Milford Opportunities Project

Additional Hydropower Potential

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Revision Schedule

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A	06/12/2023	Draft	Phelia Klopper	Robin Spittle	Andrew Bird	Sarah Velluppillai
B	09/02/2024	Final Draft	Phelia Klopper	Robin Spittle	Andrew Bird	Phelia Klopper
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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

1. Introduction

Stantec performed a desktop study to investigate the potential for hydropower generation in the Hollyford River and its surrounding tributaries as well as the Cleddau River closer to Milford Sound as part of the Milford Opportunity Project Energy Assessment for the Department of Conservation (DOC). The sites investigated are located in the vicinity of Node 5 or the Milford Hub (see Figure 1-1 and Figure 1-2). Potential output, access, and constructability were considered. Low head options at three locations along the Hollyford River were examined, three high head options in Hollyford tributaries as well as one high head option in a tributary of the Cleddau River.

The study approach involved identifying the contributing catchment area, establishing the mean flow, and analysing the river profile. Elevation data was analysed to establish the catchment area and to produce river profiles. LiDAR data flown in 2022/2023 was received from DOC which covered large areas of the study area. The areas not covered were supplemented with the New Zealand 8 m Digital Elevation Model downloaded from Land Information New Zealand's (LINZ) Data Service. Global Mapper's watershed tool and AutoDesk Civil3D were used to analyse the terrain.

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.

For each option investigated, an upper and lower limit of the potential output was calculated based on generating at mean flow and generating at MALF. A constant residual flow requirement of 85% of the MALF was assumed (chosen to correspond to the Resource Consent of the existing Milford Hydro). A water-to-wire efficiency factor of 91% for low head schemes and 88% for high head schemes was assumed, and 10% headloss as typical values for these types of schemes at this stage of development.

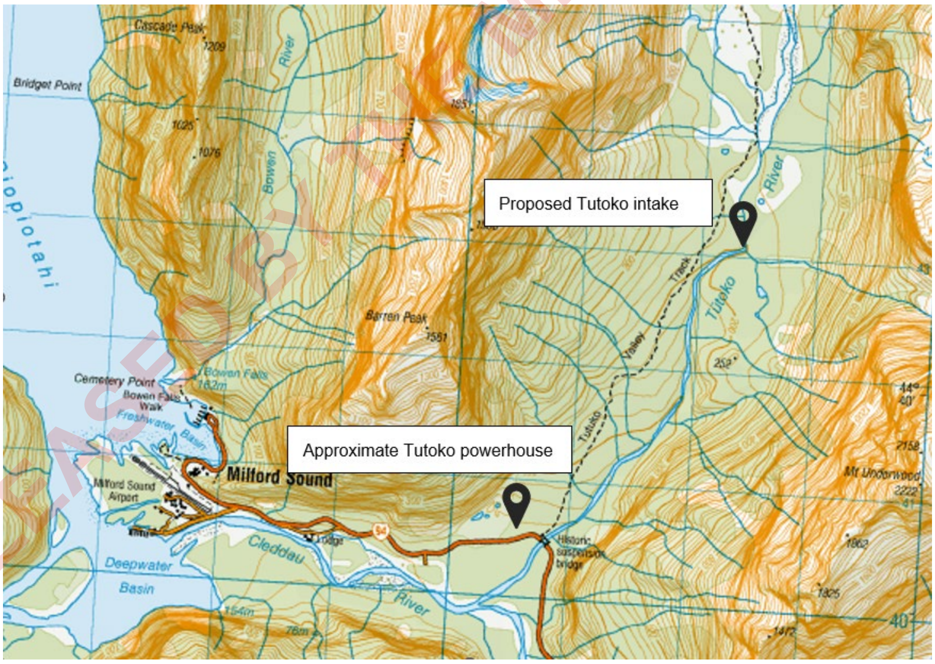


Figure 1-1: Cleddau River Site Options on NZ Topographical Map

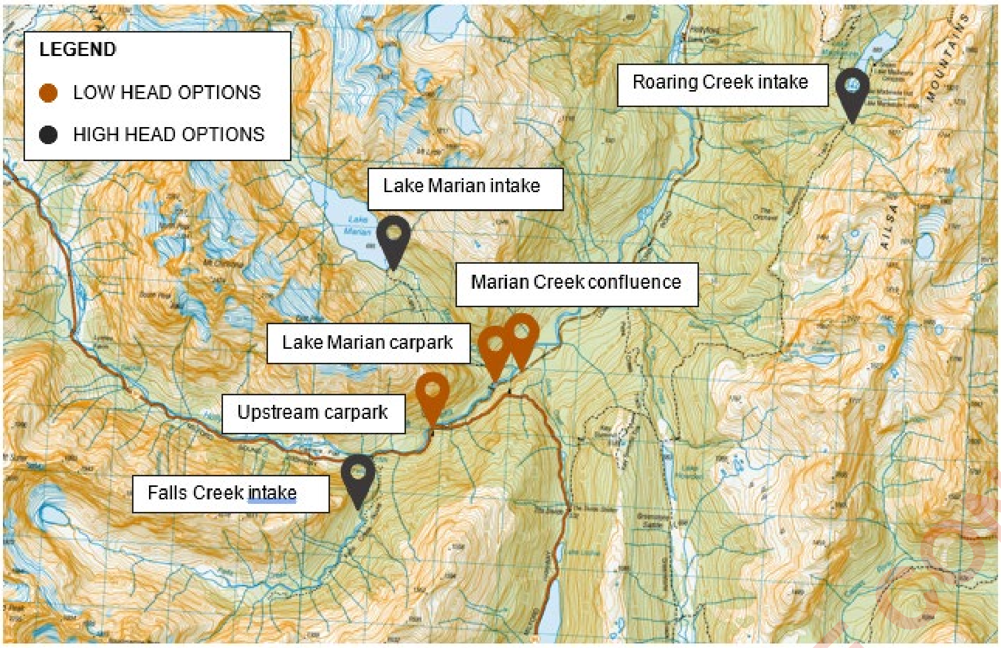


Figure 1-2: Hollyford River Site Options on NZ Topographical Map

2. Low Head Options – Hollyford River Sites

Three sites as indicated as the "Low head options" on Figure 1-1. were investigated along the Hollyford River. The location at the Marian Creek Trail carpark was identified due to its easy access and proximity to the southbound State Highway 94. Further investigation of the catchment areas and river profile revealed two alternative options at the carpark found 1.1 km upstream of the Lake Marian Trail carpark as well as 650 m downstream of the carpark after the confluence with Marian Creek.

