Greenland Hydro Project – Site 06. g
Energy Generation Study

Government of Greenland, The Ministry of Agriculture, Self-Sufficiency, Energy and Environment

2024-08-09
N/Ref.: 693233-0000-4HER-0002-01

Greenland Hydro Project Site 06.g, Energy Generation Study

Final Report

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EXECUTIVE SUMMARY

The Government of Greenland, through the Ministry of Agriculture, Self Sufficiency, Energy and Environment, has decided to expose the development of the two largest hydropower potential sites, the Tasersiaq (Site 07.e) and the Tarsartuup Tasersua (Site 06g) watershed areas in West Greenland, to public tender process for industrial use.

Prefeasibility studies for both sites were conducted in 2009 by AECOM [Ref 1], with the objective of providing electricity for a prospective aluminum reduction plant. The studies identified that the observed climate trend will lead to higher firm power potential. The main objective of the present study is to determine the firm power for different alternatives considered for Site 06.g. These studies were performed based on historical flow and considering climate trend changes based on available data.

AtkinsRéalis has been provided with hydrological data such as historical inflow series at the project intake site for a period of 42 years from 1980 to 2021, and annual inflow volume for future period corresponding to two periods. First, two initial climate change scenarios based on 20 years of annual inflow volume for future period 2031-2050, are presented. Second, the same analysis was performed for six new climate change scenarios prepared by ASIAQ (2023) covering a longer period until 2100 and based on the latest relevant scientific information available.

To evaluate the impact of the revised methodology by ASIAQ (2023), firm power for the first cases previously analysed are reevaluated using the same inflow series for the period 2031-2050. The results obtained are slightly higher than the results of former study. The results of the new climate change scenarios allowed the qualification of the results obtained from the first climate change scenarios. It is assumed that all climate scenarios studied are equiprobable. The increase of the number of climate scenarios and the corresponding firm power analyses provide a better understanding of the potential range of installed capacity for this project, considering the uncertainties associated with the future inflows forecast.

The Table E-1 below presents the minimum, the maximum and the 50% probability of exceedance of the firm power based on the inflow scenarios available for the different period of analysis.

Table E-1: Site 06.g - Firm Power (100%) – Summary of the Results

Period	Number of scenarios	Firm Power (MW)		
		Minimum	50% probability of exceedance	Maximum
Historical	1	N/A	176	N/A
2031-2050	8	203	218	237
2031-2060	6	203	214	222
2051-2080	6	209	228	265
2071-2100	6	216	240	313

The main elements to consider:

- The trend of the firm power seems to increase for the future. For the 50% probability of exceedance, the increase in firm power is about 40 MW between the evaluation based on the historical data and the results for the period 2031-2060. It continues to increase for the period 2051-2080 and 2071-2100.

- The results for the period 2031-2050 are higher than the results for the period 2031-2060, since the two initial scenarios are considered only for the period 2031-2050 and the firm power for these scenarios are significantly higher than the others;

- The minimum firm power estimate for the different periods remains similar. It corresponds to the results of the scenario SSP126_ME_MAR. This scenario shows almost no increase of the annual volume of inflows in the future, which explains the practically constant value.

As mentioned previously, at this stage of the project, each climate change scenario is considered as equiprobable. It means that the choice of the firm power for a specific project must be based on the economic analysis of the project and account for the probability that the firm power will not be met during some years (or part of the year, i.e. until the next Spring flood occurs).

We recognize the difficulty to calibrate climate models and generate annual hydrographs for the study area, considering that most of the inflow comes from glacier melting which is a complex phenomenon. For these reasons, the firm power estimated must be considered with caution; the results are representative of the information available, but it is difficult to assess their confidence interval, even with eight scenarios. Furthermore, independent events, like a volcanic eruption, can have an impact on the climate and lead to changes in the conditions for one year or more. These impacts were excluded from the present study.

1. INTRODUCTION

1.1 Context

The Government of Greenland, through the Ministry of Agriculture, Self Sufficiency, Energy and Environment (The Ministry), has decided to expose the development of the two largest hydropower potential sites, the Tasersiaq (Site 07.e) and the Tarsartuup Tasersua (Site 06g) watershed areas in West Greenland, to public tender process for industrial use.

Prefeasibility studies for both sites were conducted in 2009 by AECOM, with the objective of providing electricity for a prospective aluminum reduction plant. The studies identified a firm power potential of 185 MW at Site 06.g, based on historical flow data between 1958 and 2007.

The main objective of the present study is to determine the firm power for different alternatives considered for Site 06.g. These studies were performed based on historical flow and considering climate trend changes based on available data.

When using the data from climate models to determine the trends in the future, it is a general practice to use an ensemble of climate model outcomes that also assists in assessing the uncertainty associated with the analysis. For example, a study performed by Zakrevskaya and Huard [Ref. 10] were using results from eleven climate models and four different scenarios to estimate the potential range of firm power for a project in Northern Canada.

First, two initial climate change scenarios obtained in 2022 and based on 20 years of annual inflow volume for future period 2031-2050, were reviewed (Chapter 4). Following this first study, the same analysis was performed for six new climate change scenarios prepared by ASIAQ (2023) covering a longer period until 2100 and based on the latest relevant scientific information available (Chapter 5).

1.2 Scope

The objective of the present study is to update the Site 06.g energy generation study, for the 2009 pre-feasibility study (PFS) proposed project characteristics, using updated flow series and revised hypothesis on the effect of future climate on the available flow at the site. The scope of work include:

- Collection of all available hydrological and meteorological data;
- Review of available data;
- Based on the daily data available and annual runoff volume, development of long-term daily flow series for different cases, including future climate scenarios;
- Evaluation of firm energy generation, based on the general characteristics of the site layout developed in the 2009 pre-feasibility study (PFS);
- Summary review of the PFS energy generation study hypothesis;
- Evaluation of the firm energy generation for the different long-term flow scenarios (20- and 30-years);

- Sensitivity analysis on potential firm energy generation (1-year deficit).

The scope of work does not include a review or modification of the 2009 PFS proposed project characteristics.

1.3 Site Description & Preliminary Layout

Site 06.g is located 120 km east of midway between the towns of Nuuk and Maniitsoq in the north-south direction, as shown in Figure 1-1.

The layout of the proposed scheme, as established in the PFS study, is shown in Figure 1-2. Following the PFS scheme: the main reservoir, created by raising Lake Imarsuaq's (Big Lake) present water level (675 m) by 7 m. It is normal operating level will be between 669 m and 682 m with 945.8 hm³ of live storage. The lower reservoir, created by raising Lake Tussapp Tasis' (Lower Lake) present water level (653 m) by 14 m. It will be operated at a constant level (667 m).

The proposed conveyance structures include a 10 km long headrace tunnel, underground powerhouse equipped with 2 Pelton turbines, a transformer cavern, access and cable galleries. Moreover, it entails a tailrace tunnel discharging in Godthabsfjord. The projected gross head at a max operating level of 682.0 m is 674.5 m, and the projected net head, about 655.7 m.

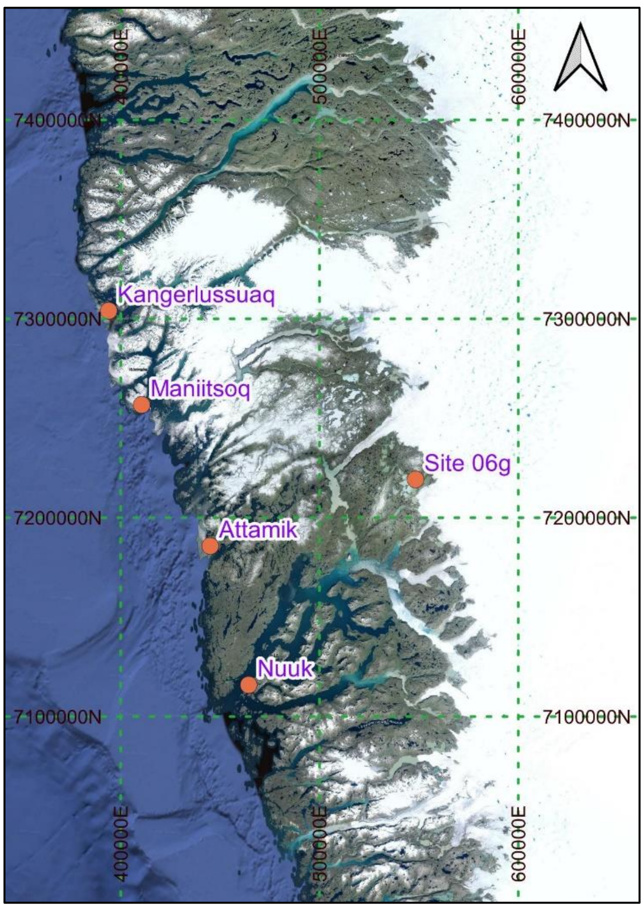

Figure 1-1: Site 06.g - Project Location

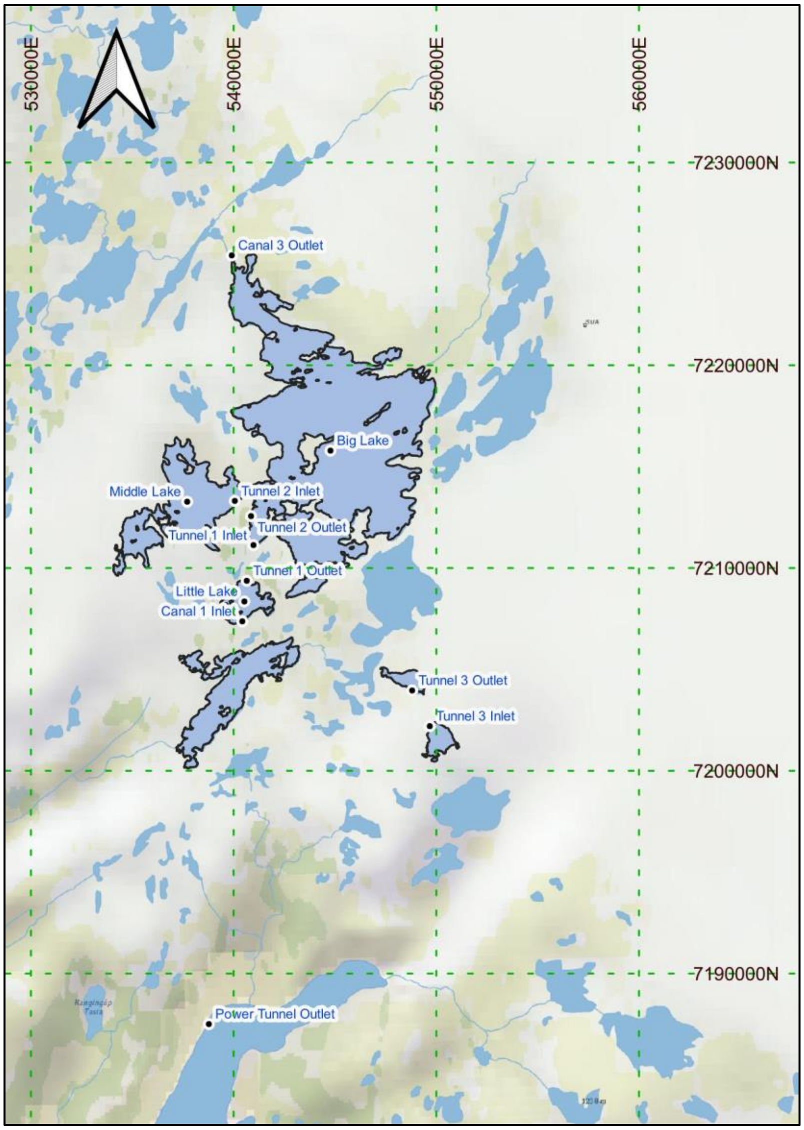

Figure 1-2: Site 06.g - Project Layout (from AECOM, 2009 [Ref 2])

The main characteristics of the scheme developed by AECOM are presented in Table 1-1. These characteristics were maintained in the present power generation study. However, some parameters were the object of a sensitivity analysis, and higher turbine capacity were selected for the inflow series allowing higher power generation, as described in Section 3.2.

Table 1-1: Site 06.g Main Project Characteristics (AECOM, 2009 [Ref 2])

Water Levels	
Reservoir	
Maximum operating level	682 m
Minimum operating level	669 m
At the intake (constant)	667 m
Downstream – Fjord	
Maximum tide level	2.1 m
Minimum tide level	-3.5 m
Headrace Canal	
Length	65 m
Flow velocity	0.65 m/s*
Headrace Tunnel	
Length	9.99 km
Diameter	5.1 m
Cross-sectional shape	Circular
Turbines	
Number of turbines	2
Type of turbines	Pelton
Level of turbine nozzles	7.5 m
Gross head (at max level)	674.5 m*
Net head (at max level)	655.7 m*
Unit discharge	16.6 m^3/s*

* Directly or indirectly the object of a sensitivity analysis in the present energy generation study.

2. SITE HYDROLOGY

The hydropower potential for this project includes the utilization of catchment of various lakes, namely, Lake Imarsuaq (Big Lake), Lake Tussapp (Lower Lake) and Little Lake. The total catchment area at Site 06.g is estimated to be 1 548 km² and is sub-divided into four sub-catchments as presented in Table 2-1. As seen from the table, sub-catchment II is the largest and would contribute most to the flow. Approximately 58% of the total catchment area is glacier covered and majority of the inflow comes from glacier melting that occurs between June and October.

Table 2-1: Site 06.g Sub-catchments - Area

Sub-Catchment	Catchment Area (km^2)	Remarks
I	109	Lower Lake
II	1 298	Big Lake
III	113	NE sub-catchment
IV	28	SE sub-catchment
Total	**1 548**	

2.1 Data Availability

AtkinsRéalis has been provided by The Ministry with the following hydrological data:

- daily historical inflow series at the project intake site for a period of 42 years from 1980 to 2021 for each of the sub-catchments. However, in the provided time series, several years have missing data. Data available for each of the sub-catchments is as follows:
    - 06.g.I: 6 years complete, 3 years partial
    - 06.g.II: 19 years complete, 4 years partial
    - 06.g.III: 3 years complete, 1 year partial
    - 06.g.IV: No Data
- annual inflow volume for historical period;
- annual inflow volume for future period corresponding to various Radiative Concentration Pathways (RCP) climate scenarios:
    - Two scenarios for the period (2031-2050);
    - Six scenarios for the period (2023-2100).

The daily flow data provided to AtkinsRéalis was derived through a combination of observed flow data, water level data and HIRHAM climate model outputs [Ref 3]. The measured time series at catchment 06.g.II had 17 years overlapping with the HIRHAM5 ice runoff time series with a strong correlation ($R^2 = 0.93$). Applying this correlation, data derived from the climate model was used to provide data series from 1980 to 2021 [Ref 3].

The summary statistic of available daily flow data for each sub-catchments are presented in Table 2-2.

Table 2-2: Sub-catchments at Site 06.g - Summary Statistics of Daily Inflows

Statistics	Flow (m^3/s)			
	06.g.I	06.g.II	06.g.III	06.g.IV (*)
Minimum	0.1	0.0	0.0	---
Maximum	22.7	307.4	15.1	---
Mean	2.88	30.2	1.6	---
Median	0.88	6.2	0.13	---

(*) No observations available on the sub-catchment

2.1.1 Available Flow Data for Site 06.g.II

Since sub-catchment 06.g.II contributes maximum to the total flow and the most available data pertains to this sub-catchment, analysis of the available flow for 06.g.II sub-catchment is reviewed in this section.

The available daily inflow time series (with missing periods) is presented in Figure 2-1. The figure shows that every year flow peaks in mid-summer. Winter and autumn flows are minimal. The high flow is snowmelt / ice melt driven as significant part of the catchment is ice covered. Mean flow is found to be about five times higher than the median flow and the time-series is positively skewed. Such significant difference between the mean and median of the data is reflective of broad range of flow in the time series.

The provided annual inflow volume data is presented in Figure 2-2. The plot also includes the mean annual temperature for Greenland [Ref 6]. Over the years a trend of increasing mean temperature is evident and the same trend is reflected inflow volumes too. Since flows in the catchment primarily result from snow and ice melt, increase in mean temperature is resulting in higher flows over the years. Mann-Kendell statistical test applied on the annual inflow volume presents a significantly increasing trend in the data.

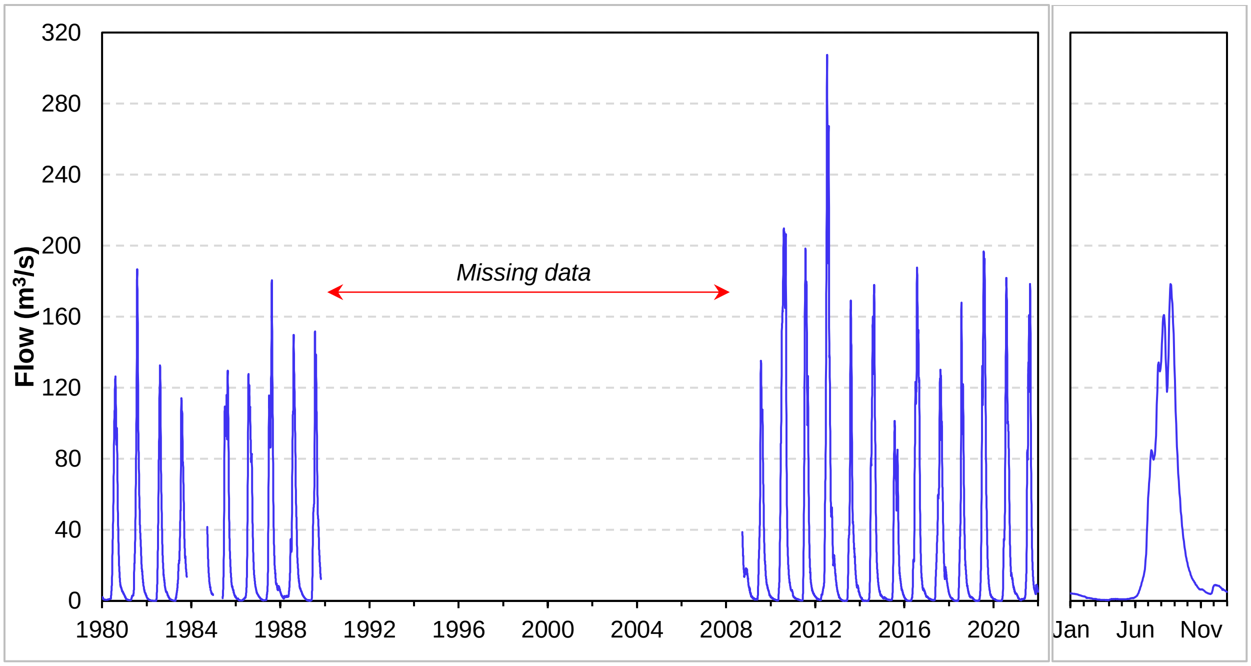

Figure 2-1: Sub-Catchment at Site 06.g.II - Daily Inflow Time Series and Typical Year Hydrograph (on Right Panel)

