Milford Opportunities Project

Existing Hydropower Potential

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PREPARED FOR:

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PREPARED BY:

Phelia Klopper

Stantec

Revision Schedule

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Abbreviations

Abbreviations	Full Name
DEM	Digital Elevation Model
DOC	Department of Conservation
LiDAR	Light detection and ranging (elevation data)
LINZ	Land Information New Zealand
NIWA	National Institute of Water and Atmospheric Research
MALF	Mean Annual Low Flow
MASL	Meters Above Sea Level
MSI	Milford Sound Infrastructure

1. Introduction

There are two existing hydropower plants currently in operation at locations forming part of the Milford Opportunity Project, namely the Milford Sound Hydro located at the Milford Sound Hub and the Knobs Flat Hydro located at Node 3. Stantec visited these sites and performed a desktop study to assess the potential for expansion of these existing schemes. Discussions with Milford Sound Infrastructure (MSI) also informed the report for the section on Milford Sound Hydro.

Expansion potential was assessed by comparing the abstraction of various flows, changes to the existing penstock, changing the intake location, and refurbishment of the machines. The assessed options were compared in terms of expected effort of obtaining resource consent, the rated output, storage requirements, and upgrades required to equipment, penstock, and infrastructure.

Hydrological values such as mean flow, Mean Annual Low Flow (MALF) and flow duration curves of the relevant rivers was obtained from NIWA's NZ River Maps website (https://shiny.niwa.co.nz/nzrivermaps/). No flow records were available in these catchments. Although rainfall data is available, due to data limitations and the significant effect of snowmelt on runoff in the region, there was not enough confidence in an estimated flow record from rainfall data.

The NIWA River Maps data is deemed sufficient for this level of study. NIWA River Maps provides estimated values from a regression model that uses data from gauge stations across New Zealand and a large range of variables such as elevation, temperature, evapotranspiration etc. (D.J. Booker, 2014). These variables will simulate the effects of snow and snow melt on the river flow. However, modelled data is not as accurate as actual measured data, therefore, it is recommended that onsite flow gauging be performed if the project is to progress further.

Figure 1-1: Existing Hydropower Schemes on NZ Topographical Map

2. Milford Sound Hydro

The Milford Sound hydropower scheme is operated by Milford Sound Infrastructure (MSI). MSI provides all electricity at Milford Sound, with the hydropower scheme supplemented by diesel generators and gas. The hydropower scheme abstracts water from the Bowen River above the Bowen Falls, conveyed through a 650 m penstock to the powerhouse, and discharges into the Freshwater Basin.

The scheme is nominally recorded by MSI as being rated at 500 kW.

Figure 2-1: Bowen Falls (source: By Krzysztof Golik - Own Work, CC by-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=67413369)

2.1 Catchment Area and Flow

The intake of the hydropower scheme is located near the end of the Bowen River with a catchment area of 19.87 km^2 and a static head of approximately 221 m.

The Resource Consent includes the following condition:

- The abstraction shall not exceed:
  - 313 l/s (0.313 m^3/s)
  - 27,000 m^3 per day
  - 7,884,000 m^3 per year
- The abstraction for hydropower generation shall not reduce flow in the Bowen River below 0.58 m^3/s

Note the minimum flow required in the Bowen River after power generation equals 85% of the MALF. This allows for the minimal operating take of the current scheme (100 l/s or 0.1 m^3/s) to be abstracted.

The previous consent allowed for the abstraction of up to 750 l/s, but this was reduced to the above-mentioned limits in 2020 to match the actual operational abstraction.

The mean flow and Mean Annual Low Flow (MALF) were obtained from NIWA's Rivermaps as shown in Table 2-1.

Table 2-1: Key Parameters for Milford Sound Hydro

Site	Mean river flow (m^3/s)	MALF (m^3/s)	Residual flow requirement (m^3/s)	Maximum operating flow (m^3/s)	Minimum operating flow (m^3/s)
Milford Sound Hydro	3.6258	0.68726	0.58	0.3	0.1

The flow duration curve as obtained from NIWA Rivermaps has been developed by a New Zealand-wide regression model using data from gauge stations and predictors representing spatial and temporal patterns (D.J. Booker, 2014). These predictors include variables such as elevation and temperature which would be associated with snow and snowmelt, relevant in the Southland region.

The flow duration curve for the catchment shown in Figure 2-2 indicates that the minimum operating flow can be abstracted 93% of the time (i.e., abstracting 0.68 m^3/s to allow for the residual flow of 0.58 m^3/s). MSI confirms sometimes throughout the year they do not have sufficient water to run their plant at maximum output and very occasionally they are unable to generate at the minimum output.

Even though the modelled flows of NIWA is not as reliable as flows as measured on site, no flow measurements are available. Therefore, the NIWA flow duration curve has been used for this study, but it should be noted that results could be optimistic, especially at lower flows. Onsite flow gauging will need to be performed in future design stages if the site is considered for expansion.

The modelled data from NIWA suggests that there are periods of much higher flows available. If these higher flows are used to generate power, it will require long duration energy storage to ensure the generated power is available when there is demand. Various abstraction options are discussed in Section 2.4.

