The British Dam Society

Hydrological Risk Management for Proposed Mentarang Induk Hydroelectric Project in Indonesia

M HUSSAIN, Stantec
C BARRY, Stantec
A R RONEY, PT KHN (Indonesia)

SYNOPSIS Stantec has been engaged by PT Kayan Hydropower Nusantara, Indonesia to review the catchment hydrology and hydropower operation for the proposed Mentarang Induk Hydroelectric Project (MIHEP) in North Kalimantan, Indonesia. The project includes a 230m high concrete faced rockfill dam, gated spillways structure, 1375MW surface powerhouse and a reservoir (226km^2). This project is planned to displace fossil fuels sourced electricity in Indonesia.

Stantec re-established a rainfall-runoff model for the Mentarang catchment to generate long-term flows. The performance of the model was significantly improved due to a longer period of observed flow record supporting the updated model calibration. This provided a better understanding of the flows at Mentarang dam site. Stantec also conducted a climate change assessment using three widely recommended Global Circulation Models (GCMs) from the Coupled Model Intercomparison Project Phase 6 (CMIP6). The assessment suggests that under a mean ensemble of the three selected climate models, there would be 10% to 15% increase in future flows compared with the baseline period of 1990-2014. Reservoir operation was established incorporating the reservoir control rules and latest flows generated. The projected increase in future flows indicates improved power output for MIHEP. However, these findings should be considered with the caveat that GCMs have high uncertainty in projecting future precipitation and river flows.

PROJECT BACKGROUND

The proposed Mentarang Induk Hydroelectric Project (MIHEP) is one of the largest Hydropower projects in Southeast Asia planned on the Mentarang River in North Kalimantan, Indonesia[1]. The project includes a 235m high and 815m long concrete faced rockfill dam, a surface powerhouse with five Francis turbines (5 × 275 MW), a gated spillway structure with six large radial gates and it will create a large reservoir with surface area of226 km^2.

MIHEP will provide affordable, reliable, and renewable energy to the industries in Indonesia's Green Industrial Park (KIPI) at Tanah Kuning, North Kalimantan. KIPI is Indonesia’s largest

---

[1] Indonesia breaks ground on $2.6bn Mentarang Induk hydropower project (nsenergybusiness.com)

green industrial park and a National Strategic Project (PSN) serving as a catalyst for Indonesia's Renewable Energy-Based Industry Development (REBID) initiative[2]. PT Kayan Hydropower Nusantara (PTKHN), which is developing MIHEP, is a joint venture company between PT Adaro Energy Indonesia Tbk (Adaro), Sarawak Energy Berhad (SEB) and PT Kayan Patria Pratama (KPP). Stantec has been engaged by PTKHN to review the hydrology, hydropower energy yield assessment and to support the project owner during the expected due diligence process to be conducted by the Lender's Engineer.

INPUT DATA

Observed meteorological data

Meteorological data including nine rainfall and three pan evaporation stations in the region were provided by PTKHN. Most of the stations sit within the Baram Catchment in Sarawak as described in (SMEC, 2014). Baram is a neighbouring catchment with long term meteorological and hydrological records. The details of these stations are provided in Table 1 and Figure 1.

The majority of the nine rain gauges have missing data in their record: Bario (1 year), Ba Kelalan (2 years), Lio Matu (3 years), Long Bawan (10 years), Marudi (1 year), Nunukan (1 year). Baram, Lg Pilah and Mentarang have no missing data in their records. Two rain gauges (Mentarang and Long Bawan) lie within the Mentarang Catchment. Nunukan lies on the eastern coastline of North Kalimantan. Rainfall depth and distribution are similar across the Baram and Mentarang catchments with the lower elevations of each catchment generally receiving more rain than the higher elevations.

The three pan evaporation stations record daily evaporation totals in millimetres. Miri and Belaga have records from 1988 to 2022 while Batang Ai Dam has a record from 1991 to present. Miri is located on the coast whilst Belaga is situated inland. Batang Ai Dam is located by an inland lake, 250km southwest of Belaga.

Satellite precipitation

There are several Satellite Precipitation Products (SPPs) available which provide precipitation coverage over Southeast Asia that is more temporally and spatially complete than rain gauge networks. Several studies have evaluated the performance of SPPs across Southeast Asia. Liu et al (2020) investigated three SPPs (GSMaP, IMERG and CHIRPS) against rainfall gauges over Bali Island, Indonesia from 2015 to 2017. The results demonstrated that IMERG achieved the highest performance on the daily time step whereas CHIRPS outperformed on the monthly time step. Wiwoho (2021) compared three different SPPs including CHIRPS, GPM and PERSIANN. CHIRPS had the best daily performance compared to these other products in Brantas, Indonesia. Liu et al (2022) argues that daily CHIRPS has high spatial resolution and is suitable for catchment scale studies when compared to rain gauge observations.

Therefore, CHIRPS (Funk et al, 2015) is chosen to infill station rainfall data. The nine rain gauges have different periods of record with missing data points. CHIRPS mitigates these challenges, as a source of rainfall estimates to address such gaps temporally and spatially across a catchment of interest. This is necessary for the hydrological modelling to generate long-term flows.

