential for any disturbing noise or vibration.

The burying of penstock also protects pipes from UV radiation, and thermal expansion and contraction (McKinney et al: 1983). Potential damage from natural hazards such as rockfalls, avalanches, and tree fall is also reduced, mitigating the need for inspection and maintenance traffic (McKinney et al: 1983).

**3.4 Roads**

While not a direct component of energy generation, road construction is an important element to be considered with ROR projects. As these projects are often located in remote locations, the creation of
new roads is usually necessary. As is often the case with ROR projects, multiple generation sites will require an even greater number of new roads.

3.4.1 Terrestrial Impacts
New road construction can have a multitude of impacts for terrestrial plants and animals. The most obvious impact is the direct loss of habitat through the clearcutting and removal of vegetation. These cleared linear corridors can act as barriers to migration, fragmenting wildlife habitat, and altering predator-prey relationships and their populations (Daigle: 2010) (Forman & Alexander: 1998). Traffic noise has been acknowledged as a key contributor to these patterns (Forman & Alexander: 1998). Studies of both birds and large mammals have shown that wildlife distribution can be related to traffic noise and volume, with population densities decreasing with proximity to roads (Parris & Schneider: 2008) (Rost & Bailey: 1979).

With the removal of the forest canopy for roads, nearby vegetation may recolonize with altered population relationships. Changes in light levels, soil water retention, and organic inputs can alter the conditions that dictate vegetative community structure (Daigle: 2010). These conditions may then become more suitable for non-native or invasive plant species growth. Traffic on these new roads may then act as a way of inadvertently introducing and distributing foreign species.

New roads also allow for a range of indirect impacts related to the increased accessibility of a region. With increased presence of humans and vehicles, the chances of forest fire, wildlife roadkill, and contaminant introduction are all heightened. Increased accessibility also provides greater opportunities for timber harvest, hunting, poaching, and angling.

3.4.2 Aquatic Impacts
Depending on characteristics such as surface type, location, and usage, roads can have a significant impact on water quality and quantity, and aquatic species. Gravel or dirt service roads are often the most popular choice for access to remote watershed locations. Without vegetation, these unsealed surfaces are more susceptible to surface erosion and sediment transport. Increases in sediment and nutrient delivery to watercourses can then alter water quality and threaten aquatic habitats and species (Daigle: 2010). Compaction and decreased soil permeability can amplify this effect, as surface runoff will increase and travel time will decrease. Contaminants such as oil, fuel, and salts on the road surface may also be transported with sediment and runoff.

Depending on the road location, these effects can be mitigated. By reducing proximity to waterbodies and increasing runoff travel time, surface runoff has a greater chance of infiltrating soil, and sediments have more time to settle out of suspension. Similarly, avoiding construction on steep embankments reduces the possibility of slope failure and increased sediment transport. Bridges can also act as a key conduit for increased water, sediment, and contaminant discharge into watercourses (Environmental Protection Agency: 1995).
3.5 Transmission Lines
Transmission lines are required to transport the generated energy from a project substation into the main electrical grid. If the project is located in a remote location, many kilometers of transmission line may be required to make this connection.

3.5.1 Terrestrial Impacts
A report by Williams (2003) outlines the key impacts of transmission line construction:

- Habitat loss and fragmentation from vegetation removal
  - Birds and mammals have also been found to avoid power lines due to coronal light discharge (Tyler et al: 2014).
  - ‘Humming’ noise from transmission lines has also been theorized as a potential factor contributing to wildlife avoidance (Flydal et al: 2009).
- Increased accessibility means greater risk of invasive species introduction and potential for recreational use.
- Potential collision hazard for birds and waterfowl.
- Decline in aesthetic quality from forest clearing and intruding infrastructure.

3.5.2 Aquatic Impacts
Similar to road construction, the removal of plant and tree cover will have implications for the quantity, quality, and timing of surface runoff. However, whereas roads remain bare of vegetation, these corridors are often re-vegetated with smaller shrubs and trees due to the lack of traffic. This may lessen the possibility of increased surface runoff and sediment discharge as compared with roads.