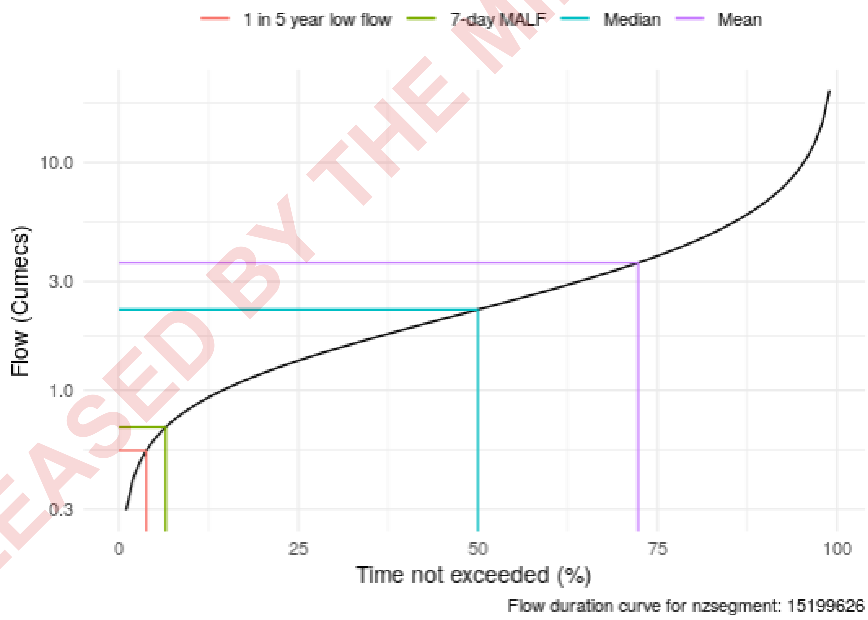

Figure 2-2: Flow Duration Curve for Bowen River (Source: NIWA Rivermaps)

2.2 Scheme Summary

- **Intake:**
  The existing intake is located 400 m upstream of Bowen Falls at about 226 MASL and consists of a steel intake screen installed over an opening cut into rocks on the right bank of the river.

  The intake is accessible by helicopter or by foot (30-minute walk).

  See photos of the intake and weir in Figure 2-3 below. Note that the weir has been upgraded since the photo was taken.

Figure 2-3: Milford Sound Hydro Weir and Intake (Source: Resource Consent Application)

- **Conveyance:**
  From the intake the water is conveyed 40 m to a stilling tank. The stilling tank allows stones and particles passed through the intake screen to settle at the bottom of the tank before the water is being discharged to the above-ground penstock. The existing 650 m long, 400 mm diameter steel penstock is in a poor condition. Concrete pedestals support the penstock through the forest until the steep slope towards the powerhouse. Steel pedestals are used down the steep slope.

Figure 2-4: Milford Sound Hydro Penstock (September 2023)

- **Powerhouse:**
  An intake valve (spear valve) controls the amount of water to the turbine dependent on the electrical load required.

  There are two turbine generators, the original Gilkes unit rated at 630 BHP (470 kW) and a newer Jinhua Electric Machinery Works ("Chinese") unit rated at 500 kW. Both generators cannot run at the same time due to the headlosses of the penstock and resource consent flow limits.

  The turbine centreline is assumed to be at about 5 MASL, estimated from the 2022/2023 LiDAR.

- **Tailrace:**
  Water is discharged through a pipe to the outfall in the Freshwater Basin.

2.3 Existing Operation

The "Chinese" unit is currently in operation the majority of the time. It uses 300 l/s to generate the maximum rated output of 500 kW. The minimum operating load is 150 kW.

From the site visit by Stantec and DOC in September 2023 and a meeting with John McCutcheon also in September 2023, the following information was obtained:

- The current peak demand is 480 kW.
- There are two diesel sets used during peak times in the morning and night whenever the hydropower generation is not meeting the demand: 50 kVA and 460 kVA.
- Gas is used for space heating, water heating, and cooking.
- It is rare for the hydropower plant to not generate any energy, but the load is often reduced due to low flows in the river.
- Especially during the shoulder seasons, there are times when the Bowen River flow is too low to generate at maximum output.

The breakdown of electrical energy for different user types are estimated as per below:

Table 2-2: Existing Energy Use at Milford Sound Supplied by MSI

Tourist Accommodation	32%
Fishing	8%
Tourist Boat operators	40%
Utility companies	17%
Other	3%

Overall annual energy supplied by MSI (pre-Covid) is estimated as per below:

Table 2-3: PreCovid Annual MSI Energy Supply

	GWh/year	Comment
Diesel	0.05	5,000 L as estimated by MSI
Hydropower	2.05	Difference between "Total Generated Energy" and energy from diesel
Total Generated Energy	2.10	Estimated by MSI. Assumed to account for diesel and hydropower generation and not gas.
Gas	1.28	100,000 kg as estimated by MSI

2.4 Potential for Expansion

Potential for expansion has been considered by increasing flow, upsizing the penstock, increasing the machine efficiency, and moving the intake location. This report did not consider adding water storage at the intake, as this is expected to be challenging in terms of resource consenting.

2.4.1 Flow

The power output of the existing scheme is limited by the flow allowed by the Resource Consent and the size of the penstock.

The ecological assessment completed as part of the Resource Consent Application for the hydropower scheme concluded that the abstraction of water for the hydropower plant has a negligible, if any, negative effect on the ecosystem of the river. Especially due to the turbulent nature of the river, the intake location just above the Bowen Falls (which already restricts migratory fish species), and as the scheme only affects a short section of the river. The Application also mentions that if a higher abstraction is considered in the future, a residual flow may be required to ensure enough water remains in the river in periods of low flow. Although the current scope of works excludes any environmental assessments associated with the proposed solutions, it is not unreasonable to believe that an increase in the abstraction rate could be allowed in the future. We have assumed that the current stipulated residual flow of 0.58 m^3/s will remain in place.