---

[2] Mentarang Induk Hydroelectric Project (MIHEP) (ptkhn.com)

Table 1. Meteorological Stations with time duration and long-term average

Station Type	Station Name	Station Owner	Elevation (m aSL)	Time Duration			LTA (mm/yr)	
				Start	End	Total (years)	Total	From 2018
Precipitation	BaKelalan	DID	945	2001-01-01	2022-12-31	22.0	2331	2551
Precipitation	Baram	SEB	40	2013-05-13	2023-05-09	10.0	3731	4310
Precipitation	Bario	DID	1,046	1988-01-01	2022-12-31	35.0	2217	2265
Precipitation	Lg Pilah	DID	40	1998-01-01	2022-12-31	25.0	4627	4746
Precipitation	Lio Matu	DID	204	1988-01-01	2022-12-31	35.0	3559	3548
Precipitation	Long Bawan	BMKG	1,125	1988-01-01	2017-08-15	29.6	2464	-
Precipitation	Marudi	DID	17	2001-01-01	2022-12-31	22.0	2826	3160
Precipitation	Mentarang	PTKHN	23	2018-02-10	2023-03-02	5.1	4307	4307
Precipitation	Nunukan	BMKG	35	1998-01-01	2017-08-31	19.7	2439	-
Pan Evaporation	Miri	DID	18	1998-01-01	2022-12-31	25.0	1775	1810
Pan Evaporation	Belaga	DID	56	1998-01-01	2022-12-31	25.0	1564	1294
Pan Evaporation	Batang Ai Dam	SEB	112	1991-01-01	Present	32.4	1675	1628

Mentarang rating curve

A detailed statistical analysis was carried out on 19 Mentarang River flow gaugings to improve the river rating curve during the tender design (Entura, 2020). A HEC RAS model was also developed for the Mentarang river channel to extend this rating curve above gauged flows. The resulting rating gives similar mean flows to the PTKHN rating for the period of record.

However, for the section of the rating between 1,048m^3/s (maximum gauged flow) and 3,015m^3/s (maximum recorded flow) the HEC RAS rating is considered more accurate than the PTKHN rating because it is based on hydraulic modelling.

River water levels and discharge data

River water level records for five years at the Mentarang Hydrometric Station located at the Mentarang Dam site were available. The station's logger records 15-minute stage data. The river stage data were converted to flow using the developed rating curve and are plotted in Figure 2.

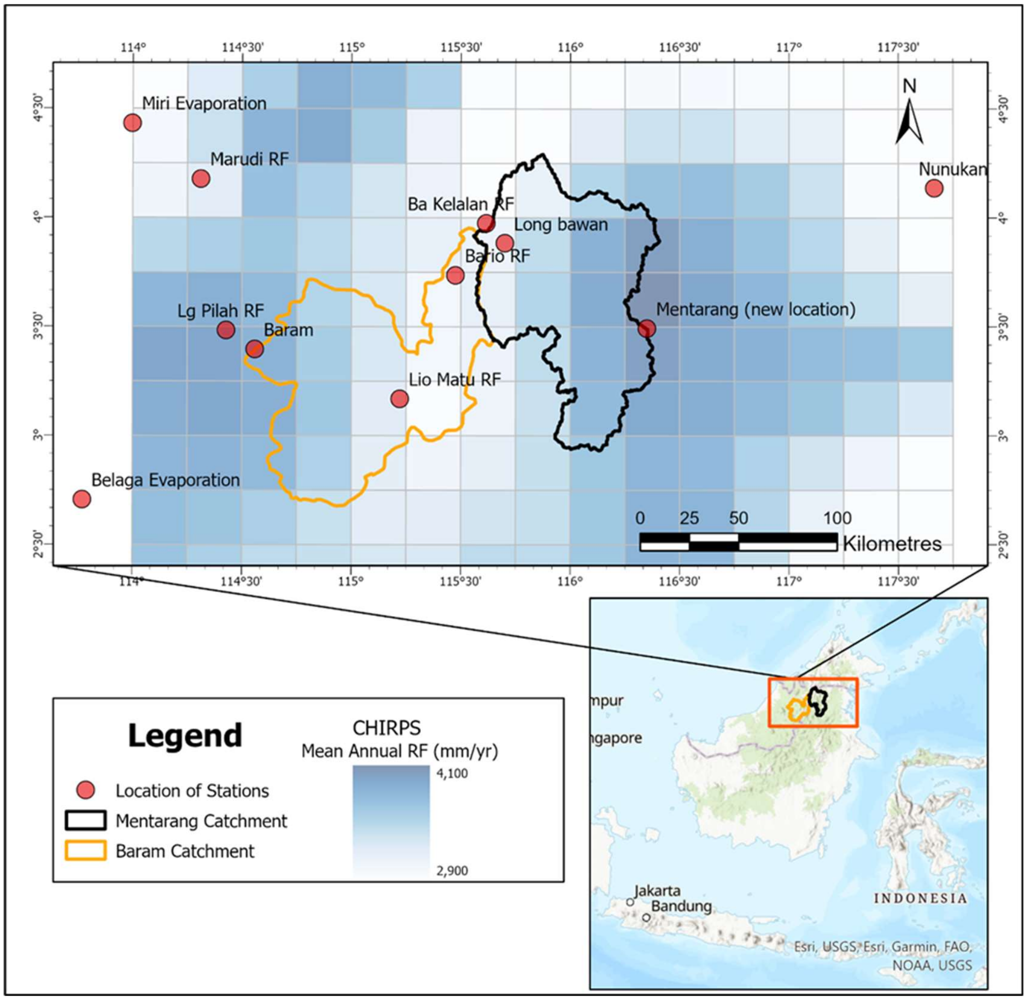

Figure 1. Map showing the meteorological and hydrometric stations in relation to the Mentarang Catchment and spatial distribution of annual rainfall from CHIRPS satellite precipitation product