Any of the sites along Hollyford River would require intake works that span the 20 m wide river (river shown in Figure 2-1). The upper carpark option would require conveyance of about 50 m. The Lake Marian carpark and Marian Creek Confluence options would only use the head created by a weir and would therefore not require long conveyance lengths. All these options are low head applications and are expected to use Kaplan turbines.

Figure 2-1: Bridge Across Hollyford River at Lake Marian Trail Start (source: www.travelswithsun.com)

2.1 Catchment Area and Flow

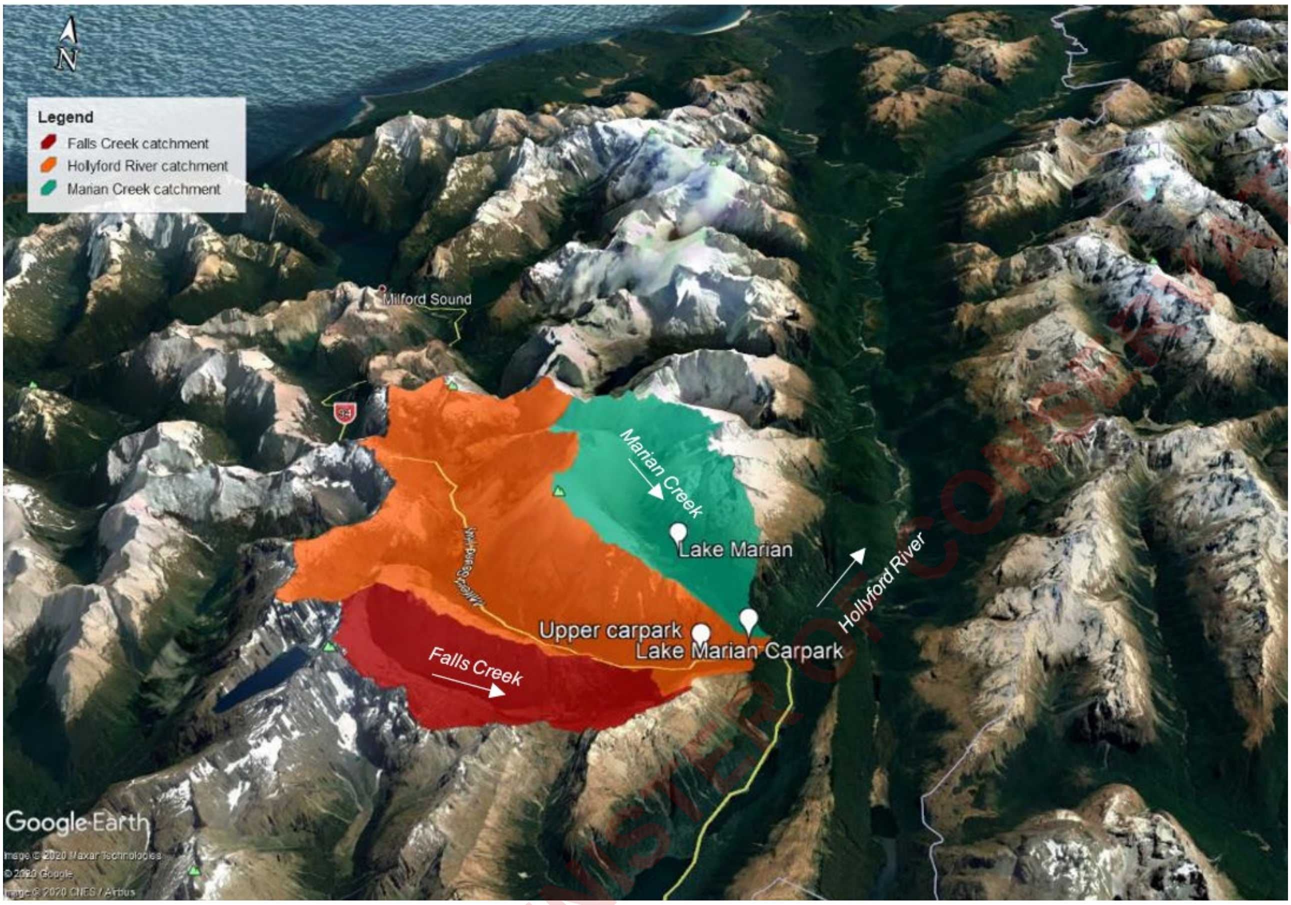


Figure 2-2: Catchment Area of Hollyford River Sites

The catchment area for the Lake Marian Carpark site encompasses an area of 65 km^2. This value was verified by catchment information on the New Zealand River Floor Statistics website (https://niwa.maps.arcgis.com/apps/webappviewer/index.html?id=933e8f24fe9140f99dfb57173087f27d) of the National Institute of Water and Atmospheric Research (NIWA).

In addition to this site, two other sites were investigated. The confluence of the Marian Creek with the Hollyford River is found about 500 m downstream of this site. Selecting a site downstream of the confluence would increase the catchment area by 24 km^2 (as depicted by the green area on Figure 2-2). A site at a carpark found upstream of the Lake Marian Carpark site is also investigated as it has a similar catchment area and is also easily accessible.

The mean flow and Mean Annual Low Flow (MALF) of the Hollyford River at the three locations were obtained from NIWA's NZ River Maps website (https://shiny.niwa.co.nz/nzrivermaps/) and is provided in Table 1 in the following section.

2.2 River Profile

A profile along the Hollyford River was created in AutoDesk Civil3D using the 2022/2023 DEM. the average river gradient over this section of the river is 2%. As seen in Figure 2-3, the intended site location at the Lake Marian carpark is at a fairly flat section of the river. However, near a carpark found about 1.1 km upstream, the gradient is steeper and still accessible. Another potential site location is found about 650 m downstream of Lake Marian carpark after the confluence with Marian Creek, where there is a higher flow rate (12.23 m^3/s compared to 9.23 m^3/s).