4. Run-of-River Operations in the Clowhom Watershed
Using a combination of spatial data and project reports, the analysis provided in this section seeks to quantify the land-use changes that have occurred as result of the Clowhom Power Project and the Bear Creek Power Project. Generation sites for each project are differentiated as either the upper or lower site. Air photos, satellite images, spatial data, and project reports have been used to explore four key land-use changes:

- headworks and powerhouse;
- penstock;
- roads; and
- transmission facilities and transmission lines

Alterations to stream conditions as a result of water diversion have been explored through the use of yearly monitoring reports provided by the project proponent and are described in section 4.5.

Based on the changes to land-use and aquatic conditions as described below, table 2 summarizes the significance – low, medium, or high – of each ROR impact on the Clowhom Watershed. The estimated significance of each impact is based on the relative status of land-use and aquatic conditions directly prior to ROR development.
4.1 Headworks and Footworks

**Headworks - Clowhom**

The Clowhom Power Project consists of two ROR facilities, located approximately 5 km apart on the Clowhom River (Figure 4). According to the project’s *Operating Parameters and Procedures Report*, the sole building at each headworks is the control room, with an area of 15 m² at the upper site, and 30 m² at the lower site (Versen: 2013a, 2013b). Using satellite imagery, the amount of forest that was cleared for each location was estimated to be 3 ha at the upper site, and 2.2 ha at the lower site.

Weirs at both the Upper and Lower Clowhom sites have created headponds that respectively extend 180 m and 300 m upstream. The headpond for the upper site spans an area of 1.5 ha, approximately 650% greater than the river under pre-diversion conditions. Similarly, the wetted area at the lower site has increased by 220% with the new headpond.

With the increases in wetted area, riparian and terrestrial habitats will be displaced. Alternatively, the headpond may provide beneficial conditions for species suited to lower stream velocity and increased water depth. These changes to velocity and depth may also cause increased settling of suspended sediments, inhibiting sediment passage and altering downstream water quality. This may be further exacerbated with forest clearing and exposure of loose gravel and sediments adjacent to the headpond.

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**Table 2 – Clowhom ROR project components and associated impacts. (L/M/H for low, medium, and high significance)**

<table>
<thead>
<tr>
<th>Project Component</th>
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<td>Erosion/Sediment Transport</td>
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<td>Weir, Intake and Water Diversion</td>
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Headworks – Bear Creek

The Bear Creek Power Project also consists of two ROR facilities, located approximately 6 km apart (Figure 5). As project reports could not be obtained from the Bear Creek project proponent, the size of the project structures is unknown. Using satellite imagery, it appears that approximately 1.4 ha and 1.0 ha of forest has been cleared at the Upper and Lower Bear sites, respectively. The Lower Bear facility has created a headpond that has expanded the wetted surface area by 160% to 0.4 ha. In contrast, the Upper Bear facility uses an existing lake to augment flow for power generation, making flooding unnecessary.
Footworks

Similar to the headworks footprint, extensive clearing was required to accommodate infrastructure at all four site locations. A total of 7 ha of stream adjacent forest were cleared for all footworks sites, exposing bare soil and creating impermeable surfaces for powerhouses and substations. Substations and powerhouses for the Clowhom project have a combined footprint of 1745 m², possibly having
implications for water and sediment delivery to the adjacent rivers. While the specific size of the structures for the Bear Creek project is unknown, the shared substation at Bear Creek 1656 m².

4.2 Penstock
The Upper and Lower Clowhom projects both employed buried penstocks. The upper site consists of 1.9 km long penstock that has been buried directly adjacent to the Clowhom Mainline Road, following its course to the powerhouse. The penstock at the lower site is 1.2 km long, requiring both a new access road and a penstock bridge to cross the Clowhom River.

The Lower Bear Project employs 950m of buried penstock. In contrast, the Upper Bear Project used 1100 m of above ground steel pipe. Due to the extremely steep gradient from the headpond to the powerhouse, a temporary gondola was built to transport workers and materials between the two locations. This required extensive clearing of forest, clearcutting a swath approximately 50 m wide along the entirety of the penstock path. Because of the size and slope of this clearcut, it is possible this had implications for the adjacent Bear Creek.

4.3 Roads
Using data obtained from MFLNRO, all roads within the watershed that existed prior to construction of the ROR projects were mapped. New roads were then mapped by digitizing project maps contained in the OPPs, and by analyzing the most recent satellite imagery (Figure 6).