The following abstraction options and associated power output were assessed. Penstock losses and machine efficiencies are discussed in the following sections.

Table 2-4: Milford Hydro Abstraction Options Summary

	Option	Rated flow (m^3/s)	Rated flow exceedance probability	Rated output (kW)[1]	Estimated annual energy (GWh)[2]	Capacity factor[3]
1	Current operation	0.30	89%	500	3.87	0.92
2	Previous consented abstraction	0.75	76%	1,258	9.58	0.87
3	Both existing turbines in operation[4]	0.50	83%	806	6.38	0.90
4	Operating at mean flow[5]	3.05	28%	5,250	26.26	0.57
5	Minimum operation at MALF[6]	1.10	65%	1,896	13.57	0.82

All options assumed continuous operation (day and night) and that the surplus energy will be stored. Note that these options can be further refined once there is a better understanding of the energy demands and specific requirements of the

[1] All these options assumed a headloss of 10% of the gross head. Water to wire efficiencies assumptions are discussed under the "Machine efficiency" section.
[2] This is based on the NIWA Riversmap flow duration curve. Assuming maintenance will take place during low-flow / zero generation times and with no forced shut down.
[3] Assumed continuous load available, i.e. day and night operation.
[4] Rated flow chosen to deliver 815 kW.
[5] Rated flow is based on maintaining 0.58 m^3/s in the river at the mean flow of 3.63 m^3/s.
[6] Minimum flow for generation is chosen at MALF (i.e. 0.69 m^3/s minus the reserve flow of 0.58 m^3/s). This option will have more operational days than Option 4 and higher annual generation than Option 2.

transportation fleets. Options such as increasing generation during the night-time (perhaps abstracting beyond the reserve flow limits), when the visual impact of the Bowen Falls are less important can be considered.

For higher flow options with a low flow exceedance probability, longer term energy storage would be required as the times of high flows will not necessarily coincide with times of high demand.

2.4.2 Penstock

An upgrade of the penstock is required for the existing operating condition or any of the abstraction options as discussed in the previous section. The penstock requirements could be the driving factor for selecting the best solution due to the potential cost, and the terrain being very challenging for the construction of a penstock, especially for larger diameters. For this study, we have assumed a steel penstock will be chosen, however, Glass Reinforced Plastic (GRP) or High-density polyethylene (HDPE) options could be investigated in further design stages.

The most economic penstock diameters have been calculated using Warnick's formula for small scale hydropower and the results provided in Table 2-6 (Warnick, 1984). This formula generally keeps the velocities in the penstock low (about 2.5 m/s) to keep hydraulic headlosses low. However, a more detailed analysis should be done on the penstock sizing to determine how much hydraulic headlosses can be accepted to allow for smaller penstock diameters and easier installation.

2.4.3 Machine Efficiency

A refurbishment of the existing machines can be a more cost-effective way to achieve a slightly higher power output. Apart from improving turbine and generator efficiencies, a refurbishment could also allow for the turbines to operate at a lower minimum flow, which will increase the operational days and annual energy output. The current minimum operating flow for the Chinese Turgo unit is 33% of the rated flow, it is expected that this could be reduced.

It should be noted that the Chinese unit was refurbished in November and December 2022 with a new runner installed and a half-life refurbishment of the generator.

Although the current efficiency and operating limits of the Gilkes Pelton turbine are not known, due to the age of the machine, it is expected that there could be potential gains in refurbishment. The turbine nameplate capacity is stated as 473 kW (635 BHP), but the Resource Consent Application states the capacity as 350 kVA (about 315 kW). The reason for the lower rating is not known, but possible reasons could be that the generator is either downrated or undersized.

A more detailed study will be required to understand the potential efficiency gains for refurbishment. However, it is expected that a refurbishment could increase the power output by between 2-5% and would not be sufficient to supply the proposed infrastructure at Milford Sound.

The following assumptions around water to wire efficiencies were made for the abstraction options based on typical industry values:

Table 2-5: Assumed Machine Efficiencies for Milford Hydro Options

	Description	Assumed efficiency
1	Existing Turgo turbine	85%
2	Existing Pelton turbine	87%
3	New Pelton turbine	92%
4	Transformer	99%
5	Generator	97%

2.4.4 Intake

The intake would need to be investigated to determine its effectiveness and might need to be extended for higher flow options.

The weir should allow for a controlled release of the reserve flow at all times, and should ensure adequate submergence of the intake works for abstraction of water. The ideal weir is expected to be a low reinforced concrete structure, crossing the width of the river, and accommodating boulders transported downstream. Note the current installed weir crosses about 20% of the river and about 70% of the river flow passes over the weir.

A new intake location was assessed for this scheme. The current location is 200 m downstream of the confluence with a small tributary, any new intake should ideally also be downstream of the confluence, to make use of the extra flow. Constructing a new intake just after the confluence, will require a 200 m extension of the penstock and deliver an elevation gain of about 35 m. As the existing penstock requires replacement and the current weir is also planned to be replaced by a permanent weir, this would provide an opportunity to consider a new intake location. An option of moving the intake and abstracting at the current consent flow rate (with a new turbine) was included. This option would deliver about 600 kW.