Further options exist when considering longer conveyance lengths. An option to construct the intake upstream of the Upper Carpark and the powerhouse at the Lake Marian carpark would require conveyance of about 1.3 km.

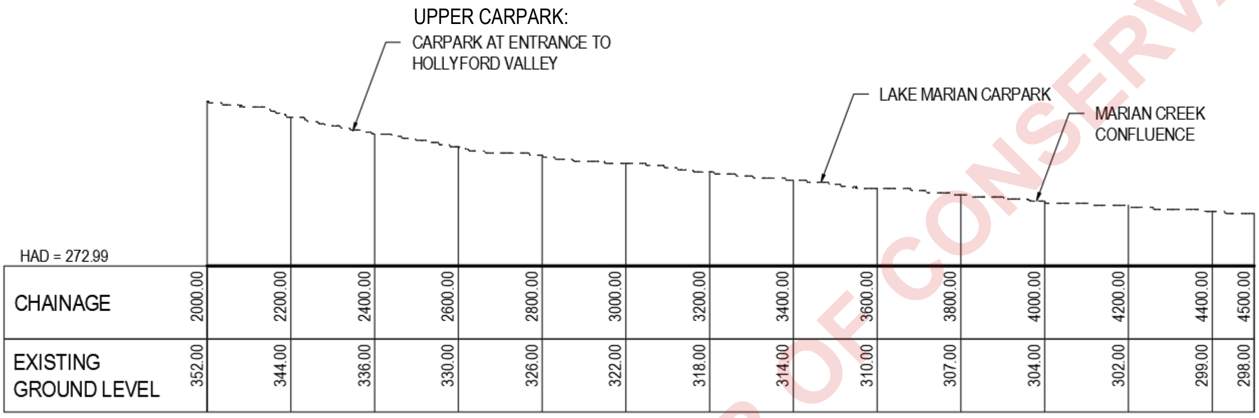


Figure 2-3: Profile along Hollyford River

2.3 Generation

Note, that a residual flow lower than 85% of MALF could potentially be allowed through resource consenting. This residual flow is seen as conservative especially for the options with no conveyance such as some of these low head options.

The table below shows a range of potential power output the resource could deliver. The final design abstraction value will depend on energy demand, storage requirements, and resource consenting.

Table 2-1: Key Paramaters for Site in Hollyford River

Site	Mean river flow [1](m^3/s)	MALF[2] (m^3/s)	Assumed residual flow requirement (m^3/s)	Gross head (m)	Output at mean flow (kW)	Output at MALF (kW)
Upper Carpark	8.56	2.05	1.74	5 (over 50 m)	275	12
Lake Marian carpark	9.23	2.04	1.73	1 (assumed head for low weir)	60	2
Immediately after confluence with Marian Creek	12.23	2.93	2.49	1 (assumed head for low weir)	78	4
Intake at Upper Carpark and powerhouse at Lake Marian Carpark	8.56	2.05	1.74	35 (over 1.3 km)	1,922	87

[1] Mean flow for this section of the Hollyford River is exceed between 31% of the time.
[2] MALF for this section of the Hollyford River is exceed between 94% and 95% of the time.

3. High Head Option – Marian Creek

Lake Marian potentially provides the opportunity to develop a low disturbance scheme using the high head difference to the Hollyford River. As Lake Marian and a series of waterfalls along the Lake Marian track is frequented by the public, only a small flow should be diverted for power generation to not disturb this attraction.

Although there is no visible outlet from Lake Marian, the intake works at the Lake Marian option is expected to be smaller and simpler to construct than an intake required on the larger Hollyford River due to the river being smaller requiring a smaller structure and less water to divert during construction. The intake would be constructed in Marian Creek at an elevation lower than the minimum lake level of 674 m. A Pelton turbine as suggested for this high head application is more cost effective than lower head Kaplan turbine applications.

The 2700 m long conveyance would be routed and constructed in such a way to minimise the environmental impact and cost. The conveyance route is recommended to follow generally the same alignment as the new loop track proposed as part of the Node 5 development concept. This will minimise disturbance to the natural environment, but also reduce construction costs and allow for easier access for maintenance purposes.

Figure 3-1: Lake Marian at Full lake Level (Source: Department of Conservation)

Figure 3-2: Lake Marian at Lower Level (September 2023)