Due to the remote location and steep terrain of the watershed, access is only available via boat or helicopter. A dock located at the eastern end of Salmon Inlet acts as the only port of entry for vehicles. Because the watershed has been exposed to logging operation for many decades, an extensive road network originating from the dock has been already been developed. The Clowhom Mainline Road runs 30 km from the dock, passing by the Lower Clowhom site, and terminating at the Upper Clowhom site.

The two Clowhom projects required the creation of 3 km of gravel roads in addition to the existing forest service roads. These mainly came in the form of access roads (2.9 km) and upgrades (.6 km) to the existing mainline road. A new concrete bridge was also installed to provide access to the Lower Clowhom powerhouse.

The two Bear Creek projects required an additional 1.5 km of new road, as access is largely provided via the existing Bear Mainline logging road. Using satellite imagery, it appears as though a new bridge has been installed at each of the Upper and Lower Bear Projects.

A total of 3 bridges and 4.5 km of new road was required for the four ROR locations. Compared to the 167 km of pre-existing road infrastructure, this is likely to have a minimal impact on the watershed, representing an increase of only 2.7%. Moreover, the small portion of road that was upgraded may actually work to mitigate aquatic impacts, as the new segment was created 250 m away from the Clowhom River. While the pre-existing segment was located directly adjacent to the river, it has since been allowed to revegetate, reducing the risk of altered runoff inputs to the river. However, the three additional bridges may act as conduits for sediment and contaminant inputs to the streams. Accessibility
to the watershed remains difficult, and the new road has not opened up any significant opportunities for recreation, hunting, and logging.

Figure 6 – Map of all active roads, transmission lines, and timber harvest in the Clowhom Watershed. (Transmission line between Bear Creek projects is an approximation).
4.4 Transmission Lines
A 138 kV transmission line has been installed to connect both the Clowhom and Bear Creek Projects to the existing BC Hydro Substation at the eastern end of Salmon Inlet (Figure 6).

7 km of transmission line spans the distance between the Upper and Lower Clowhom sites, with an additional 14 km of line connecting the Lower Clowhom Project to the Bear Creek Substation. The Upper and Lower Bear Projects are then connected to the same substation via 7 km of transmission line. From here, 6 km of shared transmission line connects both Bear Creek and Clowhom projects to the existing BC Hydro substation adjacent to the Clowhom Dam.

Most of the transmission line has been constructed directly adjacent to the existing Clowhom Mainline Road. Using a combination of satellite imagery and spatial data from MFLNRO, it appears that from the Upper Clowhom powerhouse to the BC Hydro substation only 5.6 km or 21% of the transmission line was not constructed directly adjacent to the existing road. Suitable imagery, spatial data, and site maps were not available for the Bear Creek Project and it is difficult to estimate how much of the 7 km of transmission line has been twinned with the existing Bear Creek road. Given the steep terrain in the Bear Creek Valley and need for continued access to the lines, I would imagine that as much transmission line as possible was constructed adjacent to the road. The limited imagery available also supports this.

By twinning transmission lines with existing roads and sharing lines between the two projects, the need for additional deforestation has been mitigated. By sharing corridors, this also cuts down on the potential for habitat displacement and fragmentation. Coronal noise or ‘humming’ from the 138 kV transmission is likely to be minimal or non-existent, as concerns for noise are usually associated with voltages greater than 345 kV (Tucson Electric Power: 2011). Harlequin Duck has been identified as the main bird species of concern within the watershed, and as of 2013, no transmission strikes were observed or reported.

4.5 Stream Conditions

Baseline Considerations for Stream Conditions
A lack of long-term monitoring data makes it difficult to establish ‘pristine’ pre-impact baselines. Data provided by the project proponent consists of five years (2004, 2006-2009) of baseline information, and four years (2010-2013) of post-diversion monitoring. This shift in baseline period now represents a state of the watershed that has been subjected to timber harvest and large hydro operation for many decades. Because the post-diversion dataset is so small, it is hard to definitively say if any significant changes to stream conditions have or have not occurred between the two measured periods. Nonetheless, a cursory review of the changes from the pre-diversion to post-diversion state is made here.