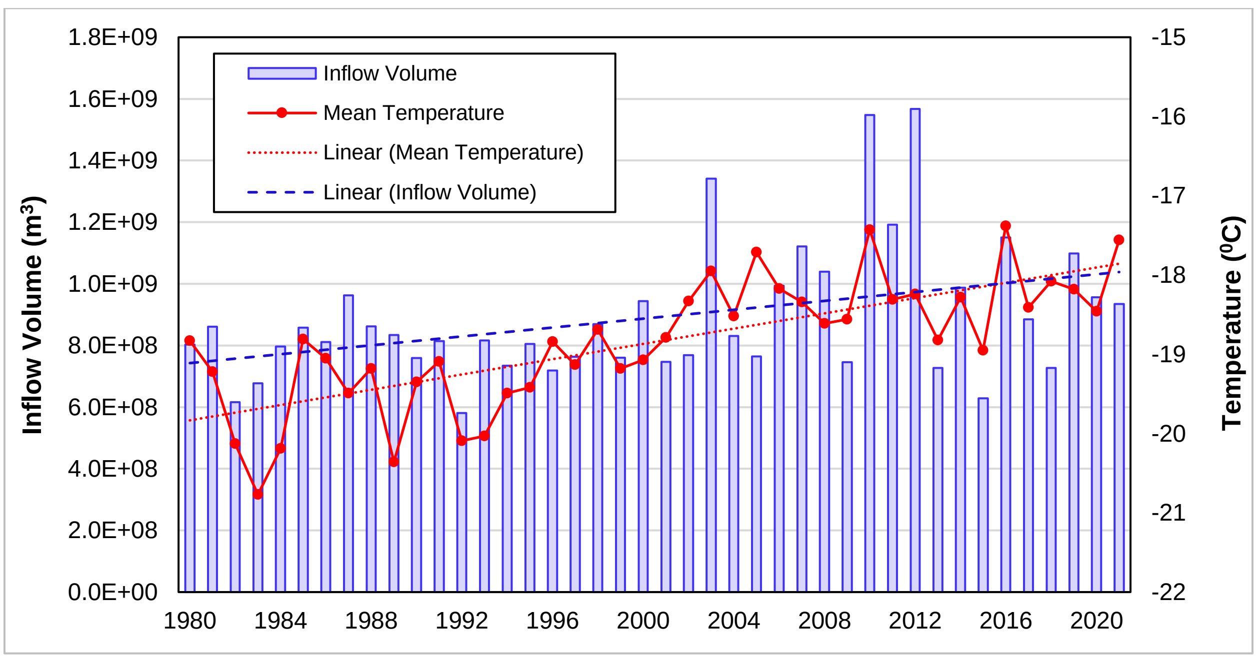

Figure 2-2: Sub-Catchment at Site 06.g.II - Annual Inflow Volume and Mean Annual Temperature

2.2 Reconstitution of Flow Time Series

In order to build an appropriate power potential model, a daily flow time series is required which is reflective of the present and the changing hydrological conditions of the catchment. The provided flow series was reconstituted after performing the following operations on it:

a) **Data gap filling**: In order to effectively use the flow data for energy generation, it is important to fill the gaps in the provided daily flow series. Since there is no nearby station with same period of observed data, data gap filling was carried out applying statistical method. Two different approaches for gap filling are applied as described in later sections.

b) **Volume correction**: Since the annual inflow volume series was provided for each year, the generated time series, after gap filling, was corrected to match the annual volume. An attempt was made to minimize the corrections on the observed data.

c) **Trend correction**: As discussed earlier, an increasing trend in the annual flows has been observed in the historical data. Mean inflow volume over each decade is computed and the decadal trend is presented in Figure 2-3. With the increasingly warming climate, the trend observed in the water resources over the historical period, is likely to continue in future. In order to estimate the hydropower potential for the catchment with minimum uncertainties, the trend in the annual inflow need to be diluted thus generating the time-series more representative of the present-day hydrological conditions.

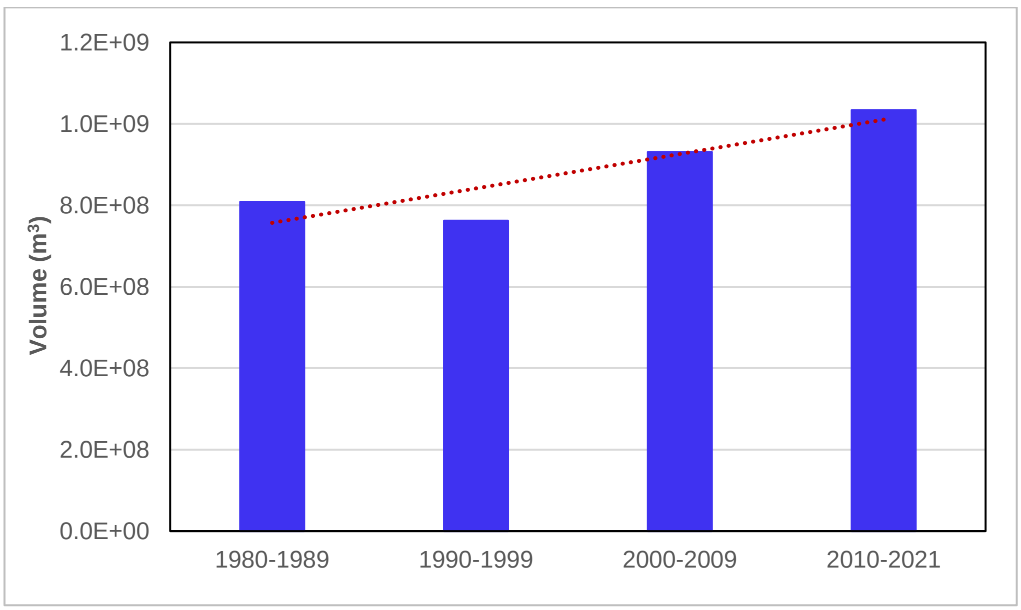

Figure 2-3: Site 06.g - Trend for Mean Decadal Inflow

To derive the flow series with no-trend two approaches were adopted. In both approaches, a factor was first derived on annual volume, which when applied to the observed inflow volume would eliminate the trend in the annual inflow volume series. The factor was then applied to the daily time-series.

The above-described methodology was applied to the largest sub-catchment 06.g. II. For the other sub-catchments inflow series was derived based on the catchment proportionate method. Total flow for the catchment 06.g was then estimated as sum of all the sub-catchments. Three sets of reconstituted flow series were generated by applying the above procedure. First a historical series was derived by performing only two operations, filling the missing data and correcting for annual volume; the series is termed as Reconstituted Series-0 (RS0). Then two more data series were derived by performing all the three operations described above. In these series the increasing trend of annual flow over the years have been eliminated. These trendless series are termed as Reconstituted Series-1 (RS1) and Reconstituted Series-2 (RS2).

2.2.1 Reconstituted Series-0 (RS0)

As described above the reconstituted series was derived by applying the above operations:

- **Data gap filling:** The missing data for any given day was filled by taking the mean flow for that day, which is computed based on 42 years of available data.

- **Volume correction:** Since the annual inflow volume series was also available, the generated time series after gap filling was corrected to match the annual volume.

2.2.2 Reconstituted Series-1 (RS1)

As described above the reconstituted series was derived by applying all the above operations:

- **Data gap filling:** The missing data for any given day was filled by taking the mean flow for that day, which is computed based on 42 years of available data.

- **Volume correction**: Since the annual inflow volume series was also available, the generated time series after gap filling was corrected to match the annual volume.

- **Trend Correction**: It is considered that the beginning year of time series was lowest in trend and a year was selected till which the trend was assumed to have diminished. The volume was increased from beginning till the last selected year which was 2010. A linear variation of 1.02% per year was applied in the volume increment for the total flow volume (for all the catchments).

2.2.3 Reconstituted Series-2 (RS2)

Similar to the steps described above, another set of reconstituted series was derived:

- **Data gap filling**: In this approach, the time series imputation was carried out using an algorithm which splits the times series into seasons and afterwards performs imputation separately for each of the resulting time series datasets. The algorithm was implemented in R programing language using the function ‘na_seasplit’. The derived inflow series after gap-filling was also validated. For this, inflow for a known year were removed from the time-series and the algorithm was run to fill this gap. This validation was performed few times to ascertain the performance of the algorithm. Figure 2-4 presents the comparison of observed data and the gap filled data for the validation years. Nash Sutcliffe Efficiency (NSE) statistic between the observed and the data filled series was also evaluated to estimate the performance of the method. NSE for most of the years is found to be good and acceptable, as seen in Table 2-3. The low value for 1986 is due to the timing error, however the overall volume appears good which is more relevant in the present analysis.

Table 2-3: Statistics for Validation Years

Year	1986	2018	2019
NSE	0.63	0.79	0.83

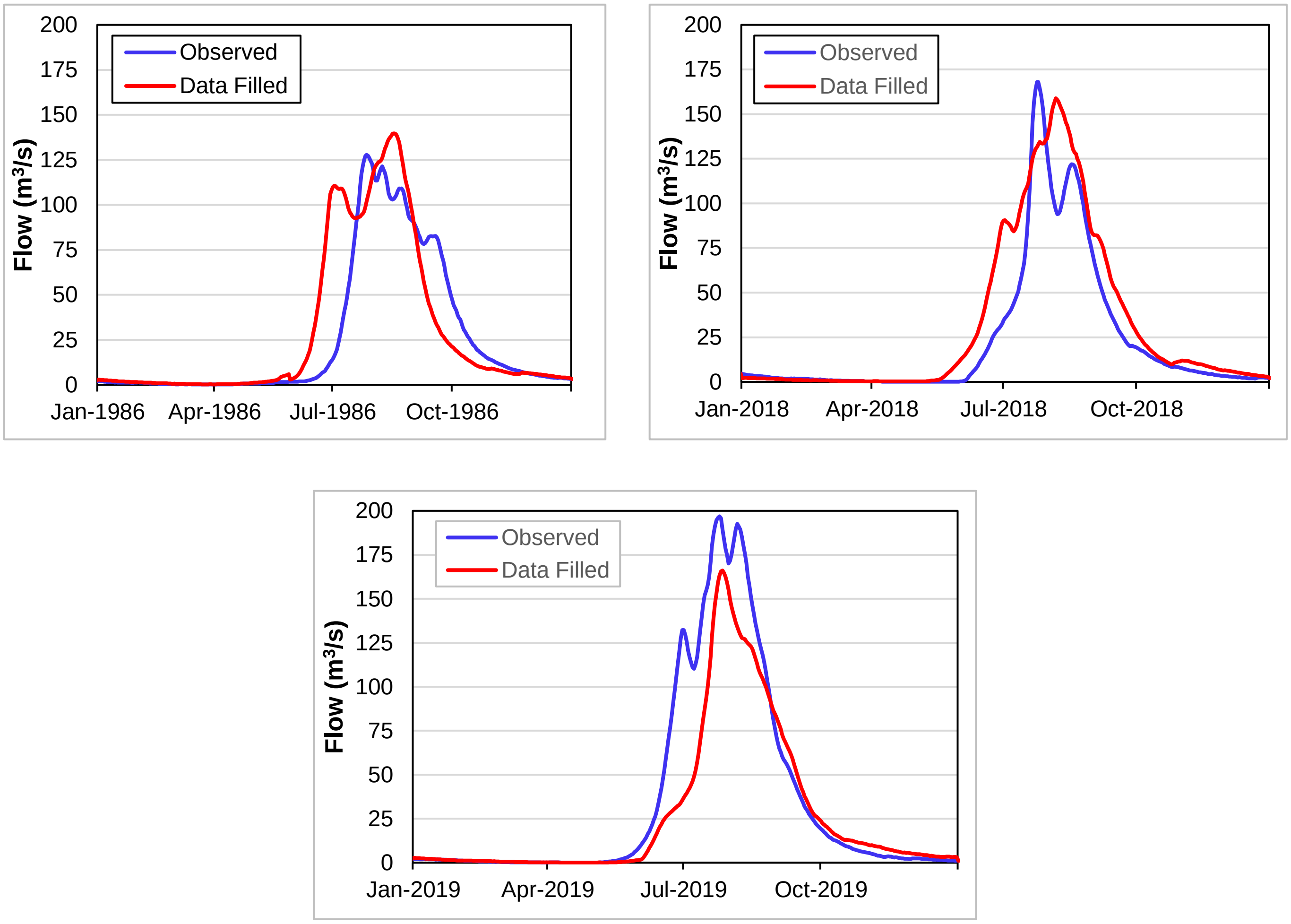

Figure 2-4: Site 06.g - Validation of Data Filling Method

- **Volume correction**: Since the annual inflow volume series was also available, the generated time series after gap filling was corrected to match the annual volume.

- **Trend Correction**: In this approach the calculation was carried out separately for each of the sub-catchment. Annual volume is uniformly increased for each of the years from 1980 till 1999 by 7%, 25%, 15% and 38% for sub-catchment I, II, III and IV, respectively**.**

2.3 Comparison of Reconstituted Flow Series

Since the generation of reconstituted flow series involved various steps, comparison of different steps and the final series is presented here.

2.3.1 Data Gap Filling

Two different approaches of data gap filling were adopted in generating the reconstituted flow series (RS1 and RS2). Both approaches compare closely. As presented in Figure 2-5 some differences in the estimated daily flow pattern are observed but the overall volume remains similar. In the plots Approach-1 and Approach-2 represents the method adopted to generate RS1 and RS2, respectively.

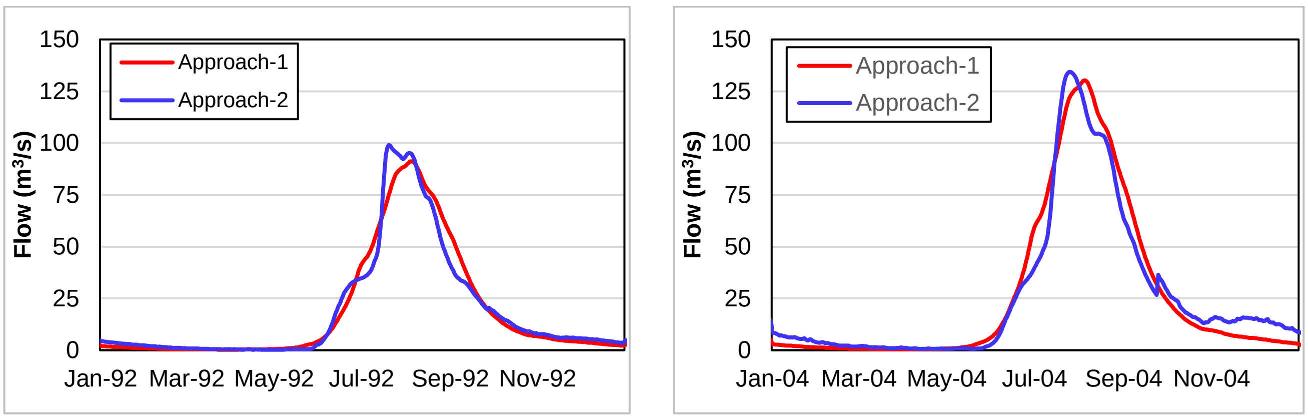

Figure 2-5: Site 06.g - Comparison of Missing Years Flow Time Series After Gap Filling

As it will be shown with the energy analysis, the annual volume of water and the beginning of the melting season are the two most key factors for the energy analyses, since the reservoir is multi-annual, i.e. it takes more than one year to empty the reservoir when generating the firm power. Under these conditions, daily inflows patterns are less significant but sensitivity analysis have been done on both set of data.

2.3.2 Correction for Trend

Elimination of the trend in the flow time series has led to the increase in the mean annual volume in the trendless series. When compared to the observed series, the increase in volume is estimated to be about 10.3% and 9.7% in RS1 and RS2, respectively. The comparison of annual volume of observed and derived trendless series is presented in Figure 2-6. It can be seen from the plot that for some of the initial year RS1 has larger volume while RS2 has a large volume increment for the years 1993-1999. For some of the low flow years such as 1982 and 1992, which are more critical in power potential analysis, both approaches yield comparable results.

The derived factors for making the annual inflow series as trendless, are then applied to the daily time series to generate final series for power potential analysis.

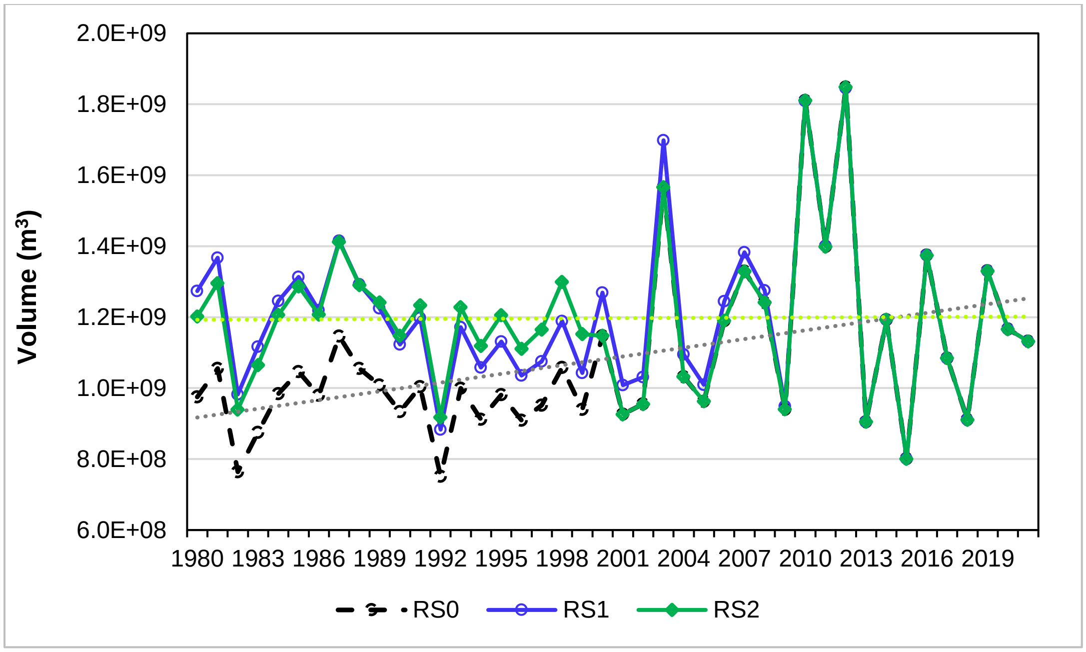

Figure 2-6: Site 06.g - Comparison of Annual Inflow Volume

2.4 Final Flow Series

The reconstituted flow series are compared in terms of flow statistic and the summary plots presented here. As seen from Figure 2-7, the mean monthly flow for the two trendless series (RS1 and RS2) is almost identical. However, RS0 has lower overall flow volume, as described earlier. In this series, inflows are lower during peak flow months of July and August.