3.1 Catchment Areas and Flow

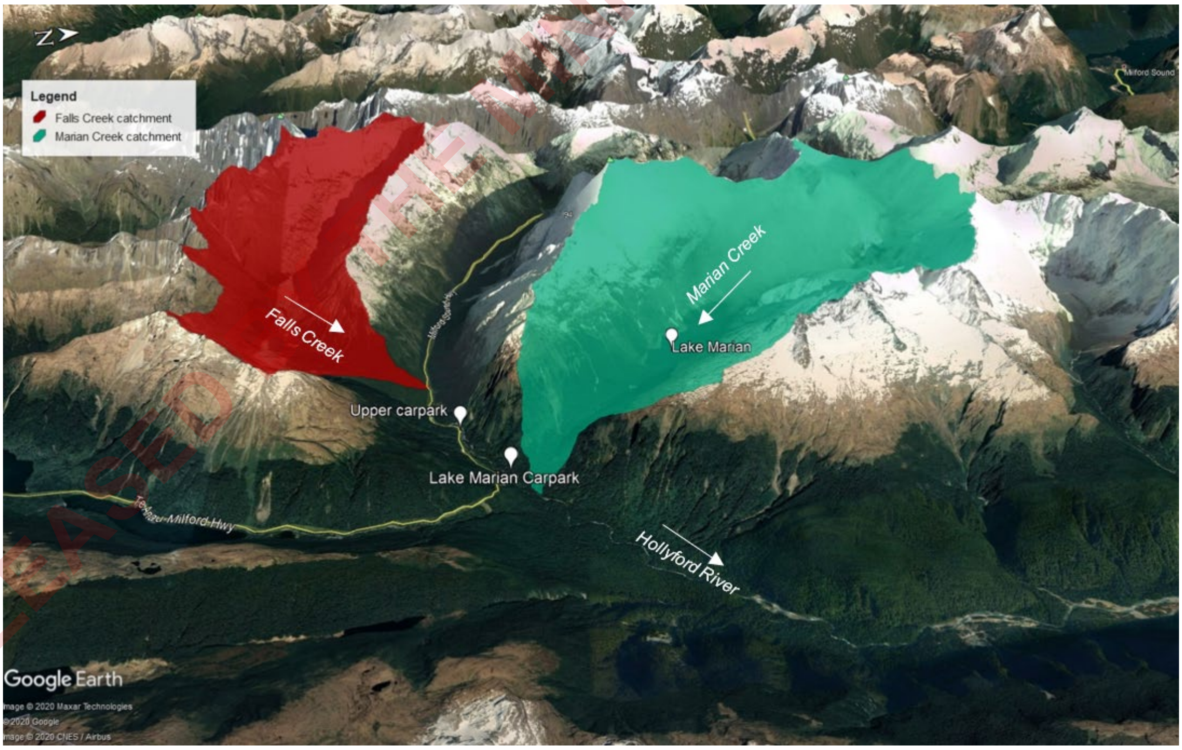


Figure 3-3: Catchment Areas for Hollyford River Tributaries

The 24 km[2] catchment area as derived from the 8 m DEM is shown on Figure 3-3 by the green shaded area (this was outside of the extents of the LiDAR provided by DOC, flown in the 2022/2023 season for the Milford Corridor). The flow data was obtained from NIWA's NZ River Maps website. Elevation data for the river profile was obtained from the 2022/2023 LiDAR.

3.2 River Profile

Marian Creek has an almost constant grade of about 14% as illustrated in Figure 3-4. The proposed scheme configuration is to locate the intake within Marian Creek at an elevation just below the minimum lake level and the powerhouse next to the Hollyford River. This would allow for the easiest intake construction and utilise the full elevation available.

Table 3-1: Key Levels for Lake Marian Site

Description		Comment
Lake Marian normal water level	680 MASL	From 2022/2023 LiDAR
Lake Marian low water level	674 MASL	Level from site visit in September 2023
Intake level	673 MASL	Assume 1 m lower than the lake low level
Tailwater level	301 MASL	From 2022/2023 LiDAR at confluence with the Hollyford River
Gross head	372 m	Taken from intake level

3.3 Generation

The table below shows a range of potential power output the resource could deliver. The final design abstraction value will depend on energy demand, storage requirements, and resource consenting.

Table 3-2: Key Parameters for Lake Marian Site

Site	Mean river flow (m^3/s)[3]	MALF (m^3/s)[4]	Assumed residual flow requirement (m^3/s)	Gross head (m)	Output at mean flow (kW)	Output at MALF (kW)
Marian Creek proposed intake	2.95	0.66	0.56	372	6,932	287

[3] Mean flow for Marian Creek is exceeded 31% of the time
[4] MALF for Marian Creek is exceeded 93% of the time

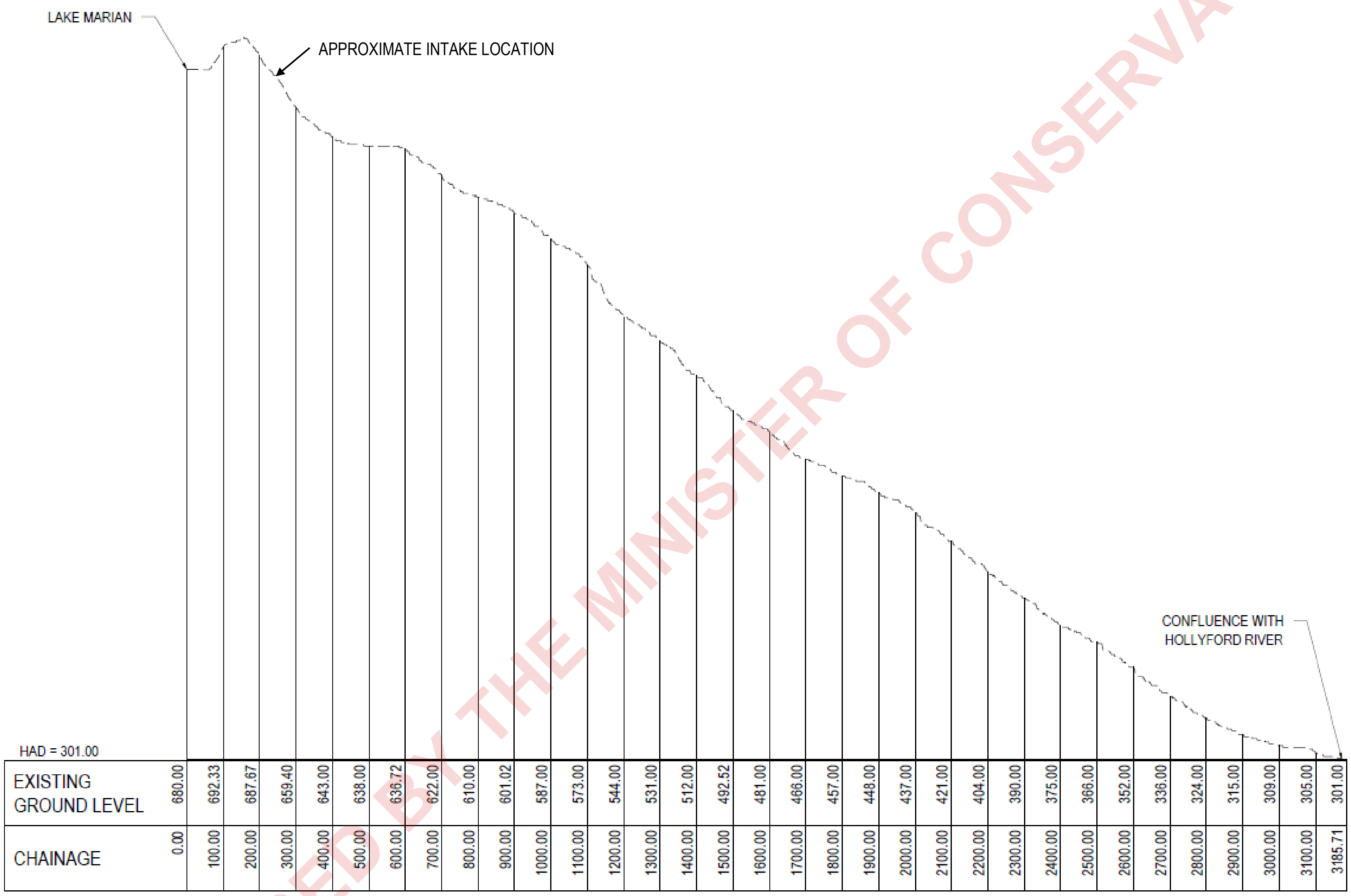


Figure 3-4: Marian Creek Profile

4. High Head Option – Falls Creek

Falls Creek is another tributary of the Hollyford River which provides an opportunity for a high head scheme. Although the flow is smaller than that of Marian Creek, the gradient of the river is steeper.