4.5.1 Streamflow
According to the Operating Parameters and Procedures reports for the two Clowhom projects, it is estimated that 53% to 86% of monthly water inflow to the Clowhom headponds is diverted for energy generation (Verasen Power: 2013a, 2013b).
Flow diversion will have its greatest impact within the depleted reach of each project, reducing stream velocity and decreasing stream width and depth. These changes can not only shrink aquatic habitats, but can reduce river connectivity and isolate fish species (U.S. EPA: 2015). Diversion will also affect the natural timing of streamflows, an integral part of preserving the ecological integrity of river ecosystems (Poff et al: 1997). Downstream of the project, natural discharge and flow timing should be preserved as all diverted flows have been returned to the river.

Reports of stream conditions for the Upper and Lower Bear Projects were not made available and thus are not included in this section.

4.5.2 Water Quality
As previously discussed, diversion can have extensive impacts to water quality measures such as turbidity, dissolved oxygen (DO), and temperature. Operational and Environmental Monitoring Reports for the two Clowhom projects indicate that changes to these parameters have so far been minimal.

Five years of baseline data (2004, 2006-2009) was compared to the four years of post-diversion from 2010 to 2013. Using a series of control and impact sites, the reports show that DO and turbidity have remained unchanged from baseline conditions at both the upper and lower sites (OEMP:2013). Water temperatures have also remained unchanged at the Lower Clowhom site, showing only a minor increase within the depleted reach of the upper site (OEMP: 2013). In this case, 15°C was the highest observed temperature over the four years of monitoring, approximately 1°C greater than normal summer peaks (OEMP: 2010). Still, temperatures remained well short of the 18°C threshold at which metabolic activity may be impeded for the most sensitive fish species in the Clowhom River (OEMP: 2010).

4.5.3 Fish Species
Dolly Varden (DV) and Rainbow Trout (RT) are the two main species that have been identified in the Clowhom River. While Chum salmon have been reported in the short reach between Salmon Inlet and the Clowhom Dam, they have not been identified above the dam (Bridge Coastal Restoration Program: 2005). The Clowhom Dam may act as an obstacle for anadromous fish, potentially accounting for their long-term absence in the remainder of the watershed.

Baseline inventories for abundance and condition of DV and RT were established in the five years prior to operation through minnow-trapping and angling. Using a before-after control-impact framework, four years of post-diversion monitoring have indicated that there have been no statistically significant changes in the abundance or species proportions at any of the Clowhom impact sites (OEMP: 2013). Similarly, no significant changes were found in the length or weight of either fish species at all sites.

As DV and RT are non-anadromous species, the need for upstream and downstream migration is less than that of anadromous fish, possibly decreasing the likelihood of fish being trapped or killed when encountering ROR infrastructure. The use of three fish deterrent mechanisms – strobe lights, underwater acoustics, and bubble curtains – may have also contributed to the stable fish populations. Still, further monitoring is required to make definite conclusions regarding the impact of ROR operations on fish.

This section describes the current and potential status of resource development and land-use change in the Clowhom watershed.

5.1 Timber Harvest

Timber harvest has been ongoing in the Clowhom Watershed for over 100 years. The development of ROR operations and their associated infrastructure may allow for further harvest in newly accessible regions of the watershed. Further timber harvest could then have implications for stream conditions and ROR operations.

Using spatial data provided by MFLNRO’s Reporting Silviculture Updates and Land Status Track System (RESULTS), a history of logging operations was mapped for the Clowhom Watershed (Figure 6). To align with the pre-impact and post-impact timeframes, logged areas were divided into those harvested prior to 2005, from 2005 to 2009, and from 2010 to 2015. Recent satellite imagery provided supplementary data that was digitized and added to the most recent timeframe.

From 2005 to 2009 approximately 890 ha of forest was logged in the Clowhom watershed. Over the 2010-2015 period, logging operations dropped by more than half, clearing only 370 ha of forest. Of this most recently logged area, it appears that only 7% of it may have been logged due to increased accessibility provided by a new road and bridge for the Lower Clowhom powerhouse (Figure 4). As road infrastructure was thoroughly developed prior to ROR development, it does not appear as though expansion of ROR operations will allow for additional logging in previously undisturbed areas.