2.4.5 Potential Expansion Options Analysis

The different abstraction options are compared in Table 2-6 in terms of ease of obtaining resource consent, rated output, annual generation / requirement for energy storage, and procurement of new turbine(s), penstock(s) and/or required changes to other infrastructure.

Although a final recommendation on these options cannot be made until a better understanding of the energy demands is available, the options analysis provides an indication of the potential capacity of the resource and the implications of expansion.

Until further investigations have been undertaken, generation at mean flow (Option 5) is sensible as a starting point for energy modelling at this stage. Energy modelling considers the demand requirements with generation from other sources and energy storage. The final recommendation would be driven by the energy demand but will also be highly dependent on hydrological (flow gauging), geotechnical and ecological assessments.

Table 2-6: Milford Hydro Option Analysis

	Option	Resource consent	Rated output	Rated flow exceedance probability	Annual generation and energy storage requirement for optimal use of energy	Turbine and generator	Penstock	Other infrastructure
1	**Current operation**	Already consented.	500 kW Expected to not be enough to cover planned infrastructure expansion.	89%	Potential to store energy if scheme is operational throughout the night (short-duration energy storage).	No new machines needed. However, output could be increased if the existing machines are refurbished (estimated by about 5%).	An upgrade to the penstock is planned due to its poor condition. The current size, 400 mm is appropriate.	Upgrades not expected.
2	**Previous consented abstraction**	Assumed to be acceptable as this abstraction has been consented before.	1,258 kW The rated output is expected to be similar to the planned infrastructure expansion.	76%	Potential to store energy if scheme is operational throughout the night (short-duration energy storage).	New machines required in addition to the existing “Chinese” unit.	A new penstock of about 600 mm diameter is required.	Upgrades not expected.
3	**Both existing turbines in operation**	Assumed to be acceptable as a larger abstraction has been consented before.	806 kW Expected to not be enough to cover planned infrastructure expansion.	83%	Potential to store energy if scheme is operational throughout the night (short-duration energy storage).	No new machines needed. However, output could be increased if the existing machines are refurbished (estimated by about 5%).	A new penstock of about 500 mm diameter is required.	Upgrades not expected.
4	**Operating at mean flow**	Will be more challenging, but could still be acceptable. If not acceptable, it could be investigated to abstract a higher flow for generation during nighttime and a lower flow during daytime.	5,250 kW Expected to be significantly more than required by the planned infrastructure expansion.	28%	Significant storage required as times of high flows will not necessarily coincide with times of demand (long-duration energy storage).	New machines required in addition to the existing “Chinese” unit.	The most economic diameter is estimated to be 1250 mm. A smaller penstock or penstocks with higher associated hydraulic head losses might be more practical due to	Upgrades to powerhouse and tailrace is expected.

	Option	Resource consent	Rated output	Rated flow exceedance probability	Annual generation and energy storage requirement for optimal use of energy	Turbine and generator	Penstock	Other infrastructure
							construction constraints.	
5	**Minimum operation at MALF**	Not significantly more than the previously consented abstraction.	1,896 kW Expected to be slightly more than planned. infrastructure expansion.	65%	Some storage required (could be combination of short- or long-duration energy storage).	New machines required in addition to the existing "Chinese" unit.	The most economic diameter is estimated to be 750 mm. A smaller penstock with higher associated hydraulic head losses might be more practical due to construction constraints.	Upgrades not expected.
6	**New intake location**	Flow already consented, construction of new intake and penstock extension to be consented.	600 kW Expected to not be enough to cover planned infrastructure expansion.	89%	Potential to store energy if scheme is operational throughout the night (short-duration energy storage).	New machines recommended.	An upgrade to the penstock is planned due to its poor condition. The current size, 400 mm is appropriate. A 200 m extension beyond the existing penstock is required,	Upgrades not expected.

3. Knobs Flat Hydro

The Knobs Flat hydropower scheme in Eglinton Valley is operated by the Milford Sound Tourism Limited (MSTL) and supplies power to the existing accommodation and facilities at Knobs Flat. The hydropower scheme abstracts water from an unnamed tributary of Kiosk Creek, conveyed through a 650 m penstock to the powerhouse, and discharges to the Eglinton River via a stormwater drain. The hydropower scheme is supplemented by diesel generators.

3.1 Catchment Areas and Flow

According to the existing Resource Consent, the catchment area above the intake is about 250 hectares (2.5 km^2) with the majority of the catchment above the bushline.

Inflows are determined by the heavy rainfall events, seasonal snowmelt and freeze and thaw cycles.

There are three NIWA hydrometric sites in the vicinity as detailed in the table below. However, as snowmelt and freeze and thaw cycles heavily influence the runoff, these weather stations are of limited use to determine an accurate flow record.

Table 3-1: Weather Stations Near Knobs Flat

Name	Period of record	Site type
Eglinton, Knobs Flat CWS	12 Aug 2009 - present	Climate - automatic
Knobs Flat	1 Jun 1952 – 1 Jan 1989	Climate - manual
Knobs Flat 2	1 Sep 1965 – 1 Jul 1980	Daily rainfall

Flow data was obtained from NIWA's NZ River Maps website for the unnamed tributary of Kiosk Creek at the intake. As mentioned in the previous section, the flow data from NIWA Rivermaps has been developed by a New Zealand-wide regression model using data from gauge stations and predictors representing spatial and temporal patterns (D.J. Booker, 2014). These predictors include variables such as elevation and temperature which would be associated with snow and snowmelt, relevant in the Southland region. For the scope of this study, the NIWA Rivermaps data is deemed sufficient, but flow measurements are recommended if the study progresses to further stages.