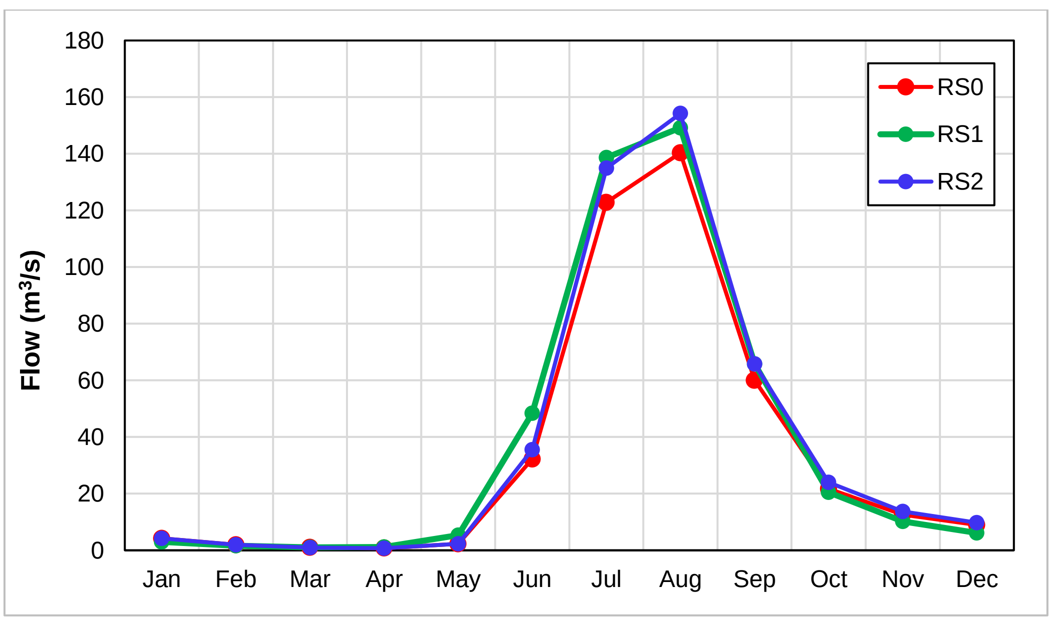

Figure 2-7: Site 06.g - Comparison of Mean Monthly Flow

Mean flow and mean annual volume of time series RS0 are lower than that of the other two series, as presented in **Error! Not a valid bookmark self-reference.**. As described above the correction of trend has led to increase of volume in the latter two reconstituted series.

Table 2-4: Site 06.g -Summary Statistics of Reconstituted Daily Flow Series

Statistic	Value		
	RS0	RS1	RS2
Daily Flow (m^3/s)			
Minimum	0.0	0.4	0.0
Maximum	337.7	321.8	337.7
Mean	34.4	37.9	37.7
Median	8.77	8.51	9.68
Specific Flow ($m^3/s/km^2$)			
	0.0218	0.0241	0.0239
Volume (x 10^6 m^3)			
Mean Annual	1085	1197	1190

Flow duration curve (FDC) is complementary to the cumulative distribution frequency of flows and is an important flow signature of a catchment. FDC's of the reconstituted series are also found to be mostly matching for all the three series as reflected in Figure 2-8. However, differences are observed between 5% to 25% exceedance flows.

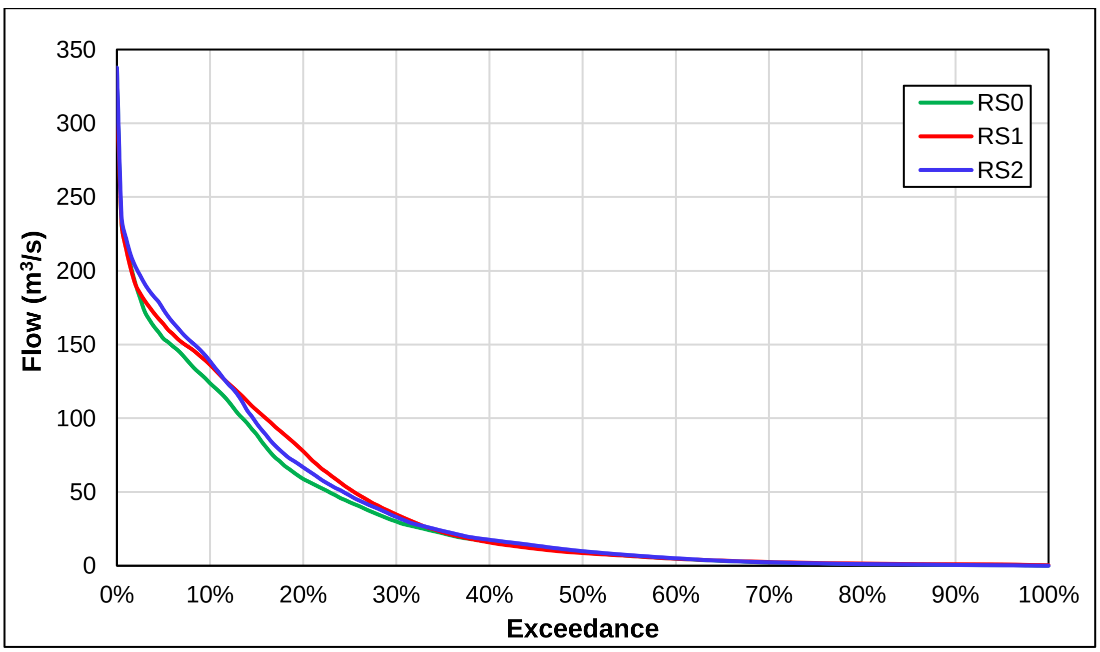

Figure 2-8: Site 06.g - Flow Duration Curves for Reconstituted Inflow Series

The above comparison illustrates that both approaches of generating trendless series lead to the reconstituted flow series that have similar characteristics. The mean monthly flow corresponding to three sets of reconstituted flow time series (RS0, RS1 and RS2) are presented in Appendix A1, A2 and A3, respectively.

2.5 Climate change scenario

2.5.1 Climate Change 2031-2050 Period

AtkinRéalis (formerly SNC-Lavalin) [Ref 9] was provided with annual inflow volume for catchment 06.g for a future period from 2031-2050. The data provided was produced through modeling of future climate in Greenland according to two of the UN climate panel (IPCC) scenarios for the future level of greenhouse gasses in the atmosphere. RCP4.5 and RCP8.5 scenarios were used [Ref 7 and 8]. The results are the outcome of the HIRHAM regional climate model (RCM) run for the future time slice.

The annual water yield for catchment 06.g.is projected to increase in the future climate scenario. Table 2-5 presents the comparison of mean annual inflow for the basin. It is evident from the comparison that the flow is projected to increase significantly during 2031 to 2050 period when compared to the historic period flow. The increase is projected to be higher for RCP4.5 scenario than for RCP8.5. In the table, the inflow volume for historic period is the mean of the inflow corresponding to the reconstituted series RS1 and RS2.

Table 2-5: Site 06.g - Mean Annual Inflow

Scenario	Period	Volume (x 10^6 m^3)	% change*
Historic	1980-2021	1193	…
RCP4.5	2031-2050	1642	37.6%
RCP8.5	2031-2050	1606	34.6%

* Change is with respect to the Historic period for series RS1 and RS2

Figure 2-9 presents the provided annual inflow volume corresponding to RCP4.5 and RCP8.5 scenarios. The trend in annual water resources is found to be decreasing for RCP4.5 scenario while it is increasing for RCP8.5 scenario. The output from climate model is a result of a complex system with processes that can have opposite effects, thus the trend in each of the scenarios could be different.

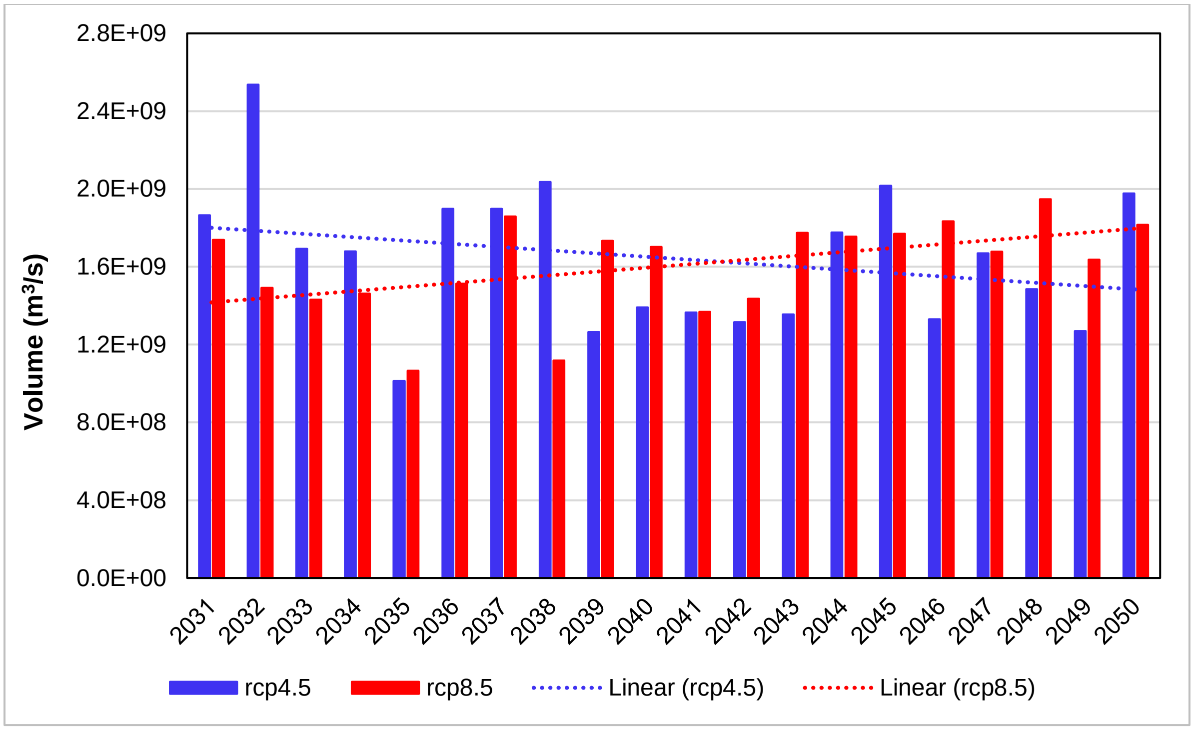

Figure 2-9: Site 06.g - Projected Annual Inflows Volume for RCP4.5 and RCP8.5 Scenarios

2.5.2 Climate Change 2031-2100 Period

ASIAQ performed a study in 2023 [Ref 4] to evaluate new climate change scenarios at Site 06.g.

Figure 2-10 presents a comparison of the annual runoff at the four catchments at Site 06.g for the two climate change scenarios considered in Section 2.5.1 and the six new scenarios proposed by ASIAQ. Adjustment factors were used to calibrate the runoff provided by the models with the observed annual runoff. The blue bar corresponds to the adjustment based on the minimum adjustment factor and the orange bar corresponds to the adjustment based on the maximum adjustment factor, which means that the average runoff for the period 2031-2050 will be the average between these two adjustments. The figure shows that the average runoff from new scenarios is lower than the two initial projection scenarios (presented in Figure 2-9), which will probably lead to lower firm power for the same period of analysis. More details are provided in the memo prepared by D. Petersen [Ref 5].

Figure 2-11 illustrates the cumulative annual runoff of the four catchments for the 2023-2100 period covering the six scenarios based on an average adjustment factor. The annual runoff remains in the relatively constant range between 2023 and 2060 for catchments. However, there is a significant increase between 2061 and 2100, particularly for the scenario SSP585_CC_MAR.

As recommended by ASIAQ [Ref 4], the monthly distribution for each year is based on the percentage of runoff per month extracted from the historical time series.

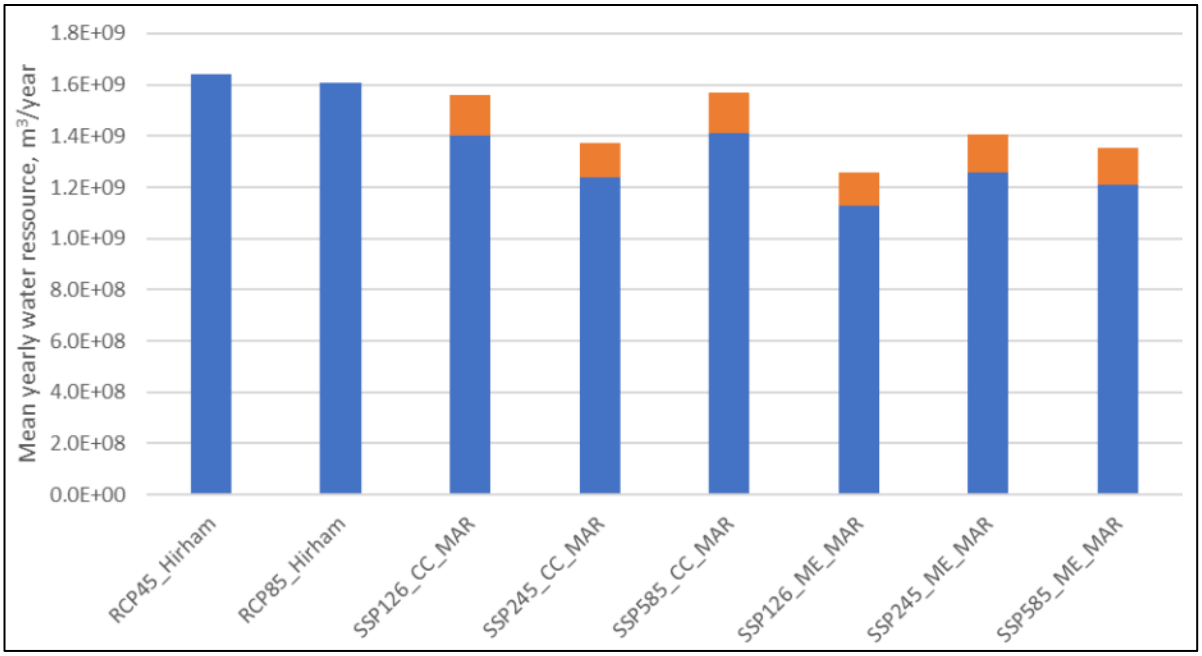

Figure 2-10: Site 06.g - Climate Change Scenarios – Comparison of Average Annual Runoff – 2031-2050 (from ASIAQ Ref 4)

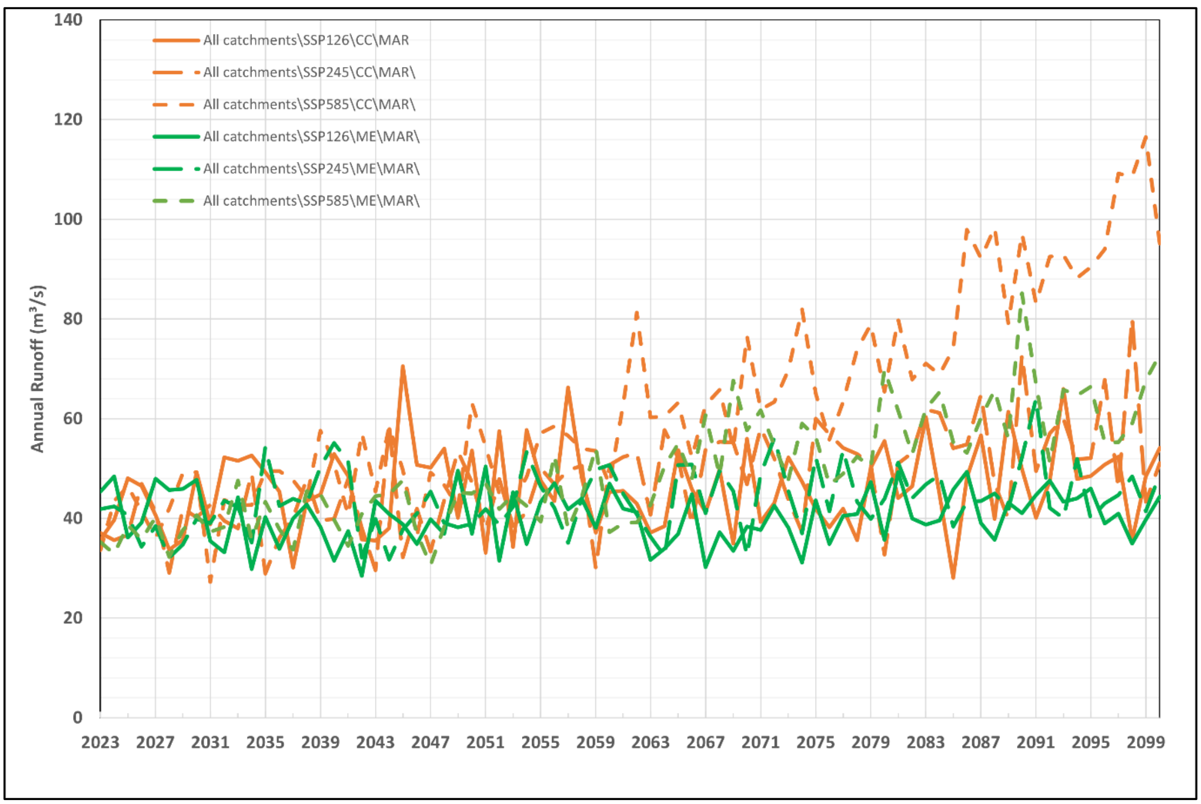

Figure 2-11: Climate Change Scenario – Cumulative Annual Runoff at Site 06.g (All Catchments) (Data Adapted from ASIAQ [Ref 4])

3. ENERGY MODELING

Energy modeling was conducted for the hydropower scheme developed by AECOM in the 2009 pre-feasibility study [Ref 1]. The PFS modeling parameters and assumptions were maintained, when possible, but modifications were made to perform sensitivity analysis, or to increase the plant capacity under high-flow hydrology scenarios, as described below.

3.1 Model & General Methodology

Modeling was performed using an in-house spreadsheet-based energy model. Simulations were performed with a daily-time step. The use of daily-time step provides sufficient accuracy for the energy analysis, considering that the reservoir operation follows a multi-annual pattern.

The general modeling methodology can be described as follows:

- Daily inflows are routed through the reservoir, using continuity equations and the reservoir storage curve (streamflow method);
- Outflows are function of the firm power target, which is constant in time. The outflow required to generate the firm power depends on the net head available;
- Water is discharged by the spillway when the reservoir level reaches the maximum operating level. The spillway capacity is considered sufficient to not exceed the maximum operation level;
- Generation is halted when the reservoir level reaches the minimum operating level (deficit).

The evaluation of the available firm power for a given scenario is a trial-and-error process. The firm power target is modified until the maximum target allowing for operating rules compliance is identified. The firm power target is assumed to be available 100% of the time during the simulation period.

3.2 System Characteristics & Modeling Assumptions

3.2.1 Storage

The Site 06.g includes sub-catchments that each provides storage as described below;

- Big Lake: for this lake, the full application of bathymetry is limited at elevations between 666 m and 668 m upstream of the intake zone of Tunnel 1 due to existence of shoals. The option to dredge the shoals would require costly excavation, thus is eliminated. Therefore, the minimum operating level of the Big Lake is limited to 669 m. The maximum operating level follows the proposed maximum level of 682 m in FEL 1. The maximum water level above this value requires raising the dams, which would be too costly compared to the firm power that can be gained [Ref 1 & 2];
- Lower Lake: The water level to ensure an adequate submergence of the intake structure with the intake invert above the natural water level of the lake is 667 m. It would be simple construction and economically

viable since no wet excavations will be required. This elevation is assumed constant since varying the operating level would not impact significantly on the firm power;

- By raising the water level of the Lower Lake to 682 m, the two lakes would merge (with L682). As a result, the transfer Tunnel 1 will be eliminated and would slightly increase the storage available. The added cost due to raise the dams and the spillway of the Lower Lake are not economically justifiable.

The storage curve of the projected reservoir is presented in Figure 3-1.