Though the future location, size, and timing of timber harvest is unknown, it is likely that future operations will in some way impact the streamflow and water quality of the Clowhom River. In addition to habitat loss, the impacts of forest harvesting are well-studied and may include (Brown: 1974):

- Increased surface runoff;
- Increased river discharge;
- Increased surface erosion;
- Increased sediment and nutrient inputs to nearby watercourses; and,
- Increased water temperature and decrease dissolved oxygen content of nearby watercourses.

5.2 Recreation and Other Land Uses

Accessibility to the Clowhom watershed remains limited following the construction of the Bear Creek and Clowhom Hydro Project. Access to the area is still via barge and forest service road, or helicopter. As such, it is unlikely that the amount of recreational visitors will change. Similarly, threats from urban and rural development likely remain unchanged. According to the BC Ministry of Energy and Mines (2014), there are no mining development or exploration projects planned for the region.
5.3 Further Hydropower Development

While there are seven active water license applications within the Clowhom Watershed, it is uncertain how many of these will actually result in further ROR development. The impacts of each of these potential developments will depend on the site locations and the infrastructure required to support them. These potential sites are largely accessible by existing road, but will still require forest clearing for site infrastructure and transmission lines. As infrastructure has now been thoroughly developed in the watershed, each additional project should require less construction of new infrastructure. Aquatic impacts will depend on the species present at each site and the particular stream characteristics. It may become possible to extrapolate some of these potential impacts from continued monitoring of the Clowhom and Bear Creek sites.

6. Climate

Reliance on natural streamflow regimes means that ROR energy generation is susceptible to any unforeseen changes in river discharge. As such, it is important to consider how climate change may impact hydrological conditions within a utilized watershed. In this section, I will examine the relationships between climatic conditions and discharge, and how this may contribute to impacts on the watershed.

A meteorological station maintained by BC Hydro has measured daily weather observations at the Clowhom Dam since 1964. While this dataset is more representative of the lower elevations of the watershed, it is the most complete meteorological record available in the watershed. An examination of the data shows that there have been some interesting climate trends over the past 50 years that may have implications for streamflow in the Clowhom Watershed. Clowhom River discharge is monitored 3 km upstream of the Clowhom Lake Reservoir. Operated by the Water Survey of Canada, this gauge provides a short record from 1993 to 2013.

6.1 Temperature

Over the past 50 years, it appears as though average minimum temperatures have been either stable or increasing for all months (Figure 7). The elevated minimum temperatures could be most influential for winter and spring snowpack, inhibiting snow formation in winter and accelerating melt in spring. In turn, this could affect the timing and quantity of discharge in rivers and streams dependent on nival and glacial inputs. During low-flow months a shift or decline in discharge could have severe implications for sensitive aquatic communities and ROR operations restricted by instream flow requirements (IFRs).
6.2 Precipitation
For many months, precipitation trends in the Clowhom Watershed remain fairly indistinct and highly variable from year-to-year (Figure 8). However, winter months from December to February appear to show a slight declining trend in total precipitation over the past 50 years. Along with elevated winter temperatures, a decline in winter precipitation will inhibit the formation of annual snowpack and glacial ice. As snow and glaciers are often important factors in maintaining baseflows in drier months, a decrease in winter precipitation may indirectly affect sensitive aquatic ecosystems and ROR operations during warmer and drier months.
6.3 Discharge

Discharge observations for the Clowhom River have a high annual variability and are based off of only 20 years of data. The lack of data in combination with the acknowledgment that glaciers in BC are receding and climate is changing, makes it hard to say whether any trends over the last 20 years will be indicative of the future (Chapin et al: 2012). However, the subtle trends exhibited for Clowhom River discharge do appear to distinctly alternate between typically drier (June-Sept) and wetter (Oct-May) months (Figure 9). As might be expected with declining winter precipitation, discharge also appears to be declining over the winter months. However, this trend is reversed during the summer months. While precipitation shows minimal changes over the June to September period, discharge has been increasing. Without an additional source of water, discharge is most likely increasing as a result of elevated minimum temperatures, and consequent acceleration of snowmelt. During the late summer months of August and September, discharge is likely being supplemented by the nine glaciers within the watershed. As expressed by Chapin et al. (2014) in the 2014 National Climate Assessment, glaciers in British Columbia are shrinking substantially and the trend is expected to continue. If snowpack and glacial ice are in fact receding in the Clowhom Watershed, the increasing trend observed for summer discharge may
eventually reverse as high elevation water sources diminish. Along with declining precipitation, this trend may increase the magnitude of annual low-flows, presenting challenges for ROR operation and instream flow requirements.