The Resource Consent Application states the gauged mean flow as 145 l/s (0.145 m^3/s). There is no information on how this measurement was taken or the period used for measurement. Any results achieved as part of this study should therefore be considered as being potentially overoptimistic.

Table 3-2: Key Parameters for Knobs Flat Hydro

Site	Mean river flow (m^3/s)	MALF (m^3/s)	Residual flow requirement (m^3/s)	Maximum operating flow (m^3/s)	Minimum operating flow (m^3/s)
Knobs Flat Hydro	0.27676	0.09022	0.03 (Jan – Mar, for the periods 06:30-09:00 and 18:00-21:00) 0.06 (all times except as listed above)	0.06	0.02

Elevation data was obtained from the 2022/2023 LiDAR and analysed in Autodesk Civil3D.

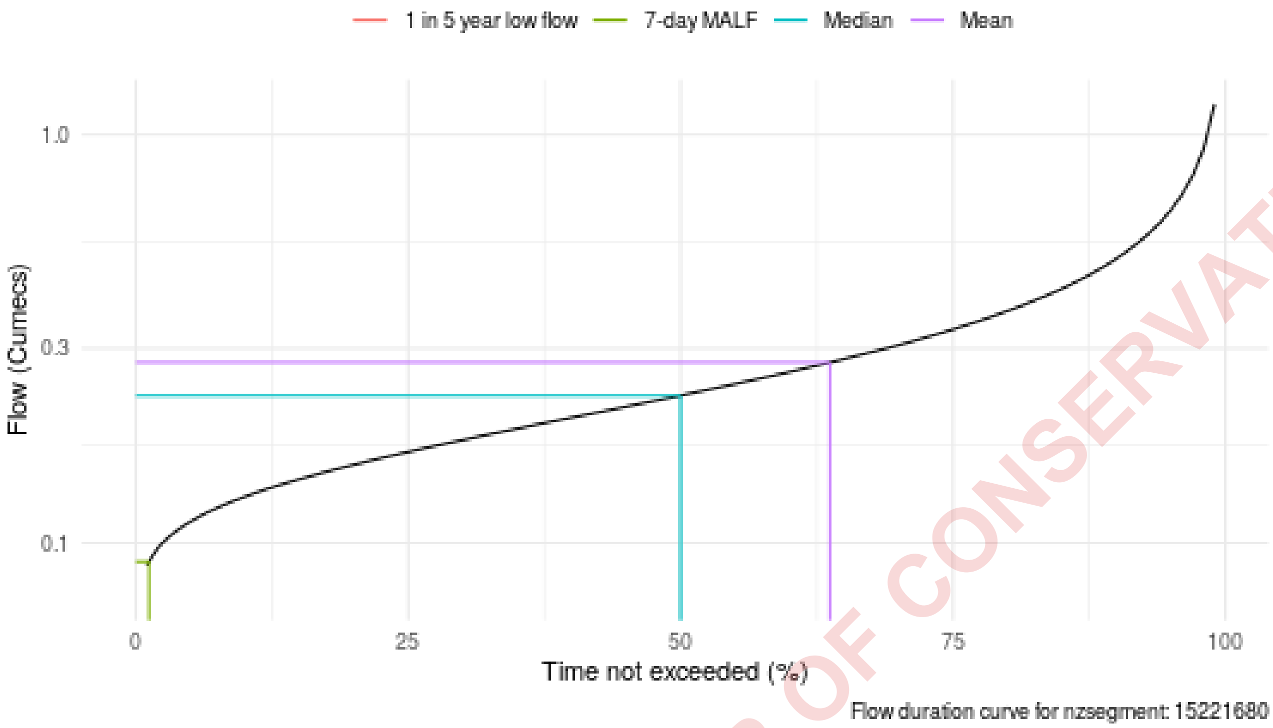

Figure 3-1: Flow Duration Curve for the tributary of Kiosk Creek (Source: NIWA Rivermaps)

The Resource Consent includes the following conditions:

- No abstraction is allowed when the river flow is below 90 l/s.
- The abstraction shall not exceed:
  - 60 l/s (0.06 m^3/s)
- The abstraction shall not reduce the residual flow below 30 l/s for the periods between January and March between 06:30-09:00 and 18:00-21:00. For all other times, the abstraction shall not reduce the residual flow below 60 l/s.

Note no abstraction is allowed when the flow is below the MALF (90 l/s).

3.2 Scheme Summary

- **Intake:**
  A 300-400 mm high, 2 m long stainless-steel weir is installed just upstream of a 1.5 m drop in the creek (see Figure 3-3). The weir causes minimal impoundment. An intake screen is installed over the weir to abstract water (Tyrolean intake). A short, piped section conveys the water from the intake to a surge chamber.