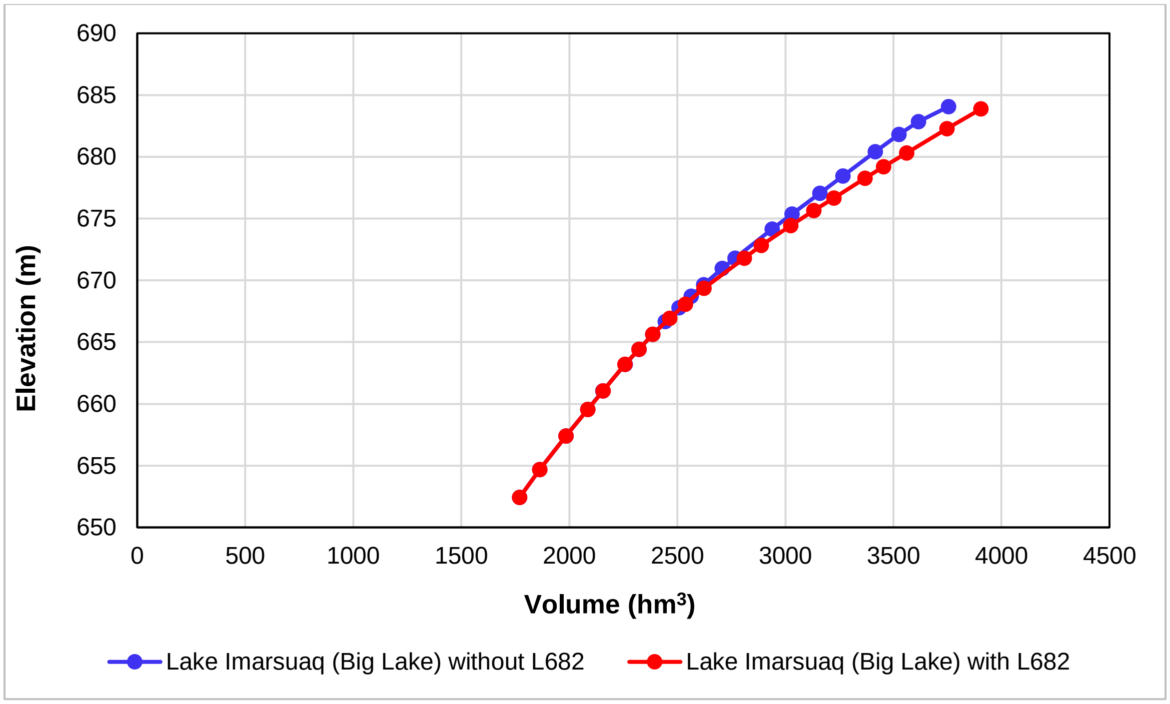

Figure 3-1: Site 06.g - Lake Imarsuaq (Big Lake) Storage Curves (derived from AECOM [Ref 1])

3.2.2 Operating Levels

The PFS minimum and maximum operating level of the Big Lake (669 m and 682 m, respectively) [Ref 1] and constant level of the Lower Lake (667 m) were selected for all scenarios of the energy generation simulations. Table 3-1 illustrates operating level -storage of the Big Lake for two scenarios of With-and without L682.

Table 3-1: Site 06.g - Operating Level (storage) Scenarios

Elevation (m)	Big Lake	
	Lake Imarsuaq without L682 (hm^3)	Lake Imarsuaq with L682 (hm^3)
669	2581.6	2598.2
671	2710.6	2747.3
673	2854.4	2901.9
675	3003.0	3074.7
677	3155.5	3254.2
679	3308.0	3435.6
681	3461.5	3625.7
682	3540.9	3720.5

3.2.3 Generation Devices

Following the scheme proposed in the PFS [Ref 1], the powerplant was modeled with 2 Pelton turbines, with nozzle elevation of 7.5 m. However, the turbine capacity was adapted to the hydrological scenario to allow for high firm power target, up to 22 m^3/s. No calculations were performed to determine the optimal number of units and their capacity, as it was outside of the objectives of the present study.

The adopted efficiency curve of the Pelton turbines is presented in Figure 3-2. The curve was extracted from the RETSCREEN software and adjusted to match the efficiency considered by AECOM (91.9%) [Ref 1]. A 98.6% generator efficiency was considered, and a 0.055% loss was added to consider the potential impact of a high velocity oxygen fuel (HVOF) coating.

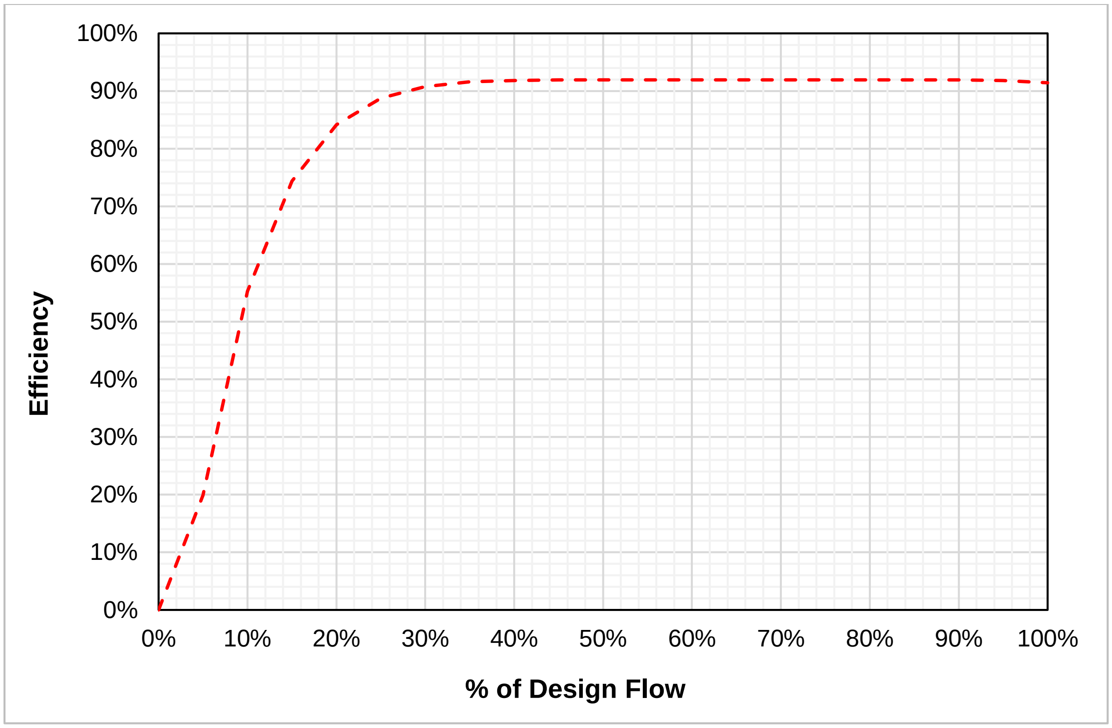

Figure 3-2: Site 06.g - Efficiency Curve for a Single Pelton Turbine

3.2.4 Head Losses

A simplified head loss relationship was defined, to match the net head values published by AECOM for typical operating conditions [Ref 1]. The characteristics of the power tunnel are:

- Length: 9.99 km;
- Diameter: 5.1 m;
- Roughness: 0.015 (likely for construction);
- Cross-sectional area: 20.4 m².

The Head-losses-Discharge curve is presented in Figure 3-3. No optimization work was done on the intake or power canal geometry to allow for lower losses at higher discharge values, as the scheme optimization was outside of the objectives of the present study.

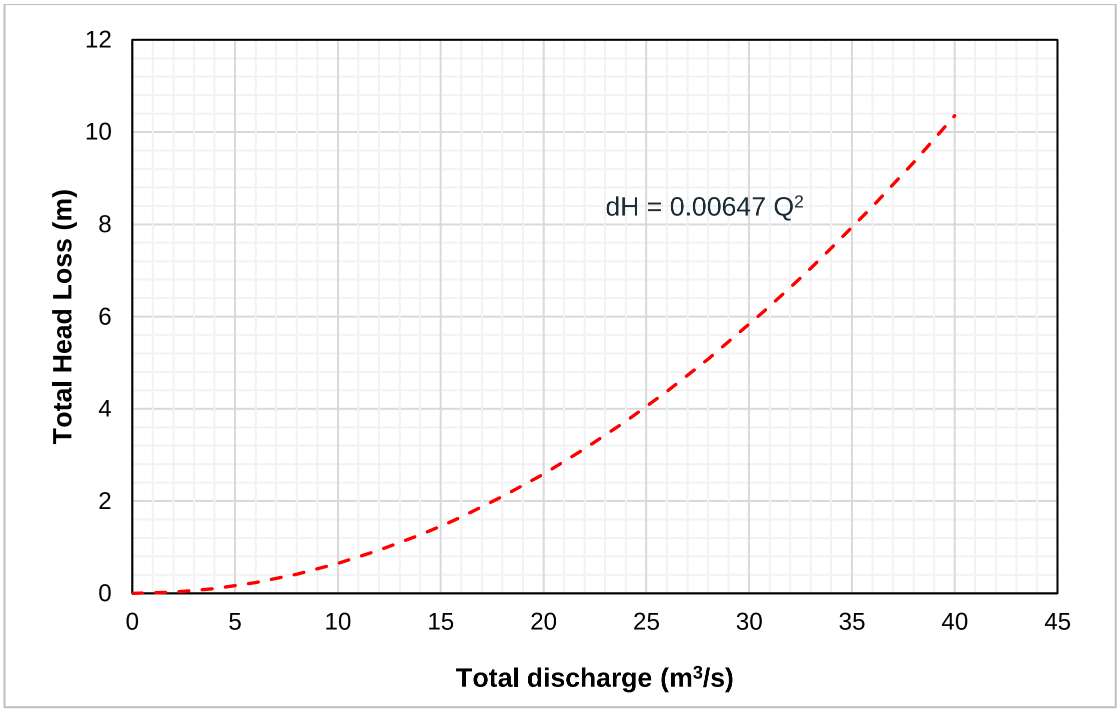

Figure 3-3: Site 06.g - Adopted Total Head Losses Curve

3.2.5 System Power & Other Losses

A power station energy requirement of 3 MW was considered, same as the value used in the PFS study [Ref 1]. Therefore, this value is subtracted from the firm power target to obtain the net firm power available for each modeled scenario.

Transmission losses were not considered, as the location of potential users is unknown.

3.2.6 Outages

No outage (planned or unplanned) was modeled. The net firm power published for each scenario is conditional to having two units available during the complete modeled period.

Maintaining the firm power target during planned or unplanned outages would require additional power units, to provide redundancy.

3.3 Scheme Optimization

No optimization study of the proposed layout was performed. Optimization work would require updated cost estimates, which is outside of the objectives of the present study.

3.4 Sensitivity Analysis

Sensitivity analyses were performed on the following parameters:

- Storage capacity (with or without L682);
- Inflow series (RS0, RS1, RS2);
    - Historical period (1980-2021);
    - Trendless annual series (1980-2021);
    - Sub-catchment inflow consideration;
        - There are four (4) sub-catchments for the Site 06.g that except the main sub-catchment II, others are considered (1) or neglected (0)
    - Historical period (1991-2010);
    - Future climate scenario (2031-2050) for RCP 4.5 and RCP 8.5.
    - Two approaches to construct inflow series as explained in Section 2.2 for RS1 and RS2.
    - Future climate scenario based on ASIAQ 2023 (2031-2050, 2031-2060, 2051-2080, 2071-2100)

An additional sensitivity analysis was performed by running scenarios allowing for a deficit in power generation for one of the modeled years.

4. Initial Climate Change Scenarios – Results Analyses

The analyses performed are described in Section 3.4. The results are with assumption of a maximum operation level of 682 m, a minimum operation level of 669 m for Big Lake, constant elevation of 667 m for Lower Lake, and storage with and without L682.

It is not possible to make any recommendation on the best alternative for the system, since an evaluation of the cost of the project and each potential alternative would have been required to determine an optimum solution.

4.1 Historical Data - ASIAQ 1980-2021

The first set of analyses were performed on the historical set of inflow data provided by ASIAQ [Ref 7] and subsequently reconstituted for the period 1980 to 2021, as described in Section 2.2. As mentioned in Section 2, two other sets of inflows were prepared to eliminate the strong trends observed on the historical set of data. Thus, the power potential analysis was performed using:

- RS0 – Data gap filling and correction of the inflows volume;
- RS1 - Data gap filling and correction of the inflows volume and trend correction for the period 1980 to 2021;
- RS2 - Data gap filling and correction of the inflows volume and trend correction for the period 1980 to 2021.

The last two sets of data are considered more representative of the situation observed over the last 10 to 20 years and should provide better indications of the actual firm power of the system.

4.1.1 Historical Data – Reconstituted Daily Inflows Series – 1980-2021 (RS0)

The first set of analyses were performed with the historical set of data using reconstituted series RS0. Table 4-1 presents the main results for the different analyses performed with the historical set of inflows. For each analysis, the initial (first year) and final (last year) reservoir water level were the same to guarantee that the total inflow in the system is equal to the total outflow.

Table 4-1: Site 06.g – RS0 – Energy Analysis Results – 1980-2021

Storage Scenario (1)	Sub-catchment Inflow Considered (2)				Firm Power (MW) (3)	Difference with base case (MW)	Firm Energy (GWh/y)	Average Energy (GWh/y)	Secondary Energy (GWh/y)
	I	II	III	IV					
Reconstituted daily inflows series – Firm at 100%									
1	1	1	1	1	174	-2 (-1%)	4220	4188	32
2 (4)	1	1	1	1	176	---	4258	4231	27
1	1	1	1	0	168	-8 (-4%)	4076	4039	37
2	1	1	1	0	170	-6 (-3%)	4111	4080	31
1	1	1	0	0	160	-16 (-9%)	3886	3842	44
2	1	1	0	0	162	-14 (-8%)	3920	3883	37
1	0	1	0	0	143	-33 (-19%)	3492	3434	58
2	0	1	0	0	145	-31 (-18%)	3522	3475	47
Reconstituted daily inflows series – 1 Year with deficit									
1	1	1	1	1	175	-1 (-1%)	4226	4195	31
2	1	1	1	1	177	+1 (+1%)	4266	4239	27
1	1	1	1	0	169	-7 (-4%)	4079	4043	36
2	1	1	1	0	171	-5 (-3%)	4117	4088	29

(1) 1 means Lake Imarsuaq (Big Lake) without L682
2 means Lake Imarsuaq (Big Lake) with L682
(2) 1 means the sub-catchment inflow is considered, 0 is not.
Sub-catchment 06.g.II is always considered in the analyses.
(3) Values are available firm power rounded at the nearest MW.
(4) Considered as the “base case” for the present study

Figure 4-1 illustrates the variation of the reservoir level corresponding to the firm power for the scenario considered as the base case for the present study, i.e. for the scenario including the four sub-catchments along with Big Lake with L682 that resulted 176 MW firm power. The figure shows that the reservoir is full in 1989 and becomes empty at mid 1998 (critical period of 9 years).

The Table 4-1 shows the difference of firm power in comparison with the base case. The following trends have been noted:

- The firm power of the system is lower than the results obtained by AECOM [Ref 1] (176 MW instead of 191 MW, i.e. -8.5%). For comparison purposes, we have used the case for which the inflows of all sub-catchments are available since it is not clear if the drainage area of the sub-catchments used in the present analysis are the same than the ones used by AECOM [Ref 1]. This difference can be explained by the fact that the critical period occurs during the period of missing data in the drainage area (1990-2008). For this period, annual inflows volume was reconstituted in 2021 [Ref 3], but it is probable that the volume used in the AECOM study was different;

- The decreases in storage capacity (without L682) has a limited impact on the firm power (i.e. a decrease of about +1% of the firm power);

- The reduction of the drainage area has an impact on the firm power varying between 5% to 30%. The “optimum” configuration of the system will require a detailed cost analysis to determine the cost of the incremental firm power capacity;

- Accepting the possibility to have deficit of generation during a year over the period of analysis has also limited impact on the firm power (about 1%). For the base case, the firm power is increased only by 1 MW.

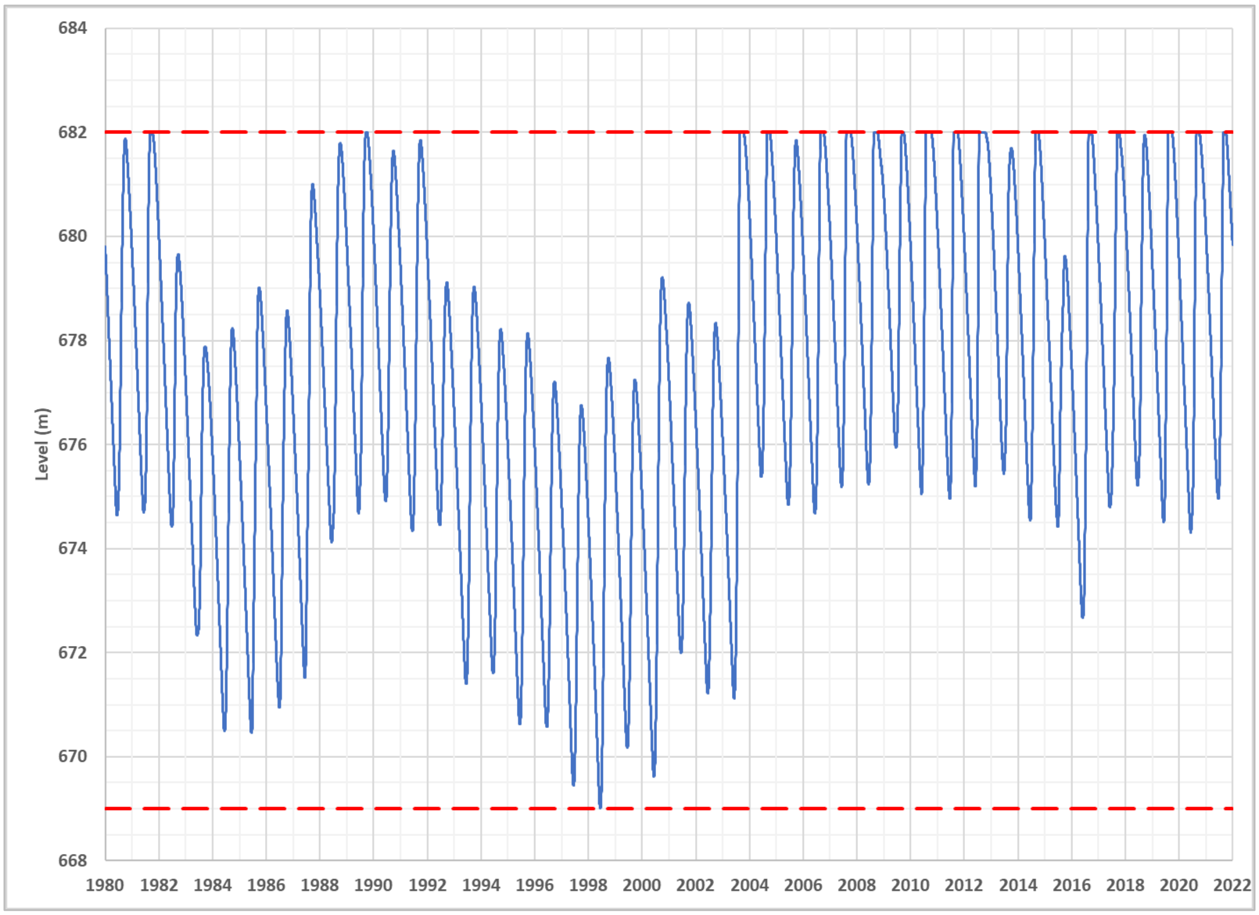

Figure 4-1: Site 06.g – Water Levels for the Period 1980-2021- Base Case - Firm Power Available of 176 MW

4.1.2 Historical Data – Trendless Inflows Series

As mentioned previously, two "trendless" series have been reconstituted to "minimize" the trend observed on the historical annual runoff volume. Since the critical period for the historical data was observed during the 1980's, it is expected that the impact on the firm power generation will be significant.