Figure 9 – Clowhom River discharge (1993-2013) near Clowhom Lake (WSC gauge 08GB013)

6.4 Aquatic ecosystems and ROR Operation

Operating Parameters and Procedures Reports specify the minimum instream flow requirements (IFRs) for each of the Clowhom Projects (table 3). Though the lowest flows of the year occur in winter, IFRs for both projects are greatest in months from May to August. Bradford and Heinenen (2008) describe that maintenance of summer low-flows is critical for aquatic ecosystems. A reduction in summer flows can increase water temperatures and decrease water quality, alter biotic interactions, and reduce instream habitats (Bradford and Heinenen: 2008). If the increasing trend in summer discharge continues, the Clowhom ROR operations may be able to divert more water and increase energy production at these times. However, a reduction in winter precipitation, snowpack, and glacial mass, may eventually reverse this trend, presenting long-term problems for ROR operations during typical peak generation times.
During extreme years in which winter precipitation is minimal and annual temperatures are elevated, this trend may eventually add to the magnitude of extreme low flows.

<table>
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<th>Month</th>
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<th>Lower Project</th>
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<tbody>
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<td>%MAD*</td>
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<tr>
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</tr>
<tr>
<td>February</td>
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<tr>
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<td>0.29</td>
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<tr>
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<tr>
<td>Mean Annual</td>
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*MAD* = Mean annual discharge

Table 3 - Instream Flow Requirements at the two Clowhom projects (Table from OEMP: 2010).

OPPs indicate Clowhom River discharge and energy production is typically lowest in winter months. If declining winter discharge trends persist, it may be necessary to decrease or shutdown winter operations. The minimum flow required to operate the Upper and Lower Clowhom sites is 0.8 m³/s and 2.0 m³/s, respectively. In combination with IFRs, this means that the required headpond inflow to each site to operate is 1.09 m³/s and 2.72 m³/s, respectively. When specifically examining the lowest flow month of February, these figures represent over 50% of river discharge. If the observed trend in February discharge continues, it may become necessary in extreme years to reduce or shutdown operations to maintain IFRs.

6.5 Disturbance by Fire

With more frequent and extreme hot and dry summer weather, the potential for forest fires in BC is growing. A recent report released from MFLNRO (2014) describes that expected climate conditions into 2080 will result in multitude of changes for forest fires in Southern British Columbia, including:

- increased fire size, doubling from an average of 7,961 ha to 19,076 ha;
- increased fire severity by 40% in spring, 95% in summer and 30% in fall;
- increased fire season length and fire frequency by 30%;

Depending on fire size, intensity, and location, forest fires can severely alter hydrological regimes and compound with impacts from existing activities within the watershed (Neary et al: 2003). While it is impossible to predict the timing and extent of forest fires within the watershed, the likelihood of occurrence is increasing and should be considered in a CEA.
7. Cumulative Assessment – Results and Discussion
This section seeks to describe the potential interactions between the effects of ROR development and the effects of other activities, projects, and land-uses within the Clowhom Watershed. Specific ROR project impacts are described in section 4 and impacts attributed to other projects, land-uses, and climate change are identified in sections 5 and 6.

Assessment of cumulative impacts will be grouped within 5 categories. These impact groups can also be defined as Valued Ecosystem Components (VECs). VECs are chosen as “specific features or attributes of the environment that are considered to be important for regulatory reasons, or because of their social, cultural, economic, or ecological value (Olagunju: 2012). For this project, popular VECs for CEAs in Canada have been chosen as a representation of the impacts defined in sections 4 (table 1), 5, and 6 (Olagunju: 2012):

- Forests and Wildlife;
- Surface Waters;
- Fish and Fish Habitat;
- Accessibility and,
- Aesthetic Quality

7.1 Forests and Wildlife
The most significant current and potential threat to forest habitats in the Clowhom watershed can be attributed to timber harvesting. Cumulatively, 7380 ha or 19% of the watershed has been deforested since 1960, with less than 0.2% of that attributed to ROR operations. Looking within the temporal scope of this project, this amount is still fairly minimal compared to the 1,261 ha that has been logged over the last ten years. While future ROR development will require further clearing, the size of clearcuts and ongoing nature of logging operations will continue to greatly outweigh this. Though the cumulative loss of 7,380 ha of forest is significant, the project related portion of 0.2% is unlikely to be ecologically significant.