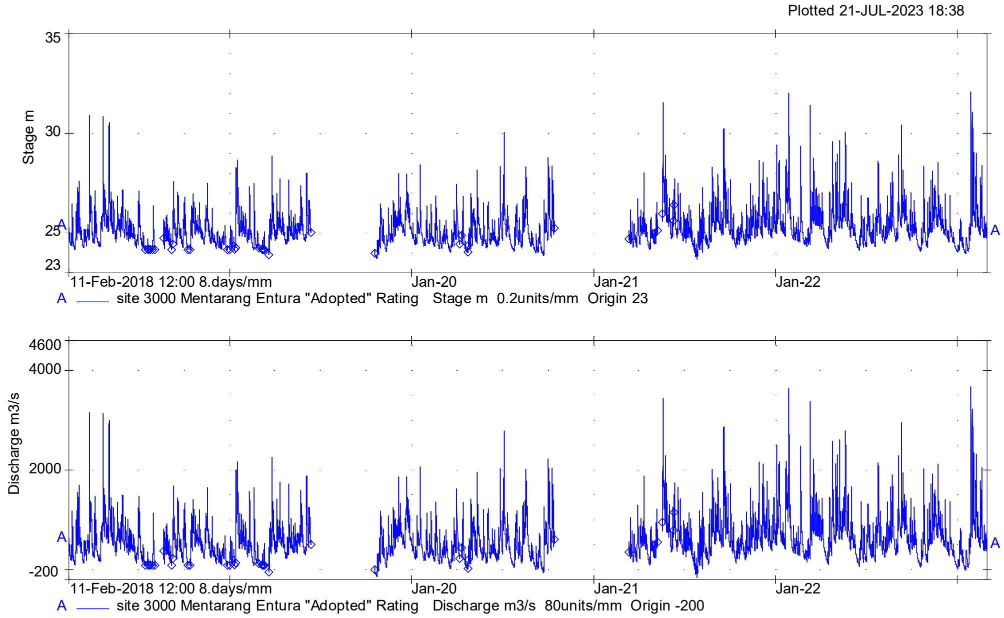

Figure 2. Stage and flow hydrographs at Mentarang Gauging Station

LiDAR survey for the reservoir area

A Light Detection and Ranging (LiDAR) survey for the Mentarang Reservoir area was conducted during the feasibility study (Norconsult, 2019) to improve understanding on the reservoir storage capacity. Reservoir surface areas and storage volumes at various elevations were calculated from the LiDAR data to plot an elevation area storage curve (Figure 3). These curves are then used in the reservoir operation model.

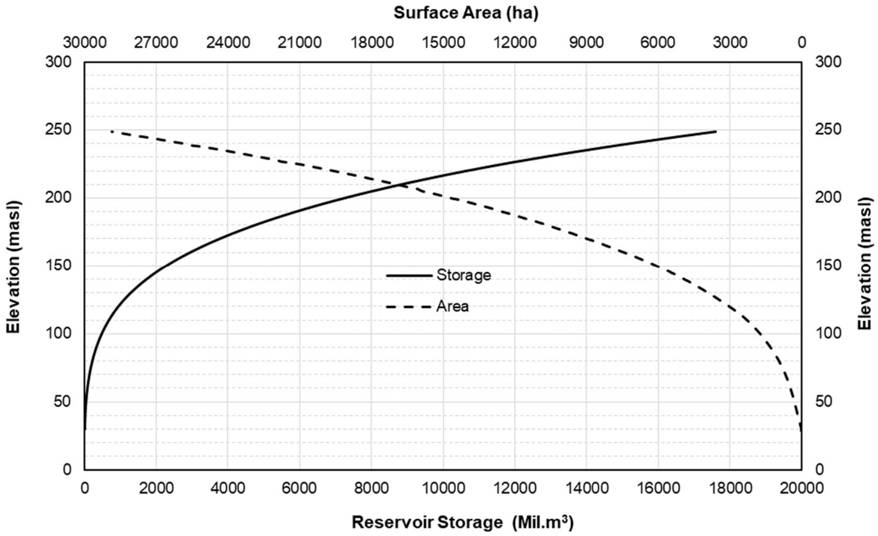

Figure 3. Elevation Area Storage Curve for Mentarang Reservoir

Tailwater rating, spillway discharge rating and waterway head losses

Tailwater rating curve, spillway discharge rating and waterway head loss were reviewed and updated while finalising design during tender design stage. Tailwater rating was developed taking into consideration both spillway and powerhouse discharges. Head losses in waterways have also been calculated for the designed penstocks. All five conduits have slightly different lengths and therefore resulted in slightly different head loss for each conduit. All these data were used here as finalised in the tender design.