Table 4-2 present the results of the energy analysis for inflow series, RS1. Only the results for the first "trendless" series are presented since the results for RS2 are quite similar to those of RS1.

Table 4-2: Trendless Inflows Series – Energy Analysis Results – 1980-2021

Storage Scenario (1)	Sub-catchment Inflow Considered (2)				Firm Power (MW) (3)	Difference with base case (MW)	Firm Energy (GWh/y)	Average Energy (GWh/y)	Secondary Energy (GWh/y)
	I	II	III	IV					
Reconstituted daily inflows series – Firm at 100%									
1	1	1	1	1	196	+20 (+11%)	4723	4716	7
2	1	1	1	1	200	+24 (+14%)	4800	4797	3
1	1	1	1	0	190	+14 (+8%)	4576	4562	14
2	1	1	1	0	193	+17 (+10%)	4645	4637	8
1	1	1	0	0	182	+6 (+3%)	4386	4366	20
2	1	1	0	0	184	+8 (+5%)	4437	4423	14
1	0	1	0	0	163	-13 (-7%)	3943	3907	36
2	0	1	0	0	165	-11 (-6%)	3994	3967	27
Reconstituted daily inflows series – 1 Year with deficit									
1	1	1	1	1	198	+22 (+13%)	4746	4740	6
2	1	1	1	1	201	+25 (+14%)	4818	4816	2
1	1	1	1	0	191	+15 (+9%)	4585	4572	13
2	1	1	1	0	194	+18 (+10%)	4662	4656	6

(1) 1 means Lake Imarsuaq (Big Lake) without L682
2 means Lake Imarsuaq (Big Lake) with L682

(2) 1 means the sub-catchment inflow is considered, 0 is not.
Sub-catchment 06.g.II is always considered in the analyses.

(3) Values are available firm rounded at the nearest MW.

The results for RS1 (Table 4-2) show an increase in firm power of about 24 MW (+14%) for the system parameters of the base case compared to the initial set of inflows (RS0). The increase of firm power for the other cases (in comparison with the same case considering RS0) is also around 20 MW.

Figure 4-2 illustrates the variation of the reservoir level for the base case considering the RS1 inflows series. The figure shows that the reservoir is empty before the flood of 2016 and was completely filled in 2012, i.e. a period of four years.

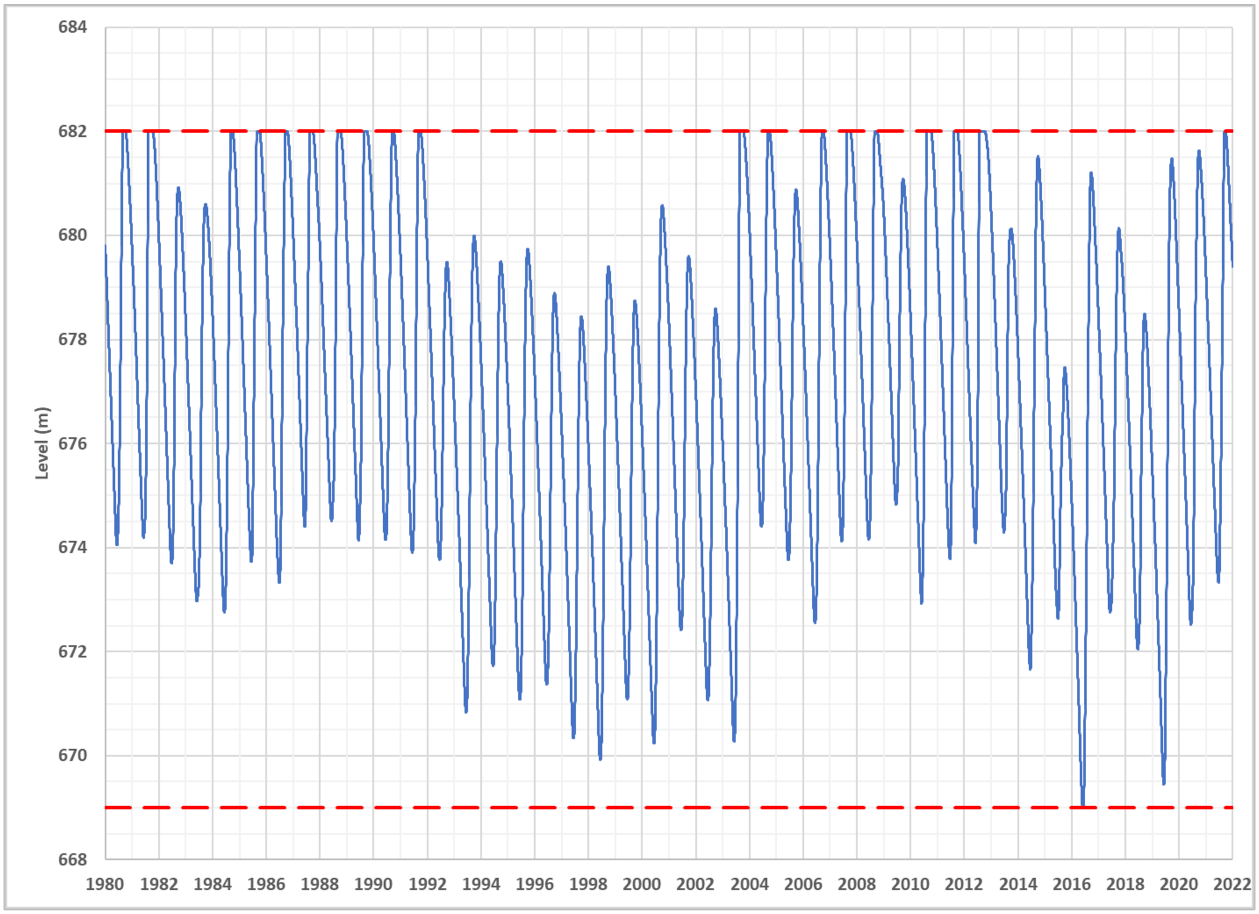

Figure 4-2: Site 06.g – RS1 – Water Levels for the Period 1980-2021 - Firm Power Available of 200 MW

4.2 Climate Change – 2031-2050 – RCP 4.5 and RCP8.5

The present section describes the results of the evaluation of the firm power based on the annual runoff volume estimated by ASIAQ for the period 2031-2050 [Ref 7]. The following points have been considered in the analysis:

- The climate change series are shorter than the initial series (20 years instead of 42 years (1980-2021)). The series are also shorter than what is normally used for this type of analysis (30 years and more), however this was the only information available at that moment. Furthermore, the critical period for the 1980-2021 series was in the 1980's, period not covered by the present sample. To determine the impact of the shorter period of analysis, the following approach was used:

    - The firm power was evaluated for the historical data for the period 1991-2010. The results of power generation for this period will be compared to the results obtained for the period 1980-2021 to evaluate the impact of the shorter period on the firm power.

    - The results for the different climate change conditions will be compared to the results obtain for the historical period 1991-2010 to determine the potential impact in the future.

- Two sets of annual inflows have been provided by ASIAQ for each climate change scenarios (RCP4.5 and RCP8.5). Both sets will be analysed to determine the potential impact on the firm power available.

- Two potential climate change conditions have been considered, i.e. for RCP4.5 and RCP8.5 based on the specific model used in the 2021 report. This is a limited sample of all possible scenarios;

- The reconstitution of the annual runoff volume is based on the observed conditions between 1991 to 2010, but it does not mean that the runoff will follow the same annual pattern. For example, the annual runoff for the second year of the 1991-2010 series was low, but it does not mean it will be similar to the second year of the 2031-2050 series;

- In the future, the daily flow pattern will be slightly different since the melting period will probably start earlier and will end later because of the increase in temperature. However, this aspect was not covered in the GEUS 2021 study [Ref 3]. For the energy analyses, the annual hydrographs were based on the shape of the observed hydrographs for the period 1991-2010 (ex. 1991 was used to reconstitute 2031, and so on) and the inflows have been corrected to obtain the annual volume provided by ASIAQ [Ref 7][Ref 8]. This assumption is conservative since the beginning of the Spring flood will be the same as the observed conditions.

4.2.1 Historical Data – Reconstituted Daily Inflows Series – 1991-2010

The firm power available based on the historical data for the period 1991-2010 is presented in Table 4-3. In comparison to the historical base case, the firm power is estimated to be 179 MW instead of 176 MW for the period 1980-2021 (see Table 4-1). The difference of about 3 MW is small and seems not to be a major concern for the following analyses.

It should be noted that firm powers considering one year with deficit are also in the same order of the results obtained for the period 1980-2021.

Figure 4-3 illustrates the variation of the water level in the reservoir over the period of analysis that concludes the lowest available firm power. For this scenario only inflow from sub-catchment 06.g.II is considered along with Big Lake without L682 that resulted 145 MW. The figure shows that the reservoir is almost empty in 1998 (and 2000) and it was full after the 1991 flood.

Table 4-3: Site 06.g - ASIAQ - Historical Data – Energy Simulation Results – 1991-2010

Storage Scenario (1)	Sub-catchment Inflow Considered (2)				Firm Power (MW) (3)	Difference with base case (MW)	Firm Energy (GWh/y)	Average Energy (GWh/y)	Secondary Energy (GWh/y)
	I	II	III	IV					
Reconstituted daily inflows series – Firm at 100%									
1	1	1	1	1	175	-1 (-1%)	4226	4195	31
2	1	1	1	1	179	+3 (+2%)	4314	4294	20
1	1	1	1	0	169	-7 (-4%)	4089	4054	35
2	1	1	1	0	173	-3 (-2%)	4167	4145	22
1	1	1	0	0	161	-15 (-9%)	3912	3871	41
2	1	1	0	0	165	-11 (-6%)	3980	3955	25
1	0	1	0	0	145	-31 (-18%)	3525	3477	48
2	0	1	0	0	148	-28 (-16%)	3575	3547	28
Reconstituted daily inflows series – 1 Year with deficit									
1	1	1	1	1	176	0 (0%)	4239	4210	29
2	1	1	1	1	179	+3 (+2%)	4318	4298	20
1	1	1	1	0	170	-6 (-3%)	4103	4070	33
2	1	1	1	0	173	-3 (-2%)	4174	4153	21

(1) 1 means Lake Imarsuaq (Big Lake) without L682
2 means Lake Imarsuaq (Big Lake) with L682
(2) 1 means the sub-catchment inflow is considered, 0 is not.
Sub-catchment 06.g.II is always considered in the analyses.
(3) Values are available firm rounded at the nearest MW.

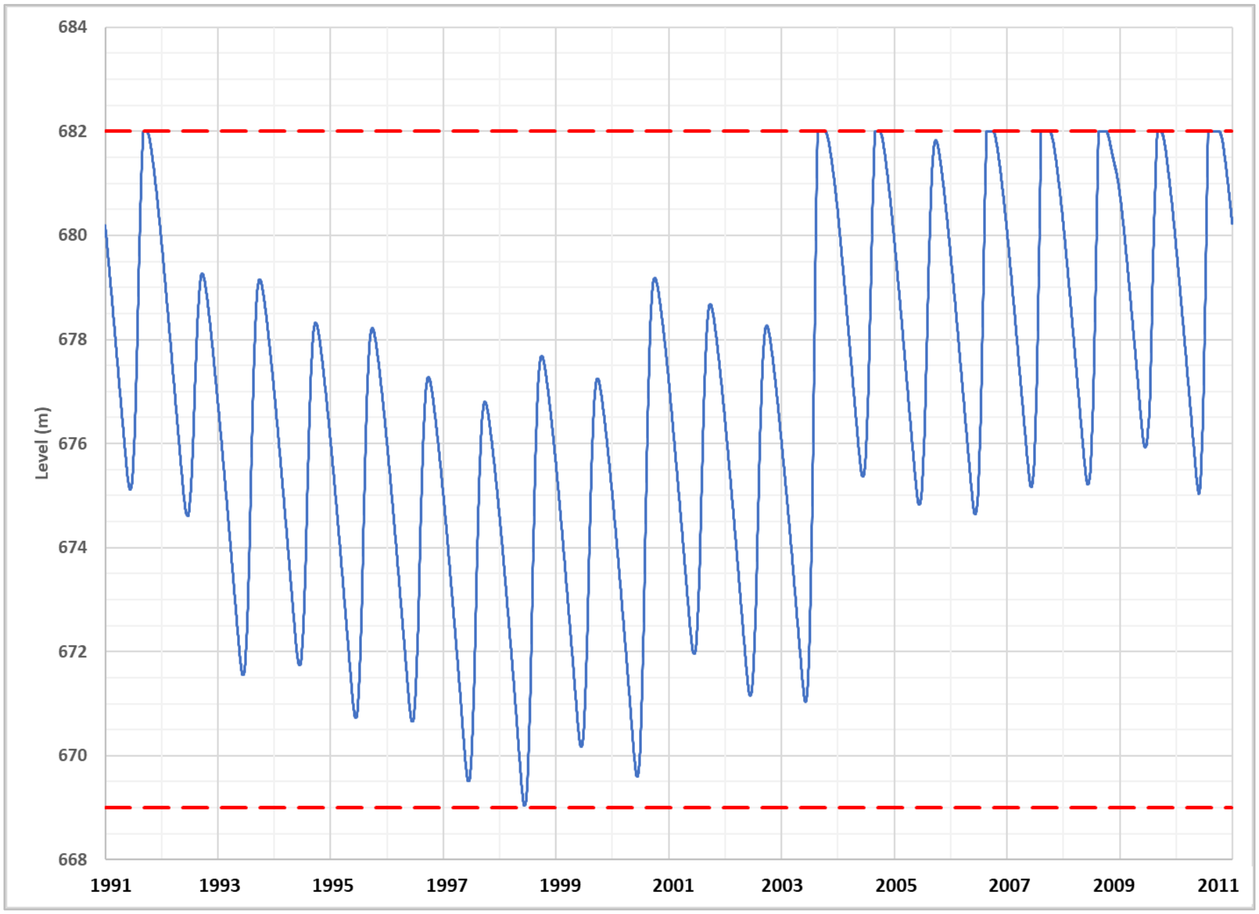

Figure 4-3: Site 06.g - Historical Inflows – Water Levels for the Period 1991-2010- Base Case - Firm Power Available of 179 MW

4.2.2 Climate Change - First Reconstituted Series – 2031-2050

As mentioned previously, ASIAQ provided two sets of annual runoff volume representing climate conditions for the period 2031-2050 based on the conditions observed for the period 1991-2010. Figure 2-9 shows the annual volume for following series:

- For the period 2031-2050 considering RCP4.5 (blue line);
- For the period 2031-2050 considering RCP8.5 (red line).

The linear trends are presented with the dotted lines. It occurs that the trend observed for the two series representing climate change are different. The trend observed for the RCP8.5 is similar to the trend of the historical data (increasing), while the trend for the RCP4.5 series is going in the other direction (decreasing).

Table 4-4 presents the firm available power for both series (i.e. RCP4.5 and RCP8.5). It shows:

- A significant increase of the firm power for each case.

- For the base case, the increase is about 39% for the first set of inflows (245 MW for RCP4.5) and 42% for the second one (250 MW for RCP8.5);
- For most of the cases, the firm power increases by 50 MW;
- The critical period is shorter and the reservoir is full at the end of the flood season for most of the years (see Figure 4-4).

These increases can be explained by the fact that the annual runoff volume is in general significantly higher than the historical values (for most of the years). However, a low annual volume of inflows, such as 2035 (see Figure 2-9) can lead to an empty reservoir before the starts of the new flood period.

Table 4-4: Site 06.g - ASIAQ – Climate Change – 2031-2050

Storage Scenario (1)	Sub-catchment Inflow Considered (2)				Scenario RCP4.5		Scenario RCP8.5	
	I	II	III	IV	Firm Power (MW) (3)	Difference with base case (MW)	Firm Power (MW) (3)	Difference with base case (MW)
Reconstituted daily inflows series – Firm at 100%								
1	1	1	1	1	229	+53 (+30%)	233	+57 (+32%)
2	1	1	1	1	245	+69 (+39%)	250	+74 (+42%)
1	1	1	1	0	224	+48 (+27%)	228	+52 (+30%)
2	1	1	1	0	241	+65 (+37%)	245	+69 (+39%)
Reconstituted daily inflows series – 1 Year with deficit								
1	1	1	1	1	250	+74 (+42%)	246	+70 (+40%)
2	1	1	1	1	255	+79 (+45%)	263	+87 (+49%)
1	1	1	1	0	242	+66 (+38%)	240	+64 (+36%)
2	1	1	1	0	246	+70 (+40%)	257	+81 (+46%)

(1) 1 means Lake Imarsuaq (Big Lake) without L682
2 means Lake Imarsuaq (Big Lake) with L682
(2) 1 means the sub-catchment inflow is considered, 0 is not.
Sub-catchment 06.g.II is always considered in the analyses.
(3) Values are available firm rounded at the nearest MW.

Figure 4-4 illustrates the variation of the water level in the reservoir, over the period of analysis, corresponding to the available firm power. For this scenario inflows, from all sub-catchments are considered and with L682, the firm power is 250 MW. The figure shows that the reservoir is full after the 2034 flood period and is almost empty before the 2036 flood period; which means that the low flood volume observed in 2035 was the main factor to determine the firm power of the system. This figure shows also that, under the “future” hydrology, it takes less than two years before reaching the bottom of the reservoir. This can be caused by the increase of the annual firm power in the system, which depletes more quickly the live storage in the reservoir (which is remaining the same).