Habitat fragmentation can be largely attributed the presence of roads and transmission lines. As the road network was extensively developed prior to ROR operations, the cumulative addition from ROR related road building is minimal, increasing the road network by 2.7%. It is likely that any future development of ROR hydro and logging operations will also use these existing roads, further mitigating any cumulative effects. However, the construction of transmission lines in both previously undisturbed forests and adjacent to roads will likely amplify the effects of fragmentation. Further hydropower development will also require additional transmission line construction.

Forest fires represent another important factor that could affect forests in the Clowhom Watershed. While it is nearly impossible to predict the frequency, size, and severity of fires within a watershed, the risk of forest fires in southern BC is increasing. In combination with logging, forest fires have the potential to result in a significant loss of forest.
7.2 Surface Waters
The quantity, quality, and timing of streams and rivers will be affected by a multitude of mechanisms. As these three parameters are largely influenced by surface runoff, the removal of vegetation and alteration of land cover by timber harvest, ROR development, and forest fires can have cumulative impacts.

Surface runoff is largely altered through the removal of vegetation and transformation of land cover. Within the Clowhom Watershed, timber harvesting is again the mechanism with the highest potential impact. Clearcuts and their access roads provide surfaces conducive to increased runoff and sediment transport. While ROR operations may require a significant amount of access roads, the ROR projects in the Clowhom depended on an existing road network. Again, the total area of forest cleared for the four sites is only 14.6 ha, likely having an insignificant ecological impact as compared to the 1261 ha that has been logged in the last ten years.

The damming and diversion of water is probably the most significant ROR component to affect surface waters in the Clowhom Watershed. The substantial amount of diverted water results in a reach that is depleted of 53-86% of its flows, thus altering stream dimensions and aquatic habitats. However, monitoring programs indicate that turbidity, dissolved oxygen, and temperature have been largely unchanged compared to pre-impact conditions. Still, further monitoring is required to ensure the strength of these conclusions. As the changes in discharge are confined to the four relatively short depleted reaches, it is not likely that the residual impacts of water diversion will act cumulatively with timber harvest or forest fires.

The greatest threat to surface waters may be attributed to climate change. As aforementioned, climate trends appear to be decreasing winter discharge and increasing summer discharge. Currently, increased summer streamflow may act to decrease the percentage of diverted water energy generation, and preserve instream flows. However, if this increasing trend can be attributed to accelerated snow and glacier melt, it is likely that the trend will eventually reverse as nival and glacial runoff sources diminish. The effects of water diversion in combination with reduced discharge as a result of climate change may act cumulatively to increase the magnitude and duration of low flows in the depleted reach. Associated changes with sediment load, dissolved oxygen, and temperature may then be severe enough to extend into downstream reaches.

7.3 Fish and Fish Habitat
Fish sampling indicated that there have been no significant changes in the abundance and condition of fish between pre and post diversion states. Though project infrastructure can inhibit migration and cause fatality, the populations have remained stable. While the depleted reach has reduced usable fish habitat, the creation of the headponds may have provided a new habitat for Dolly Varden and Rainbow Trout. In the future, it is possible that water diversion and climate change may act to cumulatively impact stream and fish conditions, especially during times of extreme low flow and within the depleted reach. Though in theory the maintenance of specific IFRs should continue to preserve aquatic ecosystems and fish populations.
7.4 Aesthetic Value
Timber clearcuts, transmission lines, and roads are the predominant elements affecting visual quality in the Clowhom Watershed. Decades of clearcutting and regrowth have resulted in landscape with a patchy appearance, interspersed with powerlines and roads.

The greatest aesthetic impacts related to ROR development in the Clowhom will arise from the construction of transmission lines and infrastructure at the headworks and powerhouse. Transmission lines will be the most noticeable feature due to their installation along the entire course of the Clowhom Mainline Road. However, clearcuts will still remain as the most noticeable watershed feature, and the projects overall contribution to visual cumulative effects will be moderate.