The Falls Creek Route attracts visitors with a waterfall along the road being the major attraction.

Figure 4-1: Falls Creek Waterfall (Source: www.world of waterfalls.com)

4.1 Catchment Areas and Flow

Flow data was obtained from NIWA's NZ River Maps website. Elevation data was obtained from the 2022/2023 LiDAR and analysed in Autodesk Civil3D. The catchment area of 14 km^2 can be seen in Figure 3-3.

4.2 River Profile

The large drop (300 m) over the last 1 km of the creek (see Figure 4-2) has been identified as showing potential for hydropower generation. This is the steepest section and the flow in the river is more substantial by this point.

Table 4-1: Key Levels for Falls Creek Site

Description		Comment
Head water level	680 MASL	From 2022/2023 LiDAR
Tailwater level	377 MASL	From 2022/2023 LiDAR at confluence with the Hollyford River
Gross head	303 m	

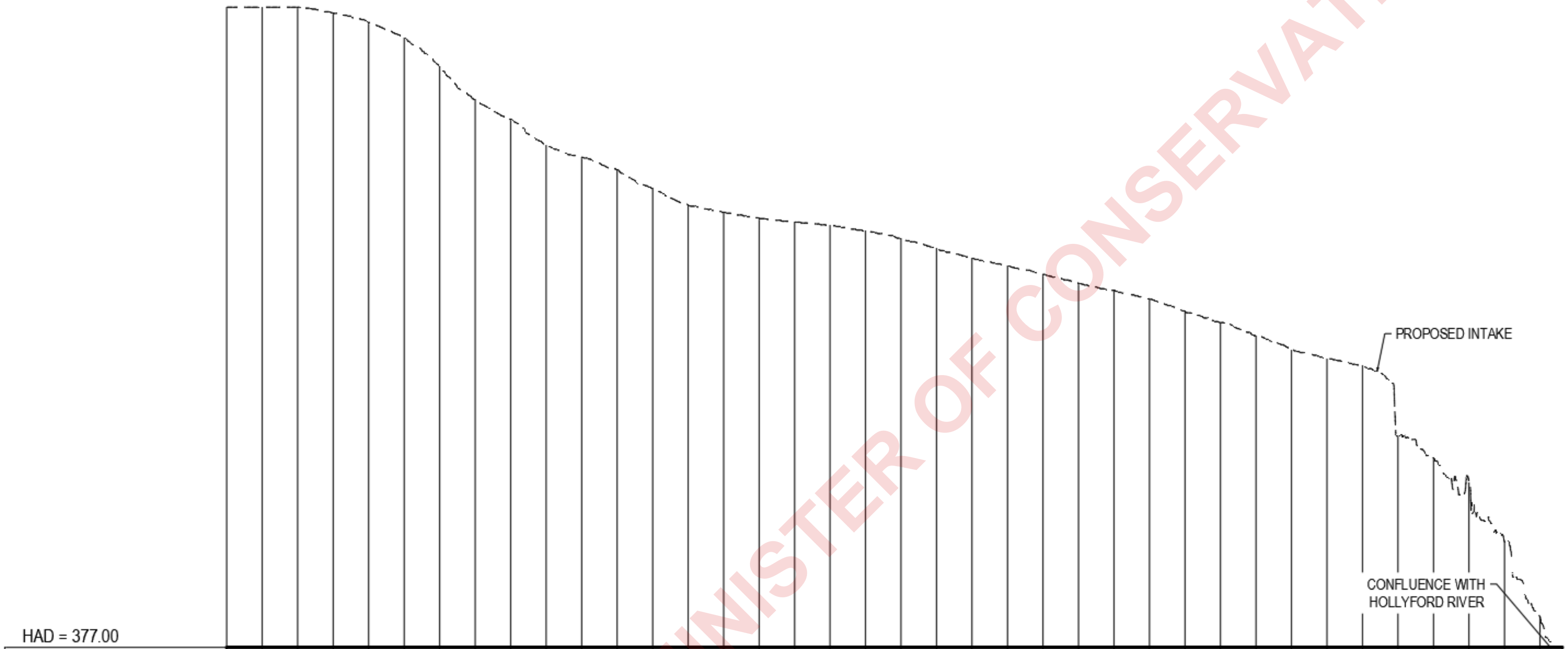
4.3 Generation

The table below shows a range of potential power output the resource could deliver. The final design abstraction value will depend on energy demand, storage requirements, and resource consenting.

Table 4-2: Key Parameters for Falls Creek Site

Site	Mean river flow (m^3/s)[5]	MALF (m^3/s)[6]	Assumed residual flow requirement (m^3/s)	Gross head (m)	Output at mean flow (kW)	Output at MALF (kW)
Falls Creek proposed intake	1.74	0.47	0.4	303	3,172	166

[5] Mean flow for Falls Creek is exceeded 34% of the time
[6] MALF for Falls Creek is exceeded 95% of the time



	0.00	200.00	400.00	600.00	800.00	1000.00	1200.00	1400.00	1600.00	1800.00	2000.00	2200.00	2400.00	2600.00	2800.00	3000.00	3200.00	3400.00	3600.00	3800.00
EXISTING GROUND LEVEL	1098.00	1098.00	1098.00	1091.97	1081.00	1063.05	1031.00	994.00	972.00	943.00	929.00	915.00	893.85	875.42	867.00	860.00	856.00	852.00	846.00	837.00

CHAINAGE	4000.00	4200.00	4400.00	4600.00	4800.00	5000.00	5200.00	5400.00	5600.00	5800.00	6000.00	6200.00	6400.00	6600.00	6800.00	7000.00	7200.00	7400.00	7524.65
EXISTING GROUND LEVEL	826.00	815.00	807.00	797.00	787.00	779.00	769.00	755.00	743.00	728.00	712.00	702.17	694.00	615.00	590.11	562.52	496.01	411.45	377.00

Figure 4-2: Falls Creek Profile

5. High Head Option – Roaring Creek

Roaring Creek offers another possibility for developing a small hydropower scheme using Lake Mackenzie as storage. There is more than 700 m elevation difference between Lake Mackenzie and the Hollyford River over a distance of about 2.5 km. As Roaring Creek is believed to not have the same touristic value as Marian Creek and Falls Creek, it could be possible for a higher abstraction to be allowed than the other high head options.