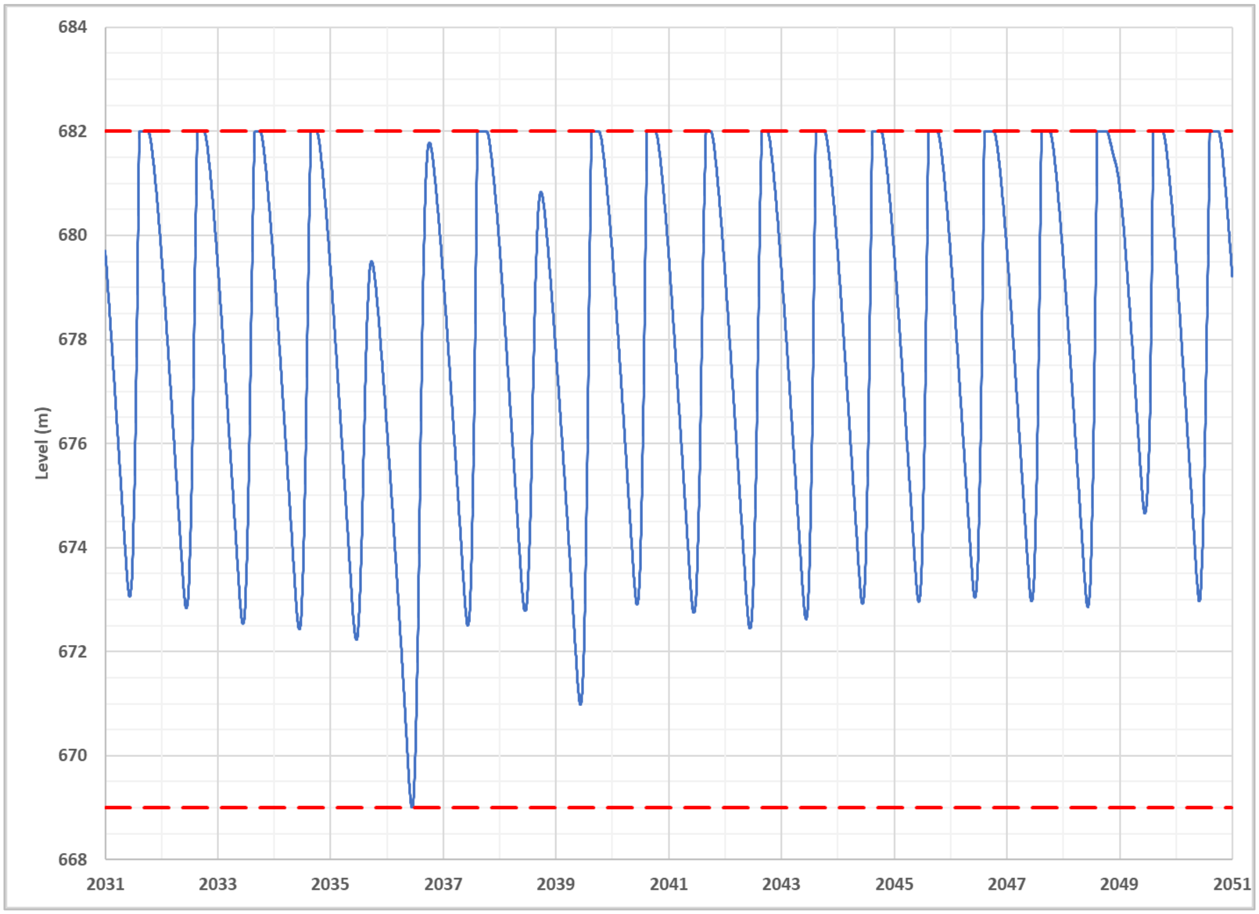

Figure 4-4: Site 06.g - First Reconstitution – RCP8.5 –
Water Levels for the Period 2031-2050 - Firm Power Available of 250 MW

4.3 Comments on the Results

Based on the main trends observed about the annual runoff volume in Greenland and other regions of the world with similar conditions, it seems to have a general consensus that the historical runoff data are not representative of the future conditions expected over the next 30 years.

A firm power of 176 MW for the period 1980-2021 appears realistic. The trendless series on the same period gives a firm power of about 200 MW, which seems more representative of the present conditions considering the second half of the historical series.

The sensitivity analysis performed on the period 1991-2010 with the historical data shows an increase of 3% of the firm power (in comparison to the 1980-2021 period), which is small. However, the total duration of the climate change sample is short, only 20 years, for this type of study and could not reflect the overall variability in the hydrology of the system. This emphasizes the importance of eliminating the bias of conducting analyses with insufficiently long time series and their impact on the confidence in the obtained results.

About the climate change series for the period 2031-2050, the results are in line with the annual volume of water available at the site, since it is based on a detailed study performed by GEUS [Ref 3]. The firm powers estimated vary around 240 MW, which seems realistic based on the information available. However, there are several factors and unknowns to consider in such a study and the firm power estimated for the period 2031-2050 must be considered with caution.

The annual runoff volume should remain higher than the average historical values (particularly the period 1980 to 2000), but the trend is not clear (as shown for RCP4.5 and RCP8.5 on Figure 2-9) and the annual runoff volume variability is also a factor difficult to qualify. For example, independent event (volcanic eruption or other) can have an impact on solar radiation on the ground and ice melt, which will reduce the annual runoff on one or more consecutive years. The probabilities related to such events are unknown, but some of them were already observed.

5. New Climate Change Scenarios – Results Analyses

ASIAQ was mandated in 2023 to prepare new climate change scenarios covering a longer period until 2100 and based on the latest relevant scientific information available [Ref 4].

This section presents the main results of the firm power evaluation performed considering the new climate change scenarios. The main characteristics of the climate change scenarios prepared by ASIAQ were presented in Section 2.5.2. This section presents the methodology used for the energy study and elaborates on the validation of the model. The results of the firm power analyses are presented with an analysis of the potential risk related to the determination of the firm power at Site 06.g.

5.1 Methodology

The methodology applied for the energy analysis of the new scenarios is similar to the methodology described in the Section 3.1. However, some modifications have been performed:

- Based on ASIAQ recommendations, the same monthly pattern distribution (in %) is used for each year. Previously, historical monthly flow patterns have been used over the period of analysis;
- ASIAQ presented two sets of annual runoffs for each studied climate change scenario, i.e. with minimum and maximum adjustment factor. For the present study, an average adjustment factor is used for each scenario (as mentioned in Section 2.5.2);
- Analyses are performed considering that runoff from the four catchments are available;
- The daily discharge during each month is assumed to be constant. In the previous study an arbitrary daily distribution was adopted to mimic a typical hydrograph. Considering the size of the reservoir (multi-annual storage capacity), it is not considered required to use an arbitrary pattern for the daily inflows;
- Considering the total duration of the new inflow scenarios, analysis periods of 30 years are used instead of the 20 years periods used for the first two scenarios (which corresponded to the total length of the available series). A period of 30 years is considered more appropriate for energy analysis to assess the impact of hydrological trends on the power generation;
- Analyses are performed with the characteristics of the base case considered for the first two scenarios, which are:
    - Reservoir: Lake Imarsuaq (Big Lake) without L682
    - Inflow: sub catchments Lower Lake (I), Big Lake (II), NE sub-catchment (III), and SE sub-Catchment (IV)
    - Maximum reservoir level: El. 682 m;

- Minimum reservoir level: El. 669 m;
- Maximum drawdown: 13 m;
- Number of units: 2.

Analyses are performed on four different periods to evaluate the impact of the climate change trends over time and for comparison purposes with the results obtained for the first two scenarios. These periods are:

- 2031-2050 (comparison with the results of the first two scenarios);
- 2031-2060;
- 2051-2080;
- 2071-2100.

The period 2023 to 2030 is not considered since it is unlikely that a future project will be fully operational before 2030.

5.2 Validation

To evaluate the impact of the revised methodology, firm power for the cases previously analysed (Section 4) have been estimated using the same inflow series for the period 2031-2050. The results are presented in Table 5-1.

Table 5-1: Site 06.g Comparison of Firm Power (100%) – Initial Methodology vs. Updated Methodology

Climate Change Scenario	Period	Initial approach	Updated approach	Difference	
		(MW)	(MW)	(MW)	%
Historical Data (Base Case)	1991-2010	175	176	+1	+0.7 %
RCP 4.5 – reconstitution 1	2031-2050	229	233	+4	+1.5%
RCP 8.5 – reconstitution 1		233	237	+4	+1.6%

The results obtained are slightly higher than the results of presented in section 4.2. This difference can be explained by the adopted changes in the monthly and daily inflows pattern.

Taking into account the uncertainties associated with the assumptions made in the 2023 and 2024 studies, the results are considered in a similar range. The updated methodology is therefore compatible with the initial methodology used for the period 2031-2050 and could be applied in the present study based on extended future annual runoff series covering the period 2031-2100.

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5.3 Results

Table 5-2 presents the firm power for each scenario and analysis period. The main aspects to consider from this table are presented below:

1. For the period 2031-2050, the firm power estimated for the new scenarios are lower than the firm power estimated for the first two climate change scenarios. The difference varies between 15 and 35 MW depending on the scenarios. Different causes can explain these differences, such as:

   - The average runoff for the new scenarios is lower for the same analysis period;

   - The variability of the annual runoff for the new scenarios, such as:

     - longer duration of a dry period; or

     - driest critical period.

   Figure 5-1 illustrates the difference between the annual runoff for two scenarios, i.e. one initial scenario (in green) and one new scenario (in blue).

2. The firm power estimated for the 2031-2050 period and the 2031-2060 period are the same, since the critical period for each scenario occurs before 2050.

3. It is expected that the firm power will increase slightly after 2050 as shown by the results for period 2051-2080 and 2071-2100 due to the trend observed in the annual runoff;

4. The duration of the critical period for the system is about two to three years (i.e. the duration from when the reservoir is full to when it becomes empty coincides with the generation of firm power).

Figure 5-2 illustrates the probability of exceedance, based on the number of climate scenarios, of the firm power for different periods. This figure illustrates the quantification of the risk related to the selection of the firm power for a future project. Analyses performed on the 2031-2060, 2051-2080 and 2071-2100 periods provide the expected range for the firm power based on the available scenarios. The 2031-2050 trend differs from the other periods since it includes the initial results for the RCP 4.5 and RCP 8.5 scenarios. Since these two values are higher than the results obtained for the new scenarios, the results of the first half of the curve are higher than the results obtained for the 2031-2060 period. As Figure 5.2 illustrates, the main risk of deficit will be in the first 20 years, which therefore is also the most critical period for a new project.

Figure 5-3 illustrates the correlation between the average annual runoff for the period of analysis and the firm power. Results for the three periods of analysis have been combined to increase the number of points for the analysis. There is a good correlation between these two variables ($R^2 = 0.86$), even though if the average runoff does not take directly into account the annual variability of the inflows. The good correlation can be explained by the fact that the system is multi-annual, and it takes more than one year to empty the reservoir if the system is operating at the firm power.

Table 5-2: Site 06.g - Firm Power (100%) for Different Climate Change Scenarios Lake Imarsuaq (Big Lake) without L682

Climate Change Scenario	Period	Average Runoff (m^3/s)	Firm Power (MW)	Difference with base case	
				(MW)	(%)
Historical Data (Base Case) *	1991-2010 (20 years	34.3	176	---	---
RCP 4.5 – reconstitution 1 *	2031-2050 (20 years)	53.1	233	57	32.4%
RCP 8.5 – reconstitution 1 *		52.0	237	61	34.7%
ASIAQ 2023 - SSP126_CC_MAR		46.9	222	46	26.1%
ASIAQ 2023 - SSP245_CC_MAR		41.4	213	37	21.0%
ASIAQ 2023 - SSP585_CC_MAR		47.2	214	38	21.6%
ASIAQ 2023 - SSP126_ME_MAR		37.8	203	27	15.3%
ASIAQ 2023 - SSP245_ME_MAR		42.2	215	39	22.2%
ASIAQ 2023 - SSP585_ME_MAR		40.6	219	43	24.4%
ASIAQ 2023 - SSP126_CC_MAR	2031-2060 (30 years)	47.0	222	46	26.1%
ASIAQ 2023 - SSP245_CC_MAR		42.4	213	37	21.0%
ASIAQ 2023 - SSP585_CC_MAR		48.7	213	37	21.0%
ASIAQ 2023 - SSP126_ME_MAR		39.3	203	27	15.3%
ASIAQ 2023 - SSP245_ME_MAR		42.9	215	39	22.2%
ASIAQ 2023 - SSP585_ME_MAR		41.8	219	43	24.4%
ASIAQ 2023 - SSP126_CC_MAR	2051-2080 (30 years)	45.4	234	58	33.0%
ASIAQ 2023 - SSP245_CC_MAR		48.3	223	47	26.7%
ASIAQ 2023 - SSP585_CC_MAR		61.2	265	89	50.6%
ASIAQ 2023 - SSP126_ME_MAR		39.5	209	33	18.8%
ASIAQ 2023 - SSP245_ME_MAR		44.3	221	45	25.6%
ASIAQ 2023 - SSP585_ME_MAR		49.9	235	59	33.5%
ASIAQ 2023 - SSP126_CC_MAR	2071-2100 (30 years)	47.2	216	40	22.7%
ASIAQ 2023 - SSP245_CC_MAR		53.9	234	58	33.0%
ASIAQ 2023 - SSP585_CC_MAR		82.5	313	137	77.8%
ASIAQ 2023 - SSP126_ME_MAR		41.3	222	46	26.1%
ASIAQ 2023 - SSP245_ME_MAR		46.0	247	71	40.3%
ASIAQ 2023 - SSP585_ME_MAR		59.7	282	106	60.2%

* Initial scenario

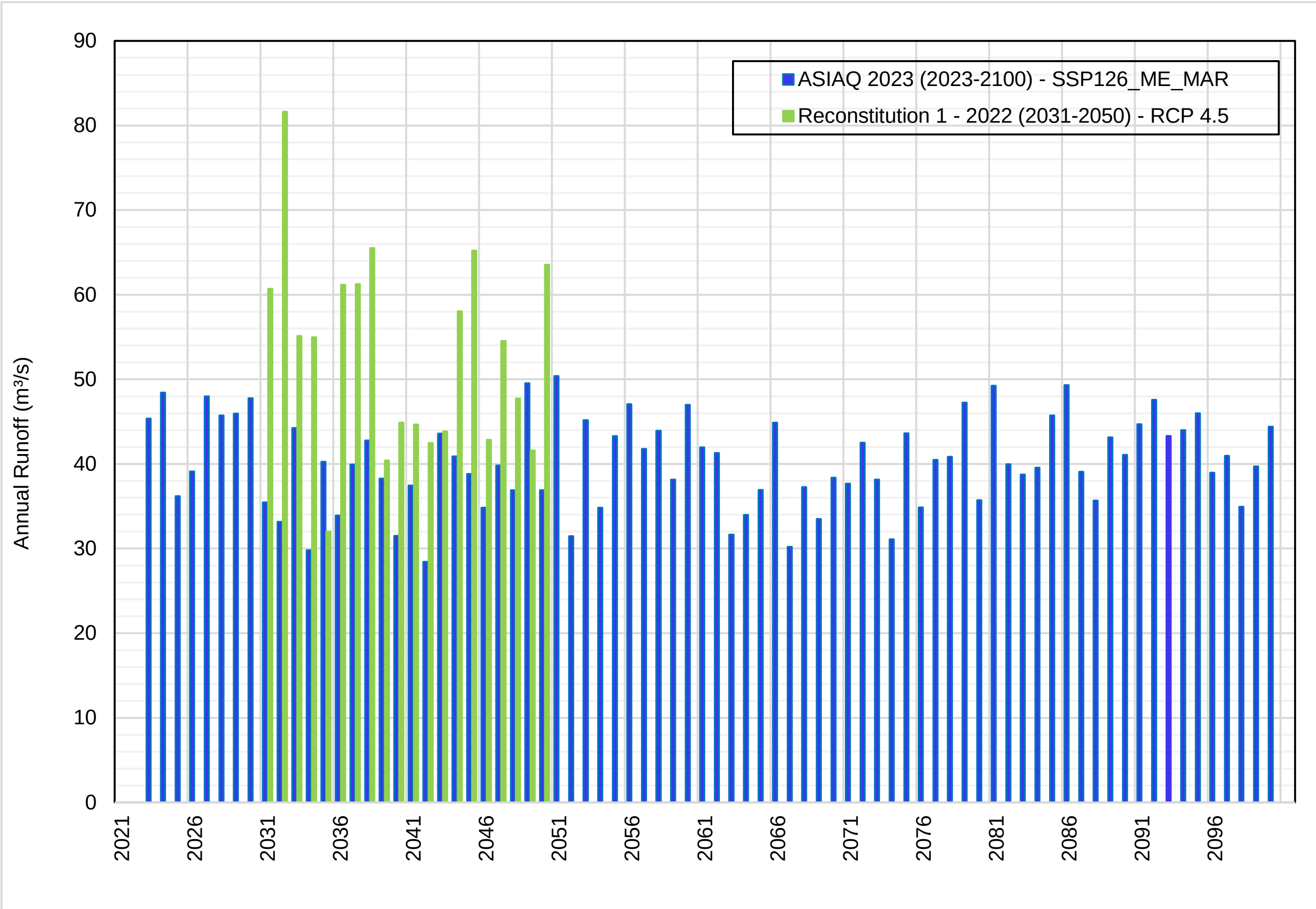

Figure 5-1: Site 06.g – Comparison of Annual Runoff for an Initial Scenario (green) and a New Scenario (blue)

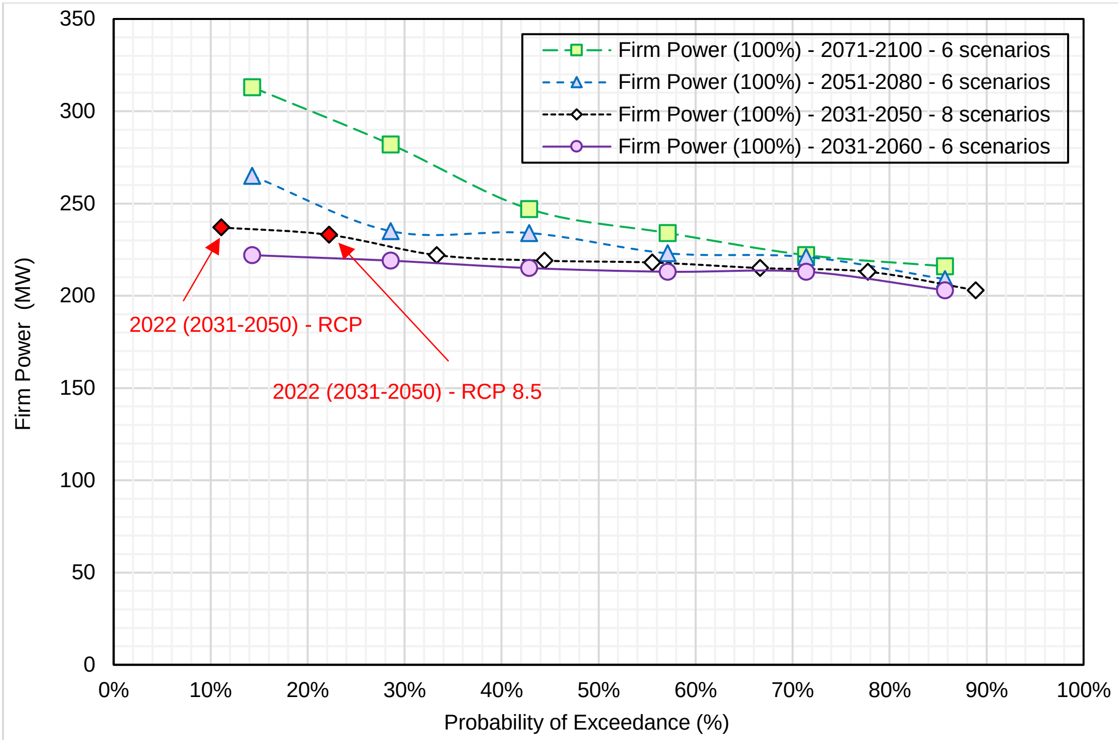

Figure 5-2: Site 06.g - Probability of Exceedance of Firm Power (100%) vs Period of Analysis

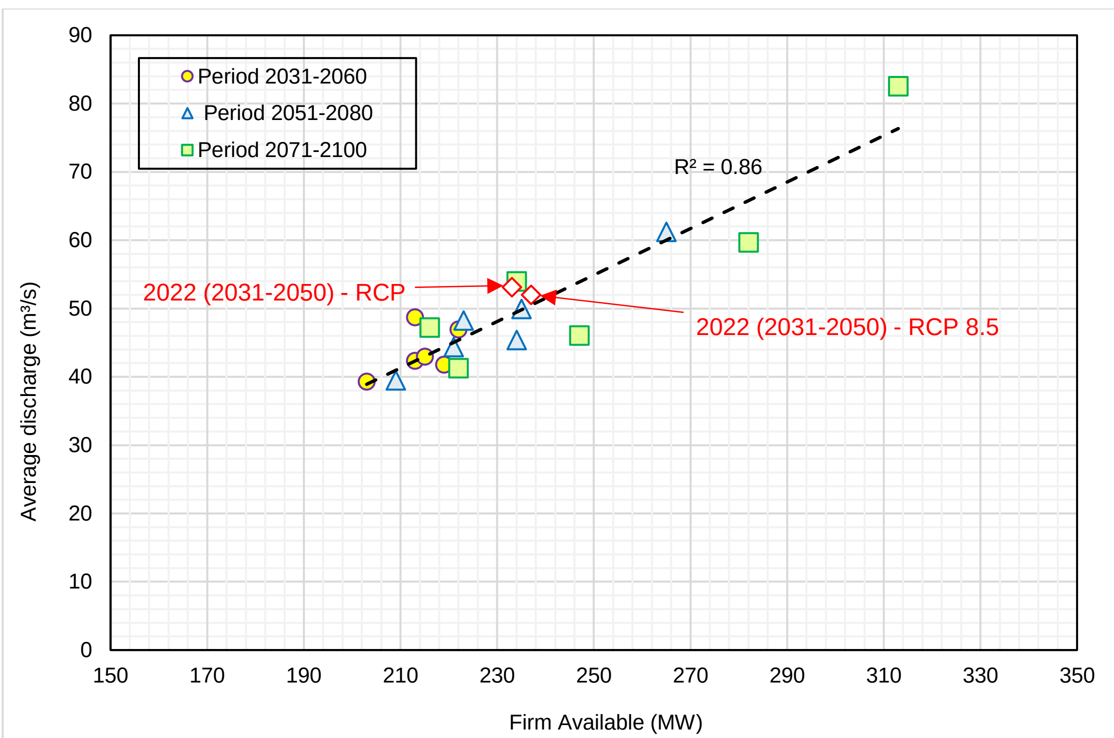

Figure 5-3: Site 06.g - Firm Power (100%) vs Average Runoff Period 2031-2060, 2051-2080, 2071-2100

Appendix C presents the results of a sensitivity analysis performed for two alternatives considered in the initial study, considering one year of deficit over the period of analysis (20- or 30-years period).