7.5 Accessibility
Additional road constructed for ROR operations has been minimal, mitigating the opportunities for expansion of logging operations and recreational activities such as hunting, fishing, and dirt biking. Road building for any additional ROR development is also likely to be minimal, as the water license locations are already accessible by existing roads. Future logging operations may result in further road expansion, but the remote location and limited access will continue to mitigate threats related to increased accessibility. The cumulative impacts of logging and ROR development on watershed accessibility are not likely to be significant.

7.6 Summary of Cumulative Effects
Table 4 summarizes the key cumulative interactions between ROR development and other effects mechanisms within the watershed. Because of the pre-existing watershed conditions, the portion of cumulative effect that can be attributed to the ROR projects is low for most VECs (table 4).

Whereas as project development in other areas of the province often require extensive road expansion, the existing road network in the Clowhom mitigated this need. These roads also provided pre-established corridors for which the majority of transmission line was constructed in and can continue to be accessed with. The absence of anadromous fish species – whether related to the Clowhom Dam or not – has also mitigated the negative impact of ROR operations on fish populations and migration. Timber harvesting has and continues to be an important activity in the region, and the additional clearing of forests for ROR operations has been a miniscule addition to these logging operations, likely having a relatively minor impact on terrestrial ecosystems and surface hydrology. For most of the VECs, the cumulative effect is largely attributed to timber harvesting. Though in the future, it is likely that this portion will begin to shift as climate change and forest fire become increasingly influential factors.
8. Conclusions

8.1 The Clowhom Watershed

Overall, it appears as though the Clowhom Watershed was a suitable location to develop ROR energy projects, while mitigating environmental damage. This can be attributed to a few key conditions:

- The project was built in an area with an extensive pre-existing road network, limiting the impact from additional roads, transmission lines, and improved accessibility.
- The isolated location limits accessibility regardless of new infrastructure development.
- The absence of anadromous fish means that ROR infrastructure does not inhibit migration.
- In conjunction with other impact mechanisms – especially logging – the incremental cumulative impacts attributed to the ROR projects are minor.

However, climate related impacts remain as the wild card for the future health of the watershed. While the observed trends may be subtle, their impact on the magnitude and duration of low-flows may have future implications for aquatic species and ROR operations. If post-diversion stream conditions for the Clowhom Projects are reflective of any future ROR development in the watershed, it appears as though the projects will not have cumulative aquatic impacts. This could change depending on further analysis of continued monitoring data and climate conditions.
8.2 ROR Development in British Columbia

It has been expressed by many groups that the main concern over ROR development in BC pertains to the cumulative environmental risk of several ROR projects in addition to other activities and projects in a watershed (Watershed Watch Salmon Society: 2007) (Helston: 2012) (Taylor: 2010) (BC Sustainable Energy Association: 2015) (Anderson et al: 2015). However, the understanding and availability of research regarding these cumulative effects is limited.

ROR development in British Columbia has a lot of potential due to the abundance of suitable and underutilized rivers. However, sites need to be chosen carefully to mitigate environmental damage. Analysis of the Clowhom River suggests that one of the key factors in determining the environmental effects of ROR development pertains to the condition of the watershed directly prior to diversion. Utilizing watersheds with pre-existing infrastructure and resource operations will largely reduce the impacts directly attributed to ROR development. Development in a remote watershed with limited human activity will open the door for further resource exploration, recreational accessibility, urban and rural development, and cumulative impacts.

A detailed analysis of future climate conditions will also help to choose appropriate locations for ROR hydro. While IFRs should maintain aquatic ecosystems, the implications climate change could have for energy generation may lessen the feasibility of a project in future years. Though often not available, extensive historic data on stream and climate conditions would greatly assist future ROR considerations. Proactive data collection on rivers located in potential ROR locations would assist in establishing more suitable baseline conditions and climate analyses.
9. References


Bridge Coastal Restoration Program. (2005). Spawning and Rearing Habitat Assessment in Lower Clowhom River. Prepare by Sigma Engineering. BCRP Project #05.CL.01


http://www.energybc.ca/profiles/runofriver.html