Figure 5-1: Roaring Creek Possible Site Near Gunns Camp

5.1 Catchment Areas and Flow

The 11 km^2 catchment area as derived from the 8 m DEM is shown on Figure 5-2 (note this shows the entire catchment area of Roaring Creek and not just the catchment area of the scheme (i.e. upstream of the intake).

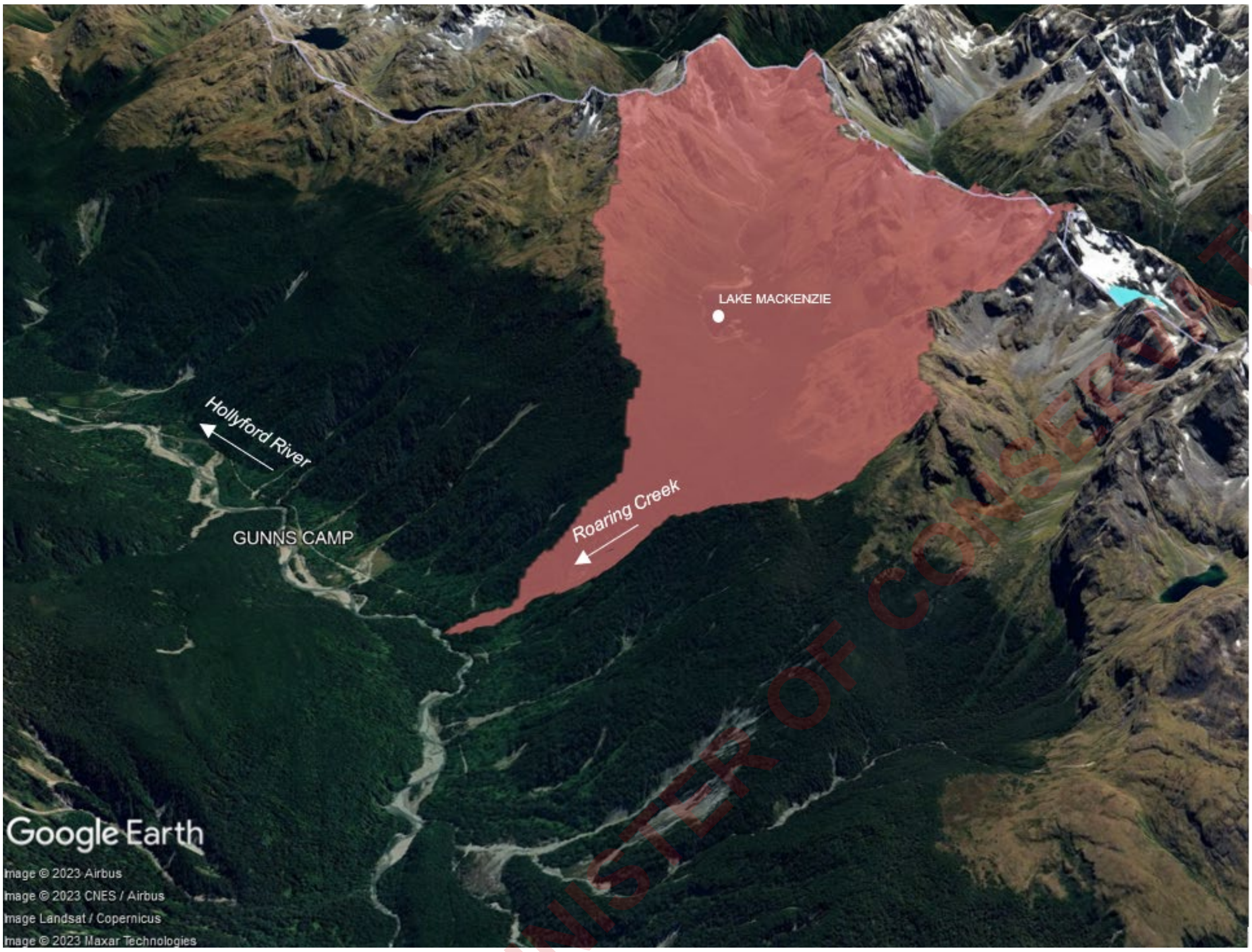


Figure 5-2: Catchment Area for Roaring Creek

Flow data was obtained from NIWA's NZ River Maps. Elevation data was obtained from the 8 m NZ DEM and analysed in Autodesk Civil3D.

The mean flow from NIWA Rivers Map was taken downstream of Lake Mackenzie Hut to account for the Hut's abstraction.

5.2 River Profile

Roaring Creek has an average grade of about 30% as illustrated in Figure 5-3**.** The steep slope starts about 800 m downstream of Lake Mackenzie. To reduce the conveyance length, the intake could be located just before the downward slope rather than at the lake if a suitable intake location is available. The final intake location will be dependent on findings of site investigations.

The powerhouse will be located next to the Hollyford River. This would allow for the easiest intake construction and utilise the full elevation available. The powerhouse, intake and conveyance would be constructed close to existing access ways where possible.

Table 5-1: Key Levels for Roaring Creek Site

Description	
Lake Mackenzie water level	889 MASL
Tailwater level	162 MASL
Gross head	727 m

Figure 5-3: Roaring Creek Profile

5.3 Generation

The table below shows a range of potential power output the resource could deliver. The final design abstraction value will depend on energy demand, storage requirements, and resource consenting.