The sensitivity analysis was performed for the 2031-2050, 2031-2060, 2051-2080, and 2071-2100 periods. For these alternatives the firm power increases, but the decision depends on the increases in cost (or generation losses in case of deficit) vs the potential increase of benefits due to a higher risk of deficit.

Figure 5-4 shows the probability of exceedance of the firm power for the 2031-2050 period for the firm power at 100% considering the Lake Imarsuaq (Big Lake) without L682 mentioned hereabove. The trends are similar for each alternative and the difference of firm power with the initial series varies between 1 MW to 22 MW. The choice of the best “firm power” to be installed will be based on the results of an economic analysis for a specific project.

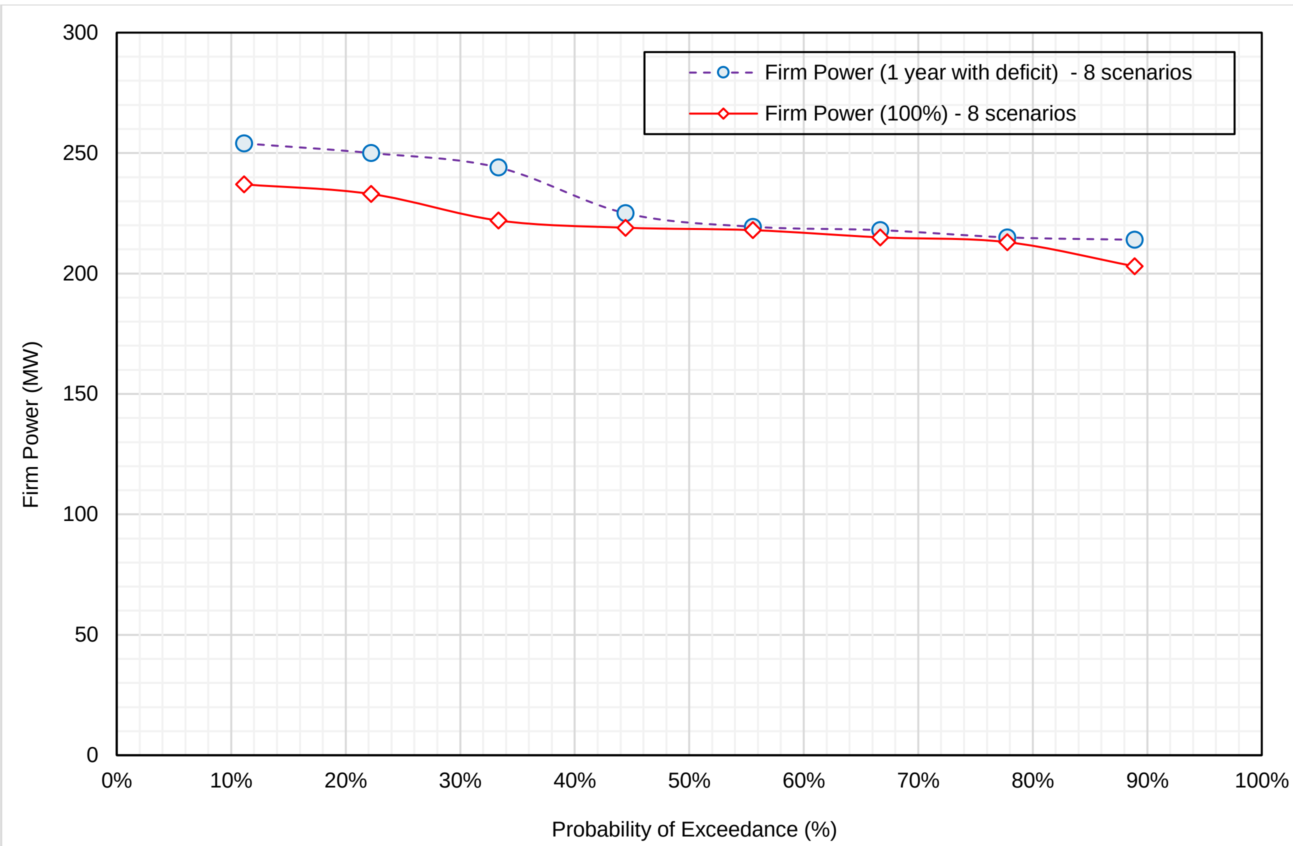

Figure 5-4: Site 06.g - Probability of Exceedance of Firm Power Based on Different Assumptions - Period 2031-2050

5.4 Comments on the Results

The energy analyses based on the two initial scenarios (as presented in Section 4-2) concluded that the firm power for the base case was exceeding 230 MW for the 2031-2050 period. The results based on the new climate change scenarios indicate that this estimate was “optimistic” for that period. Adding the two 2023 scenarios to the new scenarios, the firm power for the period 2031-2050 based on a 50% level of exceedance (scenario presenting median results) is estimated to be about 218 MW with range in the results between the studied climate scenarios from -7% to +9%. Analyses performed on the periods 2031-2060, 2051-2080 and 2071-2100 indicate that the firm power based on a 50% level of exceedance (median results) is estimated to be around 214 MW (range -5% to 4%), 228 MW (range -8% to 16%) and 240 MW (range -10% to 30%) respectively.

The results of the new climate change scenarios allowed the qualification of the results obtained with the initial climate change scenarios. The increase of the number of climate scenarios and the corresponding firm power analyses provides a better understanding of the potential range of installed capacity for this project, considering the uncertainties associated with the future inflows forecast.

Results have shown a good correlation between the average annual inflows of each scenario on a 30-years period and the firm power of the system – based on the assumptions considered in the Section 5.1. This approach can help to quickly estimate the potential impact of new climate change scenarios in the future.

As mentioned in the Section 4.3, the firm power estimated for the near future (ex. period 2031-2050) must be considered with caution since the results are representative of the information available. The results presented in this section are based on extended data and give a better understanding of the confidence interval on the firm power of the system. However, it is noted that uncertainties about the impact of climate change in the future remain. Furthermore, independent events (such as a volcanic eruption) can have an impact on the climate and impact the runoff volumes conditions for one year or more as it was already recorded in the past. The impacts of such an event are not considered in the present study.

6. Conclusions and Recommendations

The main objective of the present report consists of determining the firm power available at Site 06.g taking into account the uncertainties in the future inflows mainly caused by climate change. For these purposes, different climate change scenarios have been analysed to assess the impact on the firm power over different periods of analysis.

The study was divided in two phases, a first one based on two inflows scenarios for the period 2031-2050 and a second one taking into account six new inflows scenarios covering the period 2023-2100. The analyses were performed on a period of 20 or 30 years depending on the duration of the inflows series and to evaluate the impact of climate change on the firm power over the years. A period of 30 years is normally considered as the minimum duration considered for this type of study to take into account the variability of the hydrology in the system.

At this stage of the project, each climate change scenario is considered as equiprobable. It means that the choice of the firm power for a specific project must be based on the economic analysis of the project and take into account the probability that the firm power will not be met during some years (or part of the year, i.e. until the next Spring flood occurs).

Table 6-1 presents the minimum, the maximum and the 50% probability of exceedance (median scenario) of the firm power based on the inflows scenarios available for the different period of analysis.

Table 6-1: Site 06.g - Firm Power (100%) – Summary of the Results

Period	Number of scenarios	Firm Power (MW)		
		Minimum	50% probability of exceedance	Maximum
Historical	1	N/A	176	N/A
2031-2050	8	203	218	237
2031-2060	6	203	214	222
2051-2080	6	209	228	265
2071-2100	6	216	240	313

The main elements to consider from this table:

- The trend of the firm power seems to increase for the future. For the 50% probability of exceedance (corresponding to the median results), the increase in firm power is about 40 MW between the evaluation based on the historical data and the results for the period 2031-2060. It continues to increase for the period 2051-2080 and 2071-2100;

- The results for the period 2031-2050 are higher than the results for the period 2031-2060, since the two initial scenarios are considered only for the period 2031-2050 and the firm power for these scenarios are significantly higher than the others;

- The minimum firm power estimate for the different periods remains similar. It corresponds to the results of the scenario SSP126_ME_MAR. This scenario shows almost no increase of the annual volume of inflows in the future, which explains the almost constant value.

We recognize the difficulty to calibrate climate models and generate annual hydrographs for the study area, considering that the majority of the inflow comes from glacier melting which is a complex phenomenon. For these reasons, the firm power estimated must be considered with caution; the results are representative of the information available, but it is difficult to assess their confidence interval, even with eight scenarios. Furthermore, independent events (such as volcanic eruption) can have an impact on the climate and changes the conditions for one year or more, impact not considered in the present study.

7. REFERENCES

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APPENDIX A :
SITE 06.G
INITIAL SCENARIOS
MEAN MONTHLY INFLOWS

Table A-1: Mean Monthly Inflow in Reconstituted Flow Series-0 (RS0)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1980	1.7	0.8	0.8	1.0	1.7	26.8	107.4	130.0	66.5	17.6	8.1	5.2	30.6
1981	2.5	0.9	0.5	0.8	3.5	26.8	136.9	137.8	51.2	22.2	9.3	4.5	33.1
1982	1.7	0.7	0.3	0.1	0.1	7.7	86.1	125.2	40.3	14.5	6.8	3.7	23.9
1983	1.5	0.7	0.3	0.9	8.7	30.8	102.5	108.9	44.1	19.0	7.8	4.3	27.5
1984	1.5	0.7	0.3	0.8	6.1	35.8	116.0	122.0	55.4	19.7	7.9	4.4	30.9
1985	1.6	0.8	0.3	0.6	3.4	39.1	125.2	135.1	60.0	16.7	7.8	3.7	32.9
1986	1.7	0.9	0.3	0.5	1.4	5.7	88.7	130.5	92.1	31.3	11.1	5.3	30.8
1987	2.8	1.4	0.6	0.5	2.0	54.7	120.5	165.9	50.8	15.3	9.1	8.3	36.0
1988	4.2	2.1	2.8	2.9	5.3	31.5	91.8	150.8	68.3	22.7	9.7	5.8	33.2
1989	2.9	1.4	0.5	0.2	0.5	36.8	121.5	128.1	50.1	21.2	10.1	6.4	31.7
1990	3.3	1.5	0.6	0.3	0.6	33.0	110.8	118.7	46.7	19.9	9.8	6.5	29.3
1991	3.6	1.7	0.7	0.3	0.6	34.4	117.6	128.0	50.7	21.7	11.0	7.7	31.5
1992	4.1	1.9	0.8	0.4	0.7	26.1	88.5	93.1	37.0	15.9	8.5	6.1	23.6
1993	4.1	1.9	0.9	0.4	0.7	33.8	117.1	125.1	50.0	21.6	11.9	8.8	31.4
1994	4.5	2.1	0.9	0.5	0.8	29.7	105.1	114.2	45.9	19.9	11.3	8.6	28.6
1995	4.8	2.2	1.0	0.5	0.8	30.9	111.8	123.4	49.9	21.8	12.8	9.9	30.8
1996	5.2	2.4	1.1	0.6	0.9	29.0	104.8	111.6	45.2	19.7	12.2	9.5	28.5
1997	5.4	2.4	1.2	0.6	0.9	29.2	108.5	117.4	47.8	21.0	13.3	10.6	29.9
1998	5.6	2.5	1.2	0.7	0.9	31.4	119.4	131.4	53.8	23.7	15.5	12.5	33.2
1999	5.9	2.7	1.3	0.7	1.0	26.6	104.2	116.6	48.0	21.3	14.2	11.7	29.5
2000	6.4	2.9	1.4	0.8	1.1	33.0	130.1	140.3	57.7	25.6	18.1	14.8	36.0
2001	6.6	3.0	1.5	0.8	1.1	25.3	102.8	112.8	46.5	20.8	15.0	12.4	29.1
2002	7.0	3.1	1.6	0.9	1.1	24.9	104.7	116.8	48.4	21.7	16.0	13.4	30.0
2003	7.0	3.1	1.6	0.9	1.1	39.6	172.1	195.3	81.3	36.7	27.7	23.4	49.2
2004	7.6	3.4	1.8	1.0	1.2	25.9	113.8	124.7	51.7	23.5	18.6	15.6	32.4
2005	7.8	3.5	1.9	1.0	1.2	22.9	104.4	116.4	48.4	22.1	17.8	15.1	30.2
2006	7.8	3.5	1.9	1.1	1.2	27.0	128.5	145.8	60.9	27.9	23.0	19.6	37.3
2007	8.1	3.6	1.9	1.1	1.2	28.6	142.2	164.2	68.7	31.7	26.6	22.8	41.7
2008	8.4	3.7	2.0	1.1	1.2	26.7	134.8	150.6	62.6	29.2	25.5	21.6	39.0
2009	8.9	4.0	2.2	1.2	1.2	20.8	110.3	125.6	48.9	17.6	8.8	4.3	29.5
2010	2.2	1.3	0.8	0.4	10.0	91.7	191.6	215.4	129.4	24.8	9.9	6.2	57.0
2011	2.7	1.6	1.2	0.7	0.3	18.0	190.4	189.4	90.9	19.0	7.6	4.5	43.9
2012	2.2	1.2	0.7	3.4	9.8	87.1	257.0	201.0	67.0	34.7	22.1	9.8	58.0
2013	4.3	1.6	0.5	0.0	0.1	10.9	75.6	155.2	49.3	25.1	10.9	6.7	28.4
2014	2.6	0.7	0.1	0.0	0.3	27.5	123.5	178.8	84.7	19.9	7.4	3.6	37.4
2015	2.3	2.2	1.4	0.8	0.6	5.0	90.4	86.0	77.3	22.1	9.5	4.5	25.2
2016	1.5	0.4	0.1	0.4	12.4	73.0	166.3	171.7	67.4	13.6	7.3	4.1	43.2
2017	2.5	1.4	0.9	0.6	4.9	35.3	79.6	145.5	85.5	25.5	18.8	9.0	34.1
2018	3.7	1.9	0.7	0.1	0.1	17.5	116.0	130.5	46.6	15.6	6.6	3.1	28.5
2019	2.2	1.0	0.2	0.1	2.3	63.8	186.1	174.5	51.0	13.1	4.2	2.1	41.7
2020	1.2	0.5	0.1	0.0	1.0	30.9	136.5	155.5	74.4	20.7	12.0	6.4	36.6
2021	4.3	1.9	0.7	1.1	1.5	16.9	117.6	183.5	68.7	13.9	6.4	9.0	35.5
Mean	4.2	1.9	1.0	0.7	2.3	32.2	122.8	140.3	60.0	21.7	12.6	8.9	34.1