Power plant data

The proposed MIHEP is designed to have five Francis turbines (5 x 275 MW) with a total installed capacity of 1,375 MW. The main features of the power plant are shown in Table 2.

Table 2. Power plant design features as per tender design (Entura, 2022)

Feature	Description
Type	Surface
Number of units	5
Unit type	Francis
Rated net head	195.1 m
Minimum net head	175.0 m
Rated output per unit	275 MW
Max. turbine output	307 MW
Unite rated discharge	151.6 m^3/s
Unit maximum discharge	166.8 m^3/s
Minimum tailwater level (flood protection)	24.6 masl
Minimum tailwater level (machine setting)	23.8 masl

The turbine performance/efficiency curve was also provided in the tender design which was adopted in the reservoir operation modelling.

HYDROLOGICAL YIELD

Rainfall Runoff Modelling

GR4J is a lumped parameter hydrological model (Perrin et al, 2003), and was used to develop a rainfall-runoff model for the MIHEP catchment. The model characterises catchment rainfall-runoff processes using four parameters, converting input time series of rainfall and potential evapotranspiration (PET) to specific discharge (that is, river flow per unit area of catchment). GR4J was also used in the previous hydrological study of the Mentarang catchment (Entura, 2020), where it was calibrated with only two years of observed flows.

The model was re-calibrated using the now five years of observed flows at the Mentarang Dam Site and then long-term flows were generated using the rainfall and PET data. Analysis of overall mean flows shows that the model matches observed mean flows well, with simulated mean flows of 593m^3/s versus mean observed flows of 595m^3/s over the five years of observed flows as shown in Figure 4. The flow duration curves for the period of 2018-2022 were compared as shown in Figure 5.

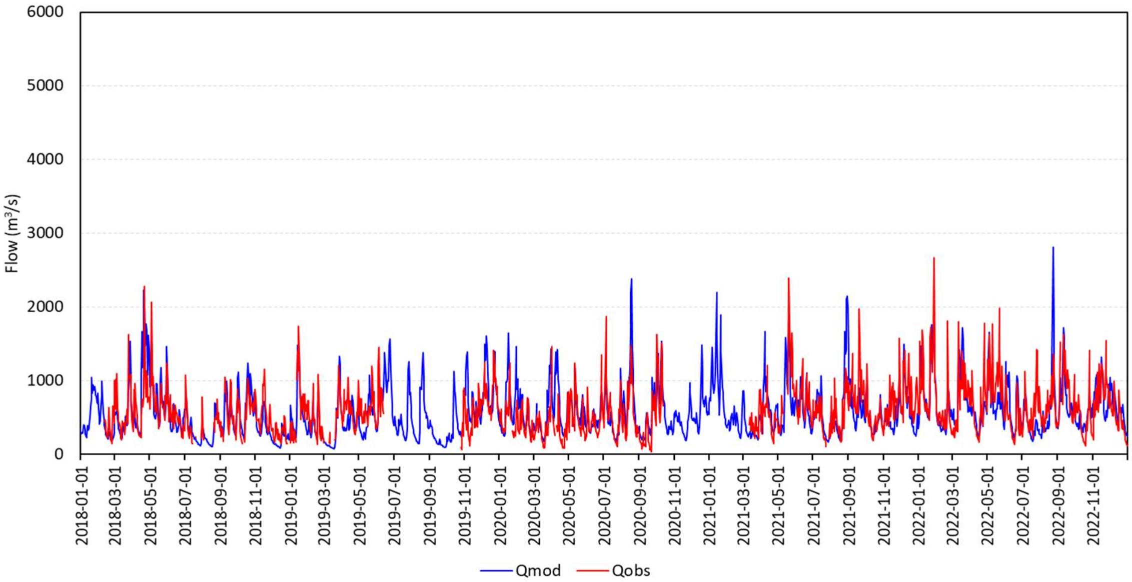

Figure 4. Observed vs Modelled flow during calibration

There is a significant difference between the average modelled flow since 2018, i.e 572m^3/s, and the long-term average modelled flow. The long-term average modelled flow is 518m^3/s for the period of 1993-2022; the 1993-2022 period excludes the earlier 12 years period (1981-1992) for which the model is dependent on less reliable and less complete rain gauge data. The reasons for this are also related to the trends in meteorological inputs, particularly the decline in PET. Therefore, the latest 30-year period is adopted for this hydrological analysis. A comparison of flow duration plots for observed, modelled and long term simulated flows is shown in Figure 5.