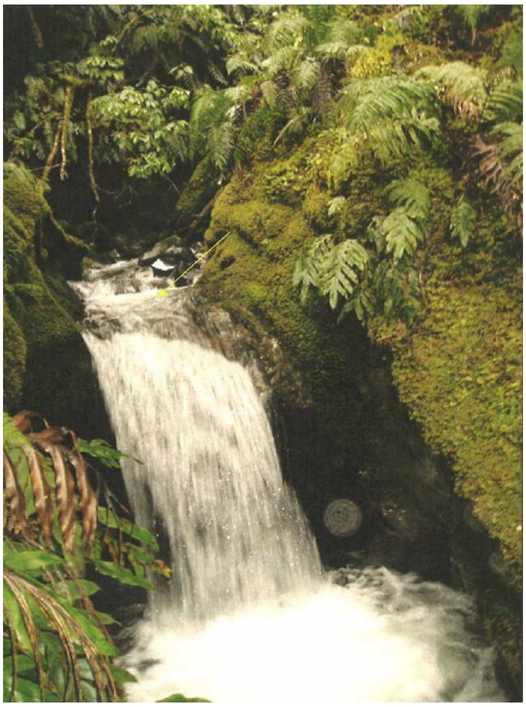

Figure 3-2: Drop in Creek Immediately after Weir (Source: Resource Consent Application)

- **Conveyance:**
  The penstock is a Alkathene penstock with a diameter of 200 mm. There is a 30 m section leading to a 1000 l surge tank. Thereafter, the 650 m penstock passes through steep terrain initially (estimated about 150 m), from where it follows a flatter route. The penstock is installed aboveground, supported by its own weight for most of its length. The last section (estimated about 200 m) is installed below ground.

  The penstock is expected to be in adequate condition, being installed less than 15 years ago and Alkathene typically expected to have a lifespan of about 50 years.

- **Powerhouse:**
  There is one turbine generator rated at 45 kW (the turbine manufactured by the Yueqing Machinery Factory and generator by Fuzhou Fangyuan Electrical Machinery Co Ltd.).

Figure 3-3: Knobs Flat Turbo Turbine

- **Tailrace:**
  Water is discharged through a pipe to an existing open stormwater drain. From the stormwater drain, the water passes underneath the highway through a 450 mm culvert, which drains to the Eglinton River.

  Any expansion of the scheme will need to take the limitations and possible upgrade of the stormwater system into account.

3.3 Existing Operation

It is unclear what the normal output of the scheme is. However, as the plant is new it is expected to be able to achieve its rated output of 45 kW under rated conditions (based on the nameplate information as seen in Figure 3-4). At the time of the site visit in September 2023, the plant was producing about 27 kW.

According to the turbine's nameplate information, its rated head is 110 m, and the rated flow is 0.05 m^3/s. Note that this flow is less than the maximum consented abstraction of 60 l/s (0.06 m^3/s).

There are two diesel generators available as back-up (45 kVA and 20 kVA).

Figure 3-4: Knobs Flat Turbine Nameplate Information

3.4 Potential Expansion

Potential for expansion has been considered by increasing flow, upsizing the penstock, increasing the machine efficiency, and moving the intake location. This report did not consider adding water storage at the intake, as this is expected to be challenging in terms of resource consenting.

3.4.1 Flow

A few abstraction scenarios were investigated to understand the power generation potential with modifications to the existing scheme.

As the rated flow of the scheme is less than the consented flow, there is a potential for expansion within the existing Resource Consent conditions. Furthermore, the penstock can convey a higher flow than the scheme's current design flow. The last scenario considers the scheme's capacity when generating using the mean flow (with allowance for the reserve flow).

Penstock losses and machine efficiencies are discussed in the following sections.

Table 3-3: Milford Hydro Abstraction Options Summary

	Option	Rated flow (m^3/s)	Rated flow exceedance probability	Rated output (kW)[7]	Estimated annual energy (GWh)[8]	Capacity factor[9]
1	Current operation	0.05	98%	45	0.38	0.98
2	Maximum consented abstraction	0.06	93%	57	0.49	0.98
3	Maximise the use of the penstock[10]	0.08	86%	76	0.64	0.96
4	Operating at mean flow[11]	0.22	36%	210	1.32	0.72

All options assumed continuous operation (day and night) and that the surplus energy will be stored. Note that these options can be further refined once there is a better understanding of the energy demands and specific requirements of the transportation fleets.

3.4.2 Penstock

As mentioned, the 200 mm penstock can take a larger flow without incurring unreasonable headlosses. Without replacing the penstock, the flow can be increase to 80 l/s. 200 mm is the most economic diameter for conveying 80 l/s when using Warnick's formula (Warnick, 1984), however, the flows can potentially be increased even further.

For the abstraction scenario at mean flow a diameter of about 350 mm is required.

3.4.3 Intake

There are no obvious alternative intake locations, except by moving the intake 400 m or more upstream where the river profile is steeper (see Figure 3-5). For example, if moving the intake 500 m upstream, an elevation gain of about 140 m can be achieved. If abstracting the consented flow of 60 l/s, such an increase in head will deliver an output of about 125 kW. This would however require an extension of the penstock by 500 m and the construction of a new intake.

[7] All these options assumed a net head of 110 m. Water to wire efficiencies assumptions are discussed under the "Machine efficiency" section.
[8] This is based on the NIWA Riversmap flow duration curve. Assuming maintenance will take place during low-flow / zero generation times and with no forced shut down.
[9] Assumed continuous load available, i.e. day and night operation.
[10] Based on the optimal penstock size formula of C.C Warnick's for small scale hydropower.
[11] Rated flow is based on maintaining 0.06 m^3/s in the river at the mean flow of 0.28 m^3/s.