Table A-2: Mean Monthly Inflow in Reconstituted Flow Series-1 (RS1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1980	2.3	1.3	1.3	1.6	4.3	51.2	142.1	157.7	79.8	21.7	10.2	6.8	40.0
1981	3.7	1.6	1.0	1.4	6.6	50.6	176.5	164.0	64.5	27.2	11.9	5.9	42.9
1982	2.5	1.2	0.7	0.5	1.4	23.6	113.2	147.0	47.9	18.0	8.5	4.9	30.8
1983	2.3	1.2	0.7	1.5	14.3	50.2	129.9	125.9	51.1	23.2	13.1	7.4	35.1
1984	3.3	1.7	1.2	1.3	5.8	52.4	147.2	157.2	68.5	18.9	7.4	4.5	39.1
1985	3.1	1.6	1.1	1.3	5.6	60.4	159.3	159.2	69.8	19.8	9.4	4.7	41.3
1986	2.4	1.4	0.8	1.1	3.5	20.2	120.1	153.0	104.8	34.4	12.4	6.0	38.3
1987	3.7	2.0	1.1	1.1	5.0	77.9	152.3	189.9	59.8	18.5	11.4	10.8	44.5
1988	5.2	2.6	3.4	3.6	8.2	51.5	121.5	170.4	77.1	25.7	11.3	6.9	40.6
1989	3.6	1.8	1.0	0.7	3.0	55.1	149.1	146.6	58.3	23.8	11.6	7.0	38.5
1990	2.8	1.5	1.0	1.1	5.1	45.9	130.2	139.6	61.5	19.1	9.6	5.8	35.3
1991	3.1	1.6	1.1	1.2	5.4	49.2	139.0	148.7	65.6	20.4	10.2	6.2	37.6
1992	2.3	1.2	0.8	1.0	4.3	37.7	102.7	108.2	47.7	14.9	7.6	4.6	27.7
1993	3.0	1.6	1.0	1.1	5.2	47.7	135.9	145.8	64.3	19.9	10.0	6.1	36.8
1994	2.7	1.4	0.9	1.1	4.8	43.7	122.8	131.2	57.8	18.0	9.0	5.5	33.2
1995	2.8	1.5	1.0	1.1	5.0	45.9	131.1	140.9	62.1	19.3	9.6	5.8	35.5
1996	2.7	1.4	1.0	1.1	4.9	43.4	120.2	127.5	56.2	17.5	8.9	5.4	32.5
1997	2.8	1.5	1.0	1.1	5.0	44.5	124.8	133.1	58.7	18.3	9.2	5.6	33.8
1998	3.0	1.6	1.0	1.1	5.3	48.2	137.8	148.1	65.3	20.2	10.2	6.1	37.3
1999	2.6	1.4	0.9	1.0	4.7	42.8	121.0	129.5	57.1	17.7	8.9	5.4	32.8
2000	3.2	1.7	1.1	1.2	5.7	51.5	147.0	158.0	69.7	21.6	10.9	6.6	39.8
2001	2.6	1.3	0.9	1.0	4.6	41.5	117.0	125.0	55.1	17.1	8.6	5.2	31.7
2002	2.6	1.4	0.9	1.1	4.7	42.5	119.5	127.7	56.3	17.5	8.8	5.4	32.4
2003	4.2	2.2	1.4	1.5	7.1	66.6	196.5	213.8	94.3	29.1	14.5	8.7	53.3
2004	2.8	1.5	1.0	1.1	5.0	45.3	127.0	135.5	59.8	18.6	9.4	5.7	34.4
2005	2.6	1.4	0.9	1.1	4.7	42.1	117.1	124.5	54.9	17.1	8.7	5.3	31.7
2006	3.1	1.6	1.1	1.2	5.4	49.9	144.2	155.8	68.7	21.3	10.7	6.4	39.1
2007	3.4	1.8	1.1	1.3	5.9	55.1	160.2	173.4	76.4	23.6	11.8	7.1	43.4
2008	3.0	1.6	1.0	1.2	5.4	49.2	141.0	151.7	67.5	23.4	19.5	16.3	40.1
2009	7.6	3.6	2.1	1.5	3.3	33.3	113.3	117.2	46.5	16.6	8.4	4.4	29.8
2010	2.4	1.5	1.1	0.8	11.3	100.9	197.6	206.4	120.5	24.4	10.1	6.3	56.9
2011	3.0	1.9	1.4	1.1	2.7	33.1	188.8	178.8	85.2	18.7	7.8	4.7	43.9
2012	2.3	1.4	0.9	3.2	11.0	97.8	254.1	194.3	67.4	32.9	20.5	9.4	57.9
2013	3.9	1.6	0.7	0.5	2.2	23.8	83.2	139.7	46.3	22.4	10.0	6.2	28.4
2014	2.6	0.9	0.5	0.5	2.6	40.2	128.4	165.4	77.9	19.1	7.5	3.9	37.4
2015	2.3	2.1	1.4	1.1	2.5	18.5	92.8	82.0	67.1	19.6	8.7	4.4	25.2
2016	1.8	0.7	0.4	0.8	13.0	80.2	167.8	162.6	64.9	14.2	7.6	4.4	43.2
2017	2.5	1.5	1.1	0.9	6.4	45.7	90.3	135.5	77.3	23.3	16.7	8.2	34.1
2018	3.5	1.9	0.9	0.6	2.3	29.5	115.9	119.6	44.1	14.8	6.5	3.3	28.6
2019	2.3	1.2	0.5	0.5	4.6	72.4	183.4	163.7	50.9	13.7	4.9	2.7	41.7
2020	1.5	0.8	0.4	0.5	3.2	43.2	138.7	145.2	68.9	19.6	11.2	6.1	36.6
2021	4.1	2.0	1.0	1.4	3.5	30.7	122.2	168.1	64.1	14.0	6.6	8.3	35.5
Mean	3.0	1.6	1.0	1.2	5.4	48.5	138.6	149.2	65.8	20.5	10.2	6.2	37.6

Table A-3: Mean Monthly Inflow in Reconstituted Flow Series-2 (RS2)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1980	1.8	0.9	0.8	1.0	1.8	33.1	132.6	160.6	82.1	21.7	10.0	6.4	37.7
1981	2.6	1.0	0.5	0.8	3.6	33.0	168.7	169.8	63.1	27.3	11.5	5.6	40.6
1982	1.7	0.7	0.3	0.1	0.1	9.5	106.0	154.2	49.6	17.8	8.4	4.6	29.4
1983	1.5	0.7	0.3	0.9	8.9	37.7	125.5	133.3	54.0	23.3	9.6	5.3	33.4
1984	1.6	0.7	0.3	0.8	6.2	44.0	142.8	150.2	68.2	24.3	9.7	5.4	37.9
1985	1.6	0.8	0.3	0.7	3.5	48.2	154.4	166.6	74.0	20.6	9.6	4.5	40.4
1986	1.7	0.9	0.3	0.5	1.4	7.0	109.6	161.2	113.7	38.7	13.8	6.6	37.9
1987	2.9	1.4	0.6	0.5	2.0	67.6	148.9	205.0	62.8	18.9	11.2	10.2	44.3
1988	4.3	2.2	2.9	3.0	5.4	38.8	113.0	185.7	84.1	27.9	11.9	7.2	40.5
1989	3.0	1.4	0.6	0.2	0.5	45.5	150.0	158.2	61.8	26.1	12.4	7.9	39.0
1990	3.4	1.6	0.7	0.3	0.6	40.7	136.6	146.3	57.6	24.5	12.1	8.0	36.0
1991	3.7	1.7	0.7	0.3	0.6	42.4	144.9	157.7	62.5	26.7	13.6	9.4	38.7
1992	4.2	1.9	0.8	0.4	0.8	32.0	108.6	114.3	45.4	19.5	10.4	7.4	28.8
1993	4.2	2.0	0.9	0.4	0.8	41.7	144.3	154.3	61.7	26.6	14.7	10.8	38.5
1994	4.6	2.1	1.0	0.5	0.8	36.6	129.5	140.7	56.6	24.5	14.0	10.6	35.1
1995	4.9	2.2	1.0	0.5	0.8	38.1	137.9	152.3	61.6	26.9	15.7	12.2	37.8
1996	5.3	2.4	1.1	0.6	1.0	35.6	128.8	137.1	55.6	24.3	15.0	11.7	34.9
1997	5.5	2.5	1.2	0.6	1.0	36.0	133.5	144.5	58.8	25.8	16.4	13.0	36.6
1998	5.7	2.6	1.3	0.7	1.0	38.7	147.3	162.1	66.3	29.3	19.1	15.4	40.8
1999	6.1	2.8	1.3	0.7	1.0	32.8	128.4	143.7	59.1	26.2	17.5	14.4	36.2
2000	6.4	2.9	1.4	0.8	1.1	33.0	130.1	140.3	57.7	25.6	18.1	14.8	36.0
2001	6.6	3.0	1.5	0.8	1.1	25.3	102.8	112.8	46.5	20.8	15.0	12.4	29.1
2002	7.0	3.1	1.6	0.9	1.1	24.9	104.7	116.8	48.4	21.7	16.0	13.4	30.0
2003	7.0	3.1	1.6	0.9	1.1	39.6	172.1	195.3	81.3	36.7	27.7	23.4	49.2
2004	7.6	3.4	1.8	1.0	1.2	25.9	113.8	124.7	51.7	23.5	18.6	15.6	32.4
2005	7.8	3.5	1.9	1.0	1.2	22.9	104.4	116.4	48.4	22.1	17.8	15.1	30.2
2006	7.8	3.5	1.9	1.1	1.2	27.0	128.5	145.8	60.9	27.9	23.0	19.6	37.3
2007	8.0	3.6	1.9	1.1	1.2	28.6	142.2	164.2	68.7	31.7	26.6	22.8	41.7
2008	8.4	3.7	2.0	1.1	1.2	26.7	134.8	150.6	62.6	29.2	25.5	21.6	39.0
2009	8.9	4.0	2.2	1.2	1.2	20.8	110.3	125.6	48.9	17.6	8.8	4.3	29.5
2010	2.2	1.3	0.8	0.4	10.0	91.7	191.6	215.4	129.4	24.8	9.9	6.2	57.0
2011	2.7	1.6	1.2	0.7	0.3	18.0	190.4	189.4	90.9	19.0	7.6	4.5	43.9
2012	2.2	1.2	0.7	3.4	9.8	87.1	257.0	201.0	67.0	34.7	22.1	9.8	58.0
2013	4.3	1.6	0.5	0.0	0.1	10.9	75.6	155.2	49.3	25.1	10.9	6.7	28.4
2014	2.6	0.7	0.1	0.0	0.3	27.5	123.5	178.8	84.7	19.9	7.4	3.6	37.4
2015	2.3	2.2	1.4	0.8	0.6	5.0	90.4	86.0	77.3	22.1	9.5	4.5	25.2
2016	1.5	0.4	0.1	0.4	12.4	73.0	166.3	171.7	67.4	13.6	7.3	4.1	43.2
2017	2.5	1.4	0.9	0.6	4.9	35.3	79.6	145.5	85.5	25.5	18.8	9.0	34.1
2018	3.7	1.9	0.7	0.1	0.1	17.5	116.0	130.5	46.6	15.6	6.6	3.1	28.5
2019	2.2	1.0	0.2	0.1	2.3	63.8	186.1	174.5	51.0	13.1	4.2	2.1	41.7
2020	1.2	0.5	0.1	0.0	1.0	30.9	136.5	155.5	74.4	20.7	12.0	6.4	36.6
2021	4.3	1.9	0.7	1.1	1.5	16.9	117.6	183.5	68.7	13.9	6.4	9.0	35.5
Mean	4.2	2.0	1.0	0.7	2.3	35.5	134.9	154.2	65.9	23.9	13.7	9.7	37.3

APPENDIX B:
SITE 06.G
ANNUAL INFLOWS
ALL SCENARIOS

Table B-1: Site 06.g - Annual Inflow (m^3/s) of Climate Change Scenarios - 2023-2100 – ASIAQ (2023)

	Average Annual Inflows (m^3/s)										
						ASIAQ 2023 (2023-2100)					
	ASiAQ - 1991-2010 Reconstituted with Annual volume	2031-2050 RCP 4.5 First set	2031-2050 RCP 8.5 First set	2031-2050 RCP 4.5 Second set	2031-2050 RCP 8.5 Second set	SSP126_CC_MAR	SSP245_CC_MAR	SSP585_CC_MAR	SSP126_ME_MAR	SSP245_ME_MAR	SSP585_ME_MAR
Year	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)
1991	31.83										
1992	23.60										
1993	31.67										
1994	28.86										
1995	31.10										
1996	28.65										
1997	30.11										
1998	33.59										
1999	29.74										
2000	36.41										
2001	29.28										
2002	30.22										
2003	50.26										
2004	32.64										
2005	30.45										
2006	37.94										
2007	42.54										
2008	39.54										
2009	29.80										
2010	57.38										
2011											
2012											
2013											
2014											
2015											
2016											
2017											
2018											
2019											
2020											
2021											
2022											
2023						35.74	37.09	33.66	45.34	41.89	35.24
2024						39.67	35.63	43.47	48.44	42.38	32.84
2025						48.06	36.66	46.44	36.18	40.68	38.68
2026						46.55	46.98	41.44	39.10	34.31	35.75
2027						40.64	41.35	36.11	48.00	38.44	40.17
2028						33.68	29.06	41.93	45.71	32.11	32.25
2029						35.73	42.00	49.12	45.94	34.76	37.64
2030						49.23	40.21	49.24	47.76	39.85	40.62
2031		60.72	56.43	59.12	55.12	38.83	42.70	27.25	35.46	39.03	37.29
2032		81.60	48.85	80.19	47.19	52.25	39.50	43.71	33.15	43.54	38.31
2033		55.12	46.25	53.69	45.36	51.52	37.96	42.55	44.25	42.27	47.55
2034		54.97	46.84	53.27	46.37	52.63	48.99	42.67	29.79	35.17	35.77
2035		32.00	34.22	32.14	33.77	49.25	28.88	49.50	40.27	54.26	43.30
2036		61.18	48.49	60.03	47.87	45.37	36.09	49.46	33.89	42.44	37.79
2037		61.26	60.23	60.21	58.93	30.13	40.10	47.69	39.93	43.94	33.72
2038		65.50	36.68	64.56	35.45	43.57	47.90	44.04	42.78	42.94	45.46
2039		40.42	57.08	40.12	54.96	44.76	39.58	57.60	38.25	50.30	44.86
2040		44.86	55.07	44.01	53.84	52.92	39.91	50.98	31.49	55.14	39.76
2041		44.65	44.50	43.30	43.38	48.49	47.86	40.68	37.44	51.38	34.46
2042		42.48	47.08	41.73	45.54	35.80	38.02	57.09	28.45	32.10	40.85
2043		43.83	57.07	42.96	56.29	35.53	29.62	45.35	43.57	39.91	44.46
2044		58.03	56.42	56.15	55.51	38.05	58.47	58.39	40.90	31.75	44.85
2045		65.22	57.17	63.96	56.13	70.51	32.21	49.70	38.82	37.72	47.63
2046		42.84	59.67	42.19	58.14	50.74	41.96	36.39	34.83	40.93	37.02
2047		54.54	53.72	52.94	53.21	50.20	33.32	49.21	39.81	45.37	30.67
2048		47.73	62.52	46.99	61.57	54.02	43.70	46.64	36.89	39.03	38.34
2049		41.59	52.75	40.26	51.87	40.14	53.42	42.22	49.55	38.17	45.18
2050		63.55	58.70	62.71	57.56	53.61	47.22	63.16	36.90	38.90	44.97

Table B-1: Site 06.g - Annual Inflow (m^3/s) of Climate Change Scenarios – 2023-2100 – ASIAQ (2023) (continued)

	Average Annual Inflows (m^3/s)										
						ASIAQ 2023 (2023-2100)					
	ASiAQ - 1991-2010 Reconstituted with Annual volume	2031-2050 RCP 4.5 First set	2031-2050 RCP 8.5 First set	2031-2050 RCP 4.5 Second set	2031-2050 RCP 8.5 Second set	SSP126_CC_MAR	SSP245_CC_MAR	SSP585_CC_MAR	SSP126_ME_MAR	SSP245_ME_MAR	SSP585_ME_MAR
Year	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)
2051						33.07	37.78	54.35	50.39	41.89	46.95
2052						57.45	47.87	44.96	31.46	38.63	41.87
2053						34.22	38.46	43.24	45.18	42.30	44.67
2054						57.75	41.26	48.31	34.82	53.26	42.47
2055						47.55	50.11	57.11	43.29	46.39	39.36
2056						43.47	46.86	58.46	47.04	42.10	52.72
2057						66.29	49.62	56.60	41.77	35.06	37.83
2058						48.08	50.52	54.01	43.92	44.02	44.31
2059						37.17	29.98	53.52	38.15	49.81	54.16
2060						45.31	50.68	46.79	46.98	50.68	37.19
2061						45.49	52.30	62.86	41.95	44.90	39.07
2062						42.92	53.15	81.29	41.28	40.76	39.19
2063						37.17	40.69	60.27	31.66	36.31	42.71
2064						38.45	57.70	60.47	33.97	32.39	50.45
2065						53.71	52.09	63.20	36.93	50.71	54.99
2066						45.86	38.76	52.12	44.87	50.80	47.96
2067						41.25	53.80	62.79	30.20	41.00	60.73
2068						49.77	55.35	65.83	37.25	49.57	48.66
2069						34.92	55.19	54.06	33.50	45.43	67.65
2070						55.97	46.85	76.54	38.38	32.56	57.61
2071						39.27	58.15	61.85	37.66	48.83	61.67
2072						43.08	51.99	63.38	42.52	56.09	54.58
2073						52.21	43.76	69.78	38.14	45.52	47.81
2074						47.36	37.23	81.93	31.09	36.96	59.03
2075						41.85	60.04	65.01	43.61	52.29	56.37
2076						38.17	56.90	55.81	34.88	41.41	46.75
2077						41.94	54.16	63.33	40.47	53.67	48.96
2078						35.60	52.94	73.90	40.84	43.30	52.39
2079						50.20	50.81	78.91	47.26	39.88	50.43
2080						55.52	32.73	65.44	35.70	43.95	69.81
2081						44.06	51.01	79.91	49.24	51.13	61.63
2082						46.41	53.14	67.84	39.95	44.05	52.90
2083						60.32	61.83	71.04	38.74	46.79	62.01
2084						44.80	61.14	68.86	39.56	48.69	65.36
2085						28.07	54.04	74.03	45.73	38.32	55.29
2086						48.21	54.84	97.86	49.30	43.30	53.14
2087						56.62	64.78	92.15	39.08	43.46	60.14
2088						39.91	47.00	98.35	35.68	44.99	65.73
2089						61.37	39.91	79.14	43.13	41.90	55.95
2090						49.83	72.80	97.17	41.05	52.24	85.18
2091						40.09	49.53	83.09	44.69	64.09	66.96
2092						47.44	57.01	92.46	47.59	42.13	51.27
2093						65.92	60.01	92.88	43.30	40.01	65.78
2094						47.92	51.87	88.25	44.00	51.92	64.67
2095						48.51	52.07	90.43	45.99	39.93	66.44
2096						50.75	67.77	93.98	38.96	43.03	55.18
2097						52.39	46.02	109.18	40.96	44.70	55.26
2098						35.61	80.24	108.54	34.94	48.39	59.04
2099						48.44	43.32	116.50	39.69	41.39	67.67
2100						54.17	51.12	95.01	44.39	48.84	72.90

APPENDIX C: SENSITIVITY ANALYSIS - FIRM POWER FOR ONE YEAR WITH DEFICIT

**Table C-4: Site 06.g - Firm Power - One Year with Deficit
Lake Imarsuaq (Big Lake) without L682**

Climate Change Scenario	Period	Firm Power	Difference with base case	
		(MW)	(MW)	(%)
Historical Data (Base Case) *	1991-2010 (20 years)	177	1	0.6%
RCP 4.5 – reconstitution 1 *	2031-2050 (20 years)	254	78	44.3%
RCP 8.5 – reconstitution 1 *		250	74	42.0%
ASIAQ 2023 - SSP126_CC_MAR		225	49	27.8%
ASIAQ 2023 - SSP245_CC_MAR		218	42	23.9%
ASIAQ 2023 - SSP585_CC_MAR		244	68	38.6%
ASIAQ 2023 - SSP126_ME_MAR		214	38	21.6%
ASIAQ 2023 - SSP245_ME_MAR		215	39	22.2%
ASIAQ 2023 - SSP585_ME_MAR		219	43	24.7%
ASIAQ 2023 - SSP126_CC_MAR	2031-2060 (30 years)	225	49	27.8%
ASIAQ 2023 - SSP245_CC_MAR		218	42	23.9%
ASIAQ 2023 - SSP585_CC_MAR		244	68	38.6%
ASIAQ 2023 - SSP126_ME_MAR		214	38	21.6%
ASIAQ 2023 - SSP245_ME_MAR		215	39	22.2%
ASIAQ 2023 - SSP585_ME_MAR		219	43	24.7%
ASIAQ 2023 - SSP126_CC_MAR	2051-2080 (30 years)	236	60	34.1%
ASIAQ 2023 - SSP245_CC_MAR		225	49	27.8%
ASIAQ 2023 - SSP585_CC_MAR		276	100	56.8%
ASIAQ 2023 - SSP126_ME_MAR		212	36	20.5%
ASIAQ 2023 - SSP245_ME_MAR		232	56	31.8%
ASIAQ 2023 - SSP585_ME_MAR		239	63	35.8%
ASIAQ 2023 - SSP126_CC_MAR	2071-2100 (30 years)	234	58	33.0%
ASIAQ 2023 - SSP245_CC_MAR		247	71	40.3%
ASIAQ 2023 - SSP585_CC_MAR		316	140	79.5%
ASIAQ 2023 - SSP126_ME_MAR		222	46	26.1%
ASIAQ 2023 - SSP245_ME_MAR		248	72	40.9%
ASIAQ 2023 - SSP585_ME_MAR		283	107	60.8%

* Initial scenario

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