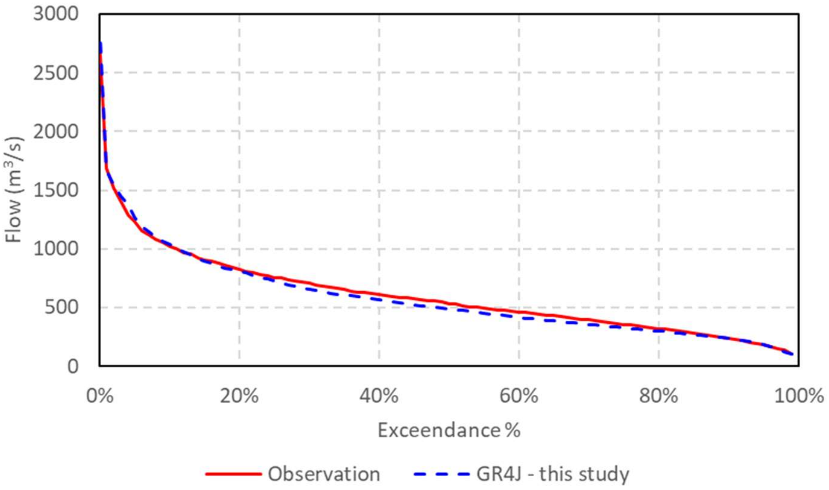

Figure 5. Flow duration curve for observed vs GR4J calibrated flows

Uncertainty

Confidence intervals have been calculated based on a log transform of the model results. Analysis of the residuals shows that log-based confidence intervals give a better representation of the uncertainty at all flow magnitudes. The confidence intervals, computed in log-transformed space, are presented in Figure 6. The uncertainty in flow is proportionate to the magnitude in flow, because of the log-transformation. This uncertainty can be minimized in the future by expanding hydrometric monitoring in the MIHEP catchment.

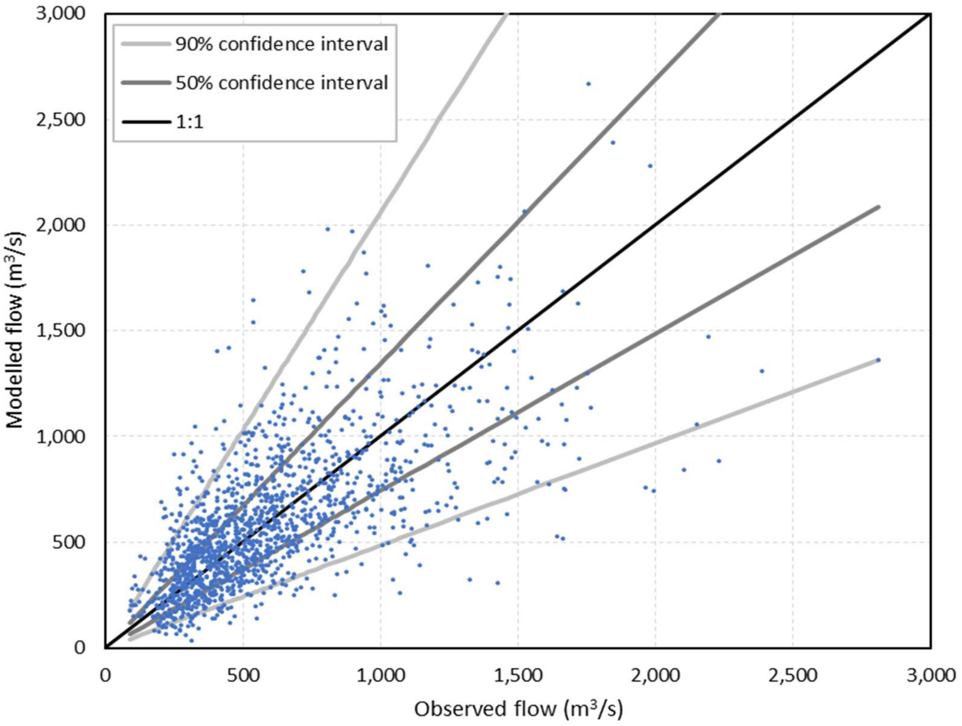

Figure 6. Modelled to observed daily mean flows, with confidence intervals

Comparison with previous work

Model uncertainty between this study and previous methods is presented in Figure 7. Previous studies attempted to estimate flow at Mentarang based on flows at Baram pro-weighted by catchment area, as well as using GR4J. The comparative confidence intervals shows that the current study has reduced the uncertainty of modelled flows, with the confidence interval closer to the match line between observed and modelled flows. However, as noted above, there is opportunity to further improve rainfall-runoff model with extended periods of observed record in the future.