Table 5-2: Key Parameters for the Roaring Creek Site

Site	Mean river flow (m^3/s)[7]	MALF (m^3/s)[8]	Assumed residual flow requirement (m^3/s)	Gross head (m)	Output at mean flow (kW)	Output at MALF (kW)
Roaring Creek	0.78	0.19	0.16	727	3,517	160

[7] Mean flow in Roaring Creek is exceeded 32% of the time
[8] MALF in Roaring Creek is exceeded 94% of the time

6. Cleddau Options

The Cleddau River discharges into Milford Sound and generation on this river would therefore be ideal in terms of location and proximity to the main energy demand. However, although the Cleddau River has reasonable flow (25.24 m^3/s mean flow at the river mouth according to NIWA's NZ River Maps), it does not have significant grade and would therefore require a low head scheme if found on the main river.

A low head scheme is not suggested in this location due to the infrastructure required (large weir spanning the river) and the sensitivity of the natural environment.

Regarding the tributaries of the Cleddau, an option providing some elevation would be the Tūtoko River. With a mean flow of 9.47 m^3/s and elevation gain of about 200 m over 3.3 km (until the mouth of the river), a scheme generating between 2 MW and 13 MW is possible. However, such a scheme would involve intake works and a weir, a canal or piped system about 2 km long, along with a high-pressure penstock of about 1 km. The powerhouse location would be chosen based on site conditions, but would be located close to the SH94 with the tailrace discharging into the Cleddau or Tūtoko and could involve passing underneath SH94. Locating the powerhouse north of the road will reduce the total head by about 15 m, however it will be less challenging to cross the road with the low-pressure tailrace than with the high-pressure penstock (as would be required if it is located south of the road).

A significant drawback of this option is the large weir that would be required to abstract water. The weir would need to be about 30 m wide and will be challenging to construct due to the terrain. The conveyance will also be challenging to construct and would involve felling of some trees to achieve the alignment. A buried pipeline would most likely be required due to the high flows, which is also more costly to construct.

6.1 Catchment Areas and Flow

Flow data was obtained from NIWA's NZ River Maps website. Elevation data was obtained from the 2022/2023 LiDAR and analysed in Autodesk Civil3D.

6.2 River Profile

There is an elevation change at about 200 MASL and the intake is proposed to be constructed above this point. The powerhouse is proposed to be located before the SH94 bridge.

Table 6-1: Key Levels for Falls Creek Site

Description		Comment
Head water level	212 MASL	From 2022/2023 LiDAR
Tailwater level	30 MASL	From 2022/2023 LiDAR upstream of SH94 bridge
Gross head	182 m	

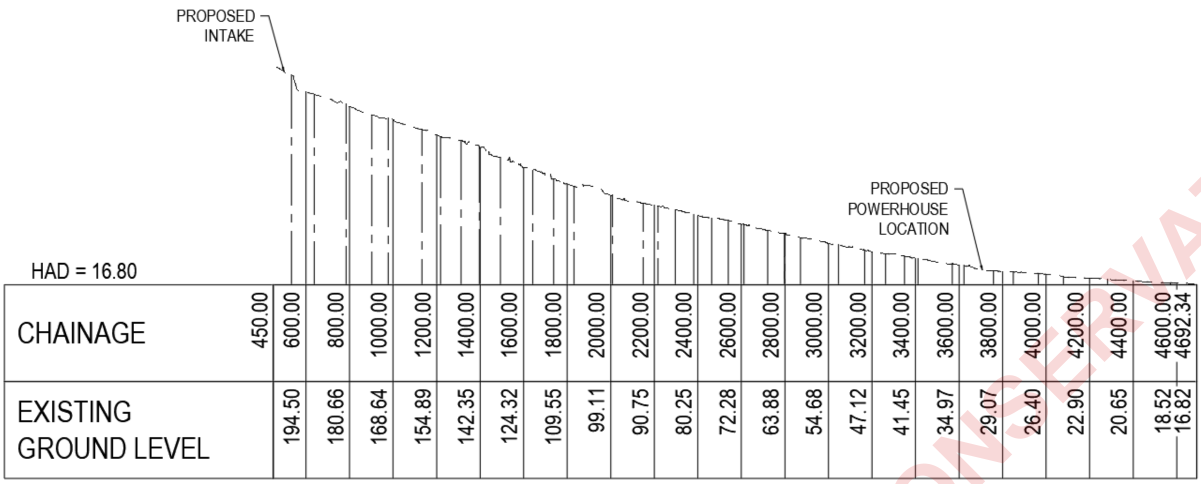


Figure 6-1: Tutoko River profile

6.3 Generation

The table below shows a range of potential power output the resource could deliver. The final design abstraction value will depend on energy demand, storage requirements, and resource consenting.

Table 6-2: Key Parameters for Tutoko River Site

Site	Mean river flow (m^3/s)[9]	MALF (m^3/s)[10]	Assumed residual flow requirement (m^3/s)	Gross head (m)	Output at mean flow (kW)	Output at MALF (kW)
Tūtoko River proposed intake	9.47	1.70	1.44	182	13,444	2,408

[9] Mean flow for Tūtoko River is exceeded 21% of the time
[10] MALF for Tūtoko River is exceeded 77% of the time

Figure 6-2: Tutoko River. Source: By Tony Hisgett from Birmingham, UK - Tutoko River 2, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=64140215

7. Flooding risk

Fiordland, being a high-rainfall region, is prone to large flood events. As detailed hydrology is not available at this stage, the expected floods cannot be assessed at this stage. A thorough feasibility study based on measured hydrology and detailed geotechnical investigations will be required to make an assessment on the risks. However, typical measures against flooding are discussed below.

Any design should take the risk of flooding into account. Where possible, the hydropower infrastructure such as the powerhouse would be designed to be located above an appropriate flood level (e.g. 1:200 year return period).

The intake works will not be able to be located above any flood level, but will be a robust design to deal with high water levels and debris being washed down the river. Typically, a low weir structure (such as presented in Figure 7-1), is designed to be submerged under flood events. Due to the shape and design of the structure, debris such as logs and rocks are not expected to cause significant damage to the concrete structure and more sensitive elements (such as a fine screen) will be protected with a more durable coarse screen.

The weir as presented in Figure 7-1, Figure 7-2 and Figure 7-3 is located in Vanuatu where it is required to withstand frequent tropical storms and cyclone events. Figure 7-2 shows a photo that was taken during a flood event where the river level rose by about 2.5 m and 500 mm rainfall was received in 24 hours. The storm did not cause any damage to the structure, even with large boulders being washed over the weir.