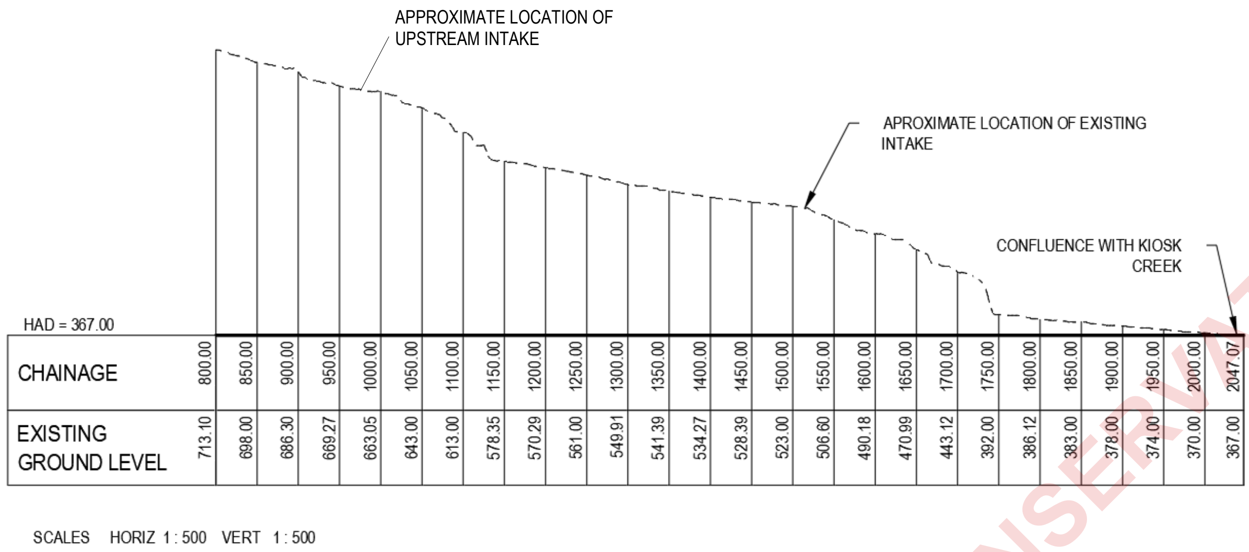

Figure 3-4: Section of Kiosk Creek Tributary Profile

3.4.4 Machine Efficiency

It is assumed that a refurbishment of the machines will not make a significant difference in the power output of the plant.

The following assumptions around water to wire efficiencies were made for the abstraction options:

Table 3-4: Assumed Machine Efficiencies for Knobs Flat Hydro Options

	Description	Assumed Efficiency
1	Existing Turgo turbine	85%
2	New Pelton turbine	92%
3	Transformer	99%
4	Generator	97%

3.4.5 Potential Expansion Options Analysis

The different abstraction and expansion options are compared in Table 3-5 in terms of ease of obtaining Resource Consent, rated output, annual generation / requirement for energy storage, and procurement of new turbine(s), penstock(s) and/or required changes to other infrastructure.

Although a final recommendation on these options cannot be made until a better understanding of the energy demands is available, the options analysis provides an indication of the potential capacity of the resource and the implications of expansion.

All upgrade options for Knobs Flat would require new machines to be installed. However, this would be recommended considering the expected energy generation gains with high flow exceedance probabilities.

Option 5 is an option worth investigating further for Knobs Flat. The power output is expected to increase by more than 250% whilst staying within the existing Resource Consent limits of flow abstraction and maintaining a high flow exceedance probability. An even higher flow could be abstracted whilst using the existing penstock diameter, delivering an even higher output. This would then impact the resource consent application.

However, until further investigations have been undertaken, generation at mean flow (Option 4) is sensible as a starting point for energy modelling at this stage rather than Option 5 due to uncertainty regarding the proposed intake location. Energy modelling considers the demand requirements with generation from other sources and energy storage. The final recommendation would be driven by the energy demand but will also be highly dependent on hydrological (flow gauging), geotechnical and ecological assessments.

Table 3-5: Knobs Flat Hydro Option Analysis

	Option	Resource consent	Rated output	Rated flow exceedance probability	Annual generation and energy storage requirement for optimal use of energy	Turbine and generator	Penstock	Other Infrastructure
1	Current operation	Already consented.	45 kW Expected to not be enough to cover planned infrastructure expansion.	98%	Potential to store energy if scheme is operational throughout the night. (short-duration energy storage).	No new machines needed.	Keep existing penstock.	Upgrades not expected.
2	Maximum consented abstraction	Already consented.	57 kW Expected to not be enough to cover planned infrastructure expansion.	93%	Potential to store energy if scheme is operational throughout the night. (short-duration energy storage).	New machines recommended.	Keep existing penstock.	Upgrades not expected.
3	Maximise the use of the penstock	This is a small increase of the existing flow and the same residual flow requirements can be met.	76 kW Expected to not be enough to cover planned infrastructure expansion.	86%	Potential to store energy if scheme is operational throughout the night. (short-duration energy storage).	New machines required.	Keep existing penstock.	Upgrades not expected.
4	Operating at mean flow	This is a significant increase in water abstracted for generation, but the same residual flow requirements can be met.	210 kW Expected to be significantly more than required by the planned infrastructure expansion.	36%	Significant storage required as times of high flows will not necessarily coincide with times of demand (long-duration energy storage).	New machines required in addition to the existing.	A new penstock of about 350 mm diameter is required to replace the existing (or the existing penstock can remain in operation and an additional penstock of about 200 mm diameter can be installed).	Upgrades to powerhouse and tailrace (and potentially the culvert under the State Highway) is expected.
5	New intake location	Flow already consented, construction of	123 kW	98%	Some storage required (short-	New machines required.	Keep existing penstock, but	New intake works is required.

		new intake and penstock extension to be consented.	Expected to be slightly more than planned infrastructure expansion.		duration energy storage).		provide 500 m extension.	