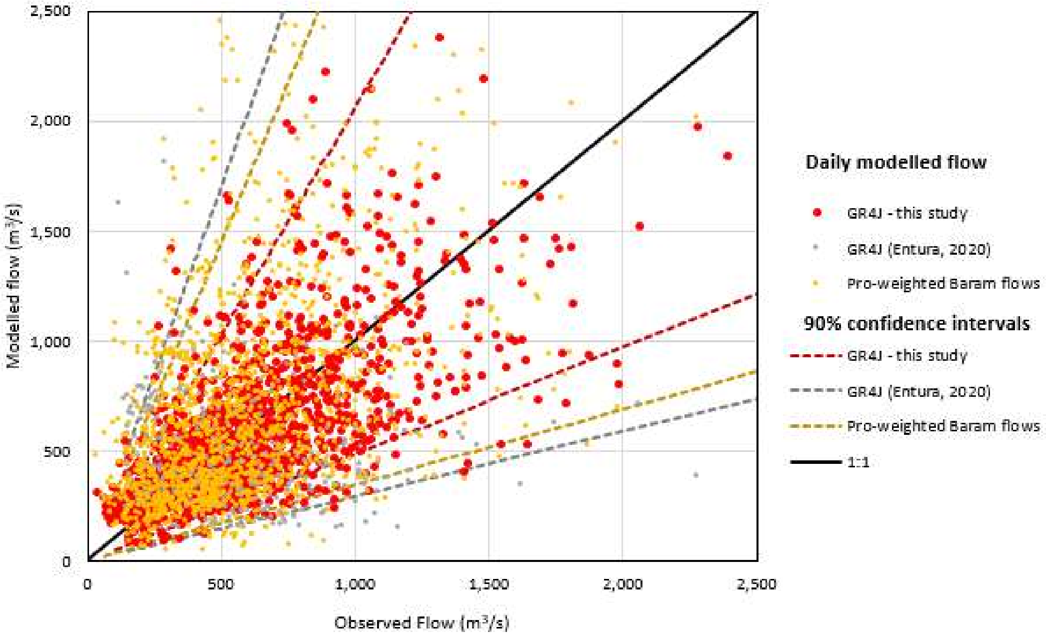

Figure 7. 90% confidence intervals of modelled daily mean flow compared with previous models

Climate change impact on future river flows

Hydrological assessment requires not only a good understanding of historical flows, but also consideration of likely changes in climate and how this will influence future rainfall and evaporation. The forecast changes to rainfall and evaporation relevant to Kalimantan have been applied to the calibrated GR4J model to forecast the likelihood of increases or decreases in flows at Mentarang.

Iqbal and Shahid (2021) investigated the performance of 35 GCMs of CMIP6 and compared against the Aphrodite SSP for mainland Southeast Asia. The results found that *mri-esm2-0*, *ec-earth3* and *ec-earth3-veg* were the most suitable subset of GCMs for rainfall projections in this region with a bias of less than 25%. A number of studies have conducted similar approaches and found that *ec-earth3-veg* worked best in Indonesia and other Southeast Asian countries (Pimonsree and Kamworapan, 2023; Sa'adi and Rohmat, 2022; Hamed and Nashwan, 2023). Bo, et al (2021) argues that *cams-csm1-0* has difficulty modelling seasonal rainfall which is related to El Niño Southern Oscillation (ENSO) events whereas Li and Chen, (2022) claim that *cams-csm1-0* is among the five best performing models (*cams-csm1-0*, *giss-e2-1-g*, *mri-esm2-0*, *access-esm1-5*, and *cesm2-waccm*) for producing a reliable future summer projections in East Asia. A summary of literature review and model performance is provided in Table 3.

Table 3. GCMs performance over South East Asia

Model Name	**Performed well**	**Performed poorly**
cams-csm1-0	(Li & Chen, 2022)	(Bo, et al., 2021)
canesm5	(Hamed & Nashwan, 2023)	
cnrm-esm2-1		
ec-earth3-veg	(Sa'adi & Rohmat, 2022) (Pimonsree & Kamworapan, 2023) (Iqbal & Shahid, 2021) (Desmet & Ngo-Duc, 2021) (Hamed & Nashwan, 2023)	
fgoals-g3		(Kurniadi & Weller, 2022)
gfcll-esm4		
Ipsl-cm6a-lr		(Kurniadi & Weller, 2022)
miroc-es2l		
miroc6		
mri-esm2-0	(Iqbal & Shahid, 2021) (Li & Chen, 2022)	
ukesm1-0-II		

Based on a literature review as presented in Table 3, five journal articles agree that *ec-earth3-veg* projects rainfall well, with *cams-csm1-0*, and *mri-esm2-0* performing reasonably well. Therefore, these three GCMs were included in a Multi-Model Ensemble for the MIHEP watershed to explore climate change impacts in the future.

Results of climate change predictions

The results of the future forecasts give a mixed picture with respect to changes in flow. The analysis has been conducted for two future 25-year epochs, 2026–2050 (2030s) and 2051–2075 (2060s), compared to a historical 25-year baseline from 1990 to 2014. The mean modelled flow within this baseline period was 495m^3/s. The predicted percentage changes in flows are presented in Figures 8a and 8b for both forecast epochs. The 90% confidence intervals presented for individual climate models and SSPs (5% to 95%) represent interannual variability, for example due to ENSO.

On average, the ensemble of climate models and SSPs predict an increase in flows through the 21st century. However, it is important to note that the forecasts of individual climate models diverge from each other significantly. Furthermore, these projections focus on annual average flows and do not capture possible seasonal changes in climate variability, such as changes in frequency of El Niño events or the frequency and intensity of extreme rainfall events and dry periods.

Managing Risks for Dams and Reservoirs

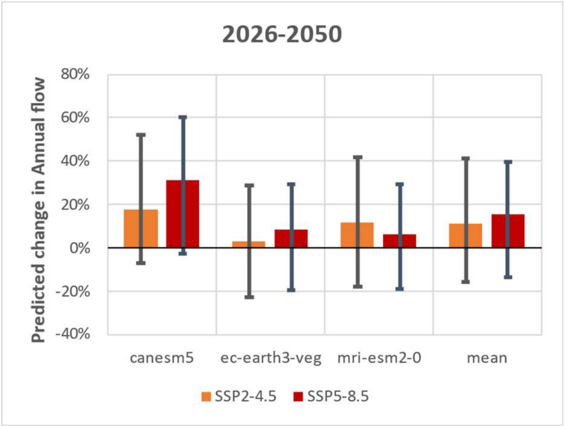

Figure 8a. Predicted change in flow during 2030's, compared to 1990–2014 baseline (Error bars show 90% intervals of interannual variability)

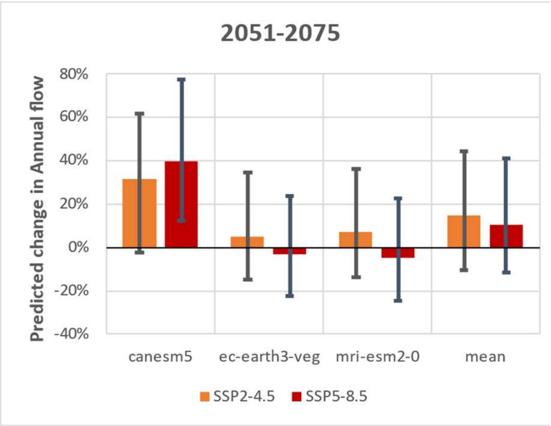

Figure 8b. Predicted change in flow during 2060's, compared to 1990–2014 baseline (Error bars show 90% intervals of interannual variability)

RESERVOIR OPERATION MODELLING

A reservoir operation model was developed in the HEC ResSim tool for the Mentarang Reservoir. HEC ResSim comprises a graphical user interface (GUI) and a computational programme to simulate reservoir operations. It is developed and made available by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC). Version 3.3 was used for this study. Reservoir operation control rules were updated as described below and then the model was simulated with updated long-term flows generated during this study to assess firm power and mean annual energy available from MIHEP.

Reservoir Control Rules

During periods of low water levels (<210masl), there is a risk of not releasing ecological flows from the MIHEP powerplant to the downstream river. The spillway crest level is set at 210masl and if the reservoir water level drops below 210masl (minimum operating level), the ecological flow release cannot be discharged over the spillway. Additionally, the spillway is designed in such a way that the minimum discharge should be 750m^3/s on one chute to ensure that the jet from the flip bucket will impact in the plunge pool to minimize erosion. Releasing water via the spillway during low flow periods is also not a sensible decision.

Therefore, the plant operating rules are set to allow a 1m buffer above the minimum operating level (MOL) to pass only ecological flows through the two penstocks and generate minimum power equivalent to the ecological flow release. The following reservoir control rules were adopted in the reservoir operation model as described below.

- Stop all units below 210masl (MOL).
- Generate minimum power (400 MW) between 210masl and 211masl to ensure ecological flow release (225m^3/s).
- Generate firm power between 211masl and 230masl.
- Generate full power and release flood water through spillway between 230.0masl and 237.8masl.

Firm Power

An analysis of power reliability was conducted to understand the firm power available at various reliability levels. Reservoir simulations were performed for the 30-year period January 1993 to June 2023, to assess the changes in reliability of target firm power values, as shown in Figure 9 below. Results from this analysis will help PTKHN to negotiate a power purchase agreement with their potential customers.

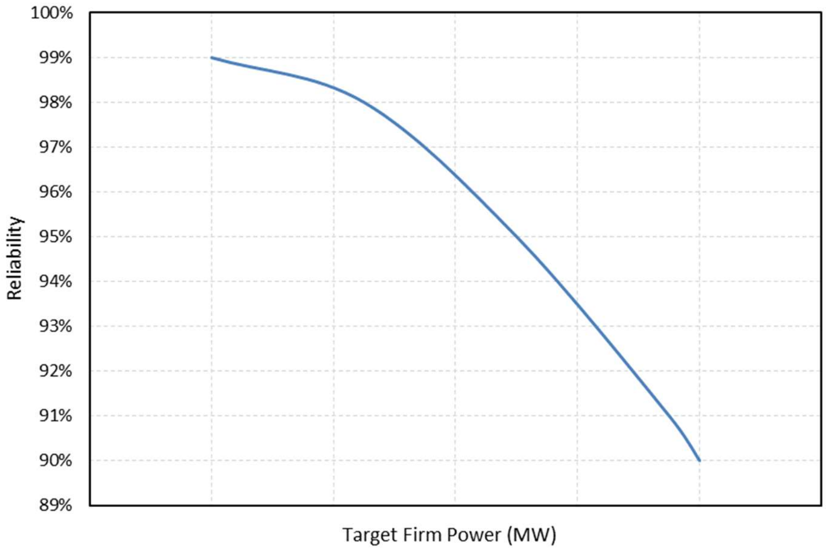

Figure 9. Target firm power vs hydrological reliability
Note: Scale on X-axis redacted due to commercial sensitivity

Figure 10 shows the reservoir water levels for 30-year (historical) operation for 95% target firm power output. It is noted that there would be three events when the reservoir level hits the minimum operating level. Figure 11 shows the MIHEP flow duration plot for 95% reliable firm power dispatch.

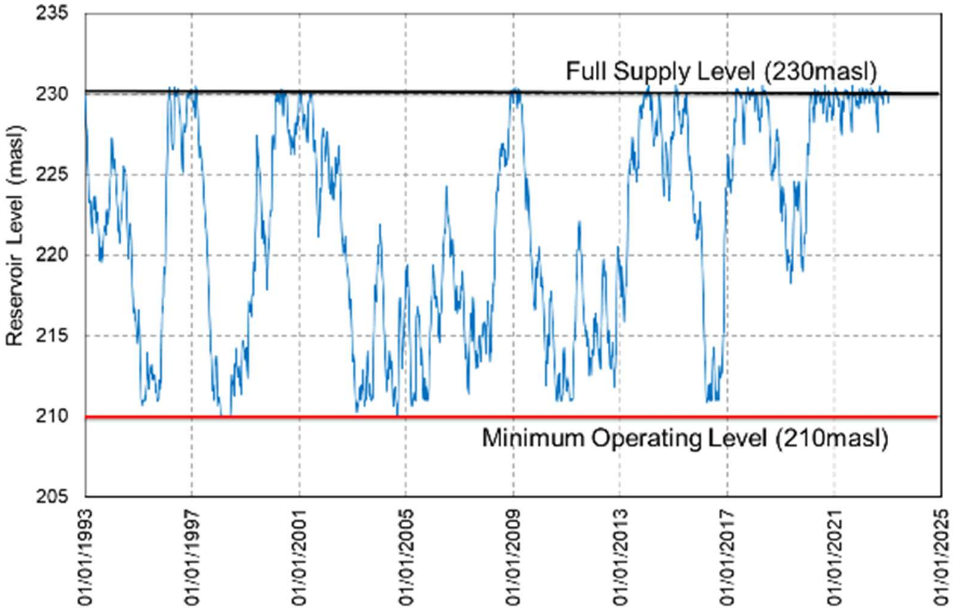

Figure 10. Reservoir water levels for 30 years historical operation

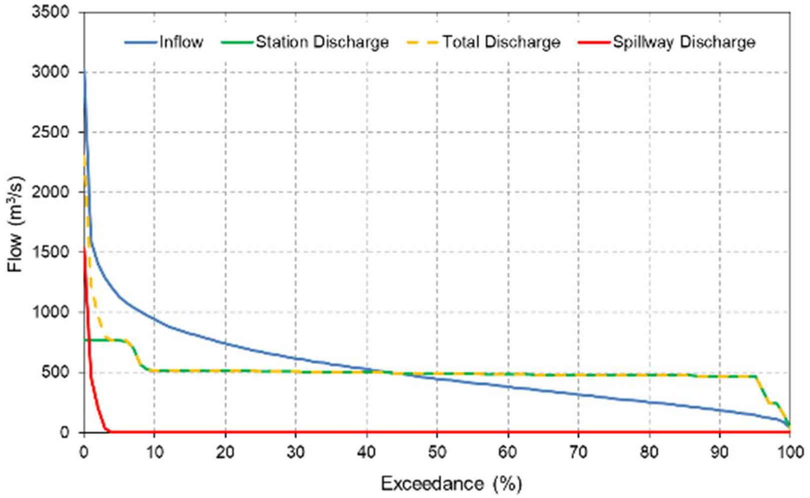

Figure 11. Inflow and outflow duration curves for 30 years historical operation with firm power of 850MW

Reservoir spills were calculated for the 99%, 95% and 90% target firm power operation,

Climate Change Impact on Hydropower

The climate change assessment suggests that overall, there would be an increase in rainfall over the MIHEP catchment in the future, which would result in higher river flow into the MIHEP reservoirs.

In line with the differences in rainfall predictions, the *canesm5* climate model predicts an increase in river flow through time. The other two climate models (*ec-earth3-veg* and *mri-esm2-0*) predict a smaller increase, compared to *canesm5*, in flows in the 2026–2050 window compared to the baseline period of 1990-2014. This assessment suggests that under the mean ensemble of three climate models, there would be 10% to 15% increase in future flows compared with baseline period of 1990-2014.

Therefore, it is projected that the MIHEP would generate more power and annual energy in the future than estimated from the historical flows. However, these findings should be considered with the caveat that climate change assessment and GCMs have high uncertainty in projecting future precipitation and river flows in various regions.

Based on 30 years of historical flows, the plant factor for the designed plant is 63% and existing plant capacity would be adequate for the projected increased flows under the mean ensemble.

REFERENCES

Bo L et al (2021). Seasonal prediction skills in the CAMS-CSM climate forecast system. *Climate Dynamics,* **57** pp 2953-2970.

Desmet Q and Ngo-Duc T (2021). A novel method for ranking CMIP6 global climate models over the southeast Asian region. *International Journal of Climatology.*

Entura (2020). *Mentarang Induk Hydroelectric Project: Hydrology - Long-Term Flow Assessment.* Entura, Cambridge, Australia.

Entura (2022). *Mentarang Induk Hydroelectric Project - Tender Design Report - Package 3 - Main Civil And Electrical & Mechanical Works.* Entura, Melbourne, Australia.

Funk C, Landsfeld M, Pedreros D, Verdin J, Shukla S, Husak G and Michaelsen J. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Nature,* **2**.

Hamed M and Nashwan M (2023). Future Köppen-Geiger climate zones over Southeast Asia using CMIP6 Multimodel Ensemble. *Atmospheric Research,* **283**.

Iqbal Z and Shahid S (2021). Evaluation of CMIP6 GCM rainfall in mainland Southeast