It should be noted, however, that the hydropower plants even if not damaged during a flood event, will not be operable during extreme weather events. If power is required during these times, it would need to be supplied by other means such as stand-by diesel generators.

Figure 7-1: Example of small-scale hydropower plant weir and intake works

Figure 7-3: Weir submerged under flood conditions

Figure 7-2: Weir under flood conditions

8. Risks

As all the proposed options are run-of-river, small scale hydropower schemes, their risks will be similar as outlined below. Some differences in the risks for high head (with the exception of higher risks for Tūtoko River) and low head-schemes are noted.

Table 7-1: Risk assessment

Risk	Description	Likelihood	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. Minor flooding could be associated with the low head schemes and Tūtoko River scheme from water stored behind the low weirs in case of damage to the weir. Such damage to these weirs is very unlikely though.	Very unlikely	Minor	Very low	Design robust intake works and powerhouse to withstand flood damage. Design powerhouse 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.	Possible	Moderate	Medium	Design sufficiently sized energy storage systems (i.e. batteries) or pair with solar where possible.
Operational safety	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.	Very unlikely	Major	Medium	Design appropriate penstock protection measures.
Channel movement	If not designed properly, the tailrace could cause erosion	Unlikely	Moderate	Medium	Design energy dissipating measures to prevent channel scour.

	of the downstream channel.				
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.
Fish Passage	The low head schemes and the Tūtoko River scheme could obstruct fish passage.	Likely	Moderate	High	With investigations and appropriate designs, passage for fish can be accommodated for these schemes.
Ground Conditions	Ground conditions are likely to be challenging which could add additional costs.	Likely	Moderate	High	Extensive intrusive investigations (bore holes, trial pits and testing.
Resource consent	It could be challenging to gain resource consent as the projects will involve working in a water course in a national park. The low head schemes are expected to be harder to gain consent, as they would be more intrusive, and involve larger infrastructure.	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 also be extensive due to complicated design interfaces and long lead times for generation and hydromechanical equipment. The resource consent timeframes are expected to be longer though.	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	The Tūtoko River option has the risk of impacting the State Highway Road and/or bridge.	Unlikely	Moderate	Medium	Taking the State Highway into account when locating the new powerhouse as well as the design of the tailrace will minimise the risk
Statutory Acknowledge ment Areas	The Tūtoko River option should consider the Ngai Tahu Settlement Act schedules of Topuni as Tūtoko is listed as a Statutory Acknowledgement Area.	Possible	Minor	Medium	Take into consideration if option progressed further.

9. Summary

Note that the power output as stated in the table below represents the upper and lower limits of each option's generation range. Although the rivers' maximum hydropower potential would exceed this upper limit, the upper limit represents generation at the river's mean flow which is a reasonable upper limit for this level of study. The actual design output will be dependent on the energy demand and environmental assessments. As the demand at Node 5 is still unknown, the upper limit generation potential ("Output at mean flow") for some options potentially produce significantly more power than actually required. Apart from lowering the output by abstracting less water, the scheme could be configured differently such as moving the intake downstream, reducing the head and hence the power output. If the full power potential is generated, it could be investigated to use the excess energy to charge batteries or produce hydrogen.

Table 8-1: Summary of Potential Sites

Site	Mean river flow (m^3/s)	MALF (m^3/s)	Residual flow (m^3/s)	Gross Head (m)	Expected conveyance length (m)	Turbine type	Output at mean flow (kW)	Output at MALF (kW)
Upper carpark (low head)	8.56	2.05	1.74	5	50	Kaplan	275	12
Lake Marian carpark (low head)	9.23	2.04	1.73	1	0	Kaplan	60	2
After confluence with Marian Creek (low head)	12.23	2.93	2.49	1	0	Kaplan	78	4
Lake Marian Carpark powerhouse and upper carpark weir (low head)	8.56	2.05	1.74	35	1,300	Kaplan	1,922	87
Marian Creek (high head)	2.95	0.66	0.56	379	2,700	Pelton	6,932	287
Falls Creek (high head)	1.74	0.47	0.40	303	1,000	Pelton	3,172	166
Roaring Creek (high head)	0.78	0.19	0.16	727	2,600	Pelton	3,517	160
Tūtoko River (high head)	9.47	1.7	1.44	182	2,800	Pelton or Francis	13,444	2,408

In terms of costs, the low head options would be significantly more expensive in terms of cost per kW. Coupled with the constructability issues (i.e. river diversions) and the environmental impacts of a significant structure on the river will likely make these unfeasible. The intakes associated with the high head options (except the Tūtoko option) will have a smaller impact on fish passage than those for low head options.

The best options are the high head options, where there is significant head available, and it is recommended that further investigations focus on these options.

10. Recommendations

Regarding the eight options investigated in this report, the Marian Creek option and Tūtoko River options seem the most promising. The Tūtoko River option has the highest potential power output, however the Marian Creek option has benefits in terms of constructability. Both of these options have long conveyance routes and might pass through challenging terrain. The significant weir structure and larger conveyance of the Tūtoko option, will have a larger environmental impact and therefore make gaining resource consent more challenging, even larger than the low head schemes on the Hollyford River. For this reason, the lower-impact Marian Creek option is recommended. However, if proximity to Milford Sound and the generation output is prioritised, the Tūtoko River option could be investigated, noting its bigger environmental impact and challenging construction.

The required design output will be determined once more information is available on the load requirements. Thereafter, a cost can also be developed.

The key next steps to progress this assessment are listed below:

- Energy demand assessment to appropriately size the schemes.
- Hydrological assessment/flow and rainfall gauging to understand the actual flows and flow patterns.
- Ecological assessments to understand any ecological sensitivities that could constrain the design or prevent the project.
- Geotechnical investigations will need to be performed at any proposed infrastructure locations, especially for the weirs/intake works, powerhouses, and any steep slopes proposed as part of the conveyance routes.

11. References

D.J. Booker, R. W. (2014). Comparing and combining physically-based and empirically-based approaches for estimating the hydrology of ungauged catchments. *Journal of Hydrology*, 227-239

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