4. Risks

The risks associated with the expansion of a hydropower plant will typically be less than the development of a new scheme, especially regarding disturbance of the natural environment.

Table 4-1: Risk assessment

Risk	Description	Probability	Consequence	Assessed risk	Mitigation measures
Flooding impacts	Run-of-river scheme does not store water and do not pose a risk of flooding. During flood events, the intake works and powerhouse could be damaged.	Very Unlikely	Minor	Very Low	Design (or review existing design) to ensure robust intake works and powerhouse to withstand flood damage. Review powerhouse elevation to be above appropriate flood levels and with adequate drainage.
Operational risk	The required flows for generation will not always be available and could be significant in times of drought. Due to the high pressures associated with the high-head schemes, there could be serious damage caused to the penstock through pressure surges if protection measures not adequately designed.	Possible	Moderate	Medium	Design sufficiently sized energy storage systems (i.e. batteries) or pair with solar where possible. Design appropriate penstock protection measures.
Channel movement	If not designed properly, the tailrace could cause erosion of the downstream channel, especially if the flow is increased from the existing operational flow.	Unlikely	Moderate	Medium	Install energy dissipating measures to prevent channel scour considering potentially increased design flows.
National Park risk	Depending on the chosen transformer type and cooling system, there could be a risk of oil spills.	Very Unlikely	Moderate	Low	Choose equipment that do not use oil. If new intake locations are required, choose

	The moving of intake works, could involve inundating a small area which could have ecological impacts.				location to minimise inundation area.
Resource consent	Moving of intakes and abstracting higher flows will require revising the existing resource consents.	Likely	Moderate	High	Start the resource consent process as soon as possible and design with minimal environmental impact.
Development timeframe	Apart from gaining resource consent, hydropower construction timeframes can be extensive due to complicated design interfaces and long lead times for generation and hydromechanical equipment.	Possible	Moderate	Medium	It will be important to use consultants, project managers and contractors familiar with hydropower projects and who has successfully delivered these types of projects in the past.
Existing infrastructure	Expansion of both schemes could impact the existing infrastructure. Apart from potential upgrades to the intake works, penstocks, powerhouses and machines, the tailrace might require upgrade.	Unlikely	Moderate	Medium	Review all infrastructure including infrastructure located downstream of the scheme and their capacities at the start of the next design phase, to fully understand the impact of expansion and the constraints.

5. Conclusion

This report investigated the two existing hydropower plants in the Milford Corridor in terms of potential for expansion. Both schemes show potential for various expansion scenarios, involving upgrades to the penstocks, moving of the intakes, and the associated upsizing of machines.

The options with the highest potential power considered as part of this scope, propose generating at the water course's mean flow. Note this is not the maximum generation potential of the water course, just the highest generation option considered in this report. However, these high outputs would often not be achieved as the mean flow is only exceeded about 30% of the year and lower outputs will be delivered at other times depending on the water availability in the water course.

Both schemes have the potential to expand whilst still within the limits of their respective Resource Consents (or perhaps the previous Resource Consent in the case of Milford Hydro). These options could potentially save time in the planning and development of the projects.

The options within the existing Resource Consent conditions seems sensible for an expansion at Milford Hydro, mostly due to higher flows not being available throughout the year. There are a number of options to be considered further at Milford namely, abstracting flow at the previous consented rate, the operation of both turbines, operating at mean flow, and moving the intake. A combination of two or more of these options can also be considered.

Moving the intake at Knobs Flat is an option worth considering further. The flow required has been consented and the existing penstock can be used, but the output increases by almost 80 kW. Site investigations would need to be undertaken to determine whether a suitable intake location and penstock route can be found. If the intake location is found to be unsuitable, other options to consider involves maximising the use of the penstock (it is currently oversized) or generating at mean flow. As with the Milford Hydro, a combination of these options can be considered as well.

The final recommendations would be made based on energy modeling of the demand and other energy supply options, as well as hydrological, geotechnical and ecological assessments. Until this information is available, it would be sensible to consider a scheme designed for generating at mean flow as a starting point for energy modeling.

The next steps in progressing the assessment of the expansion options would involve:

- Energy modeling of hydropower resources, alternative energy sources, and energy demands.
- Flow gauging of the rivers to understand the actual flow availability and rain gauging within the catchment.
- Geotechnical investigations especially where intakes are proposed to be moved or where larger penstocks are proposed.
- Ecological assessments especially where intakes are proposed to be moved or higher abstraction rates proposed.

6. References

Beale Consultants Ltd. (2019). *Resource Consent Application Milford Sound Hydroelectric Power Scheme Water Takes and Discharges.*

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Stantec New Zealand
Hazeldean Business Park, Level 2,
2 Hazeldean Road, Addington 8024
PO Box 13-052, Armagh, Christchurch 8141
Tel +64 3 366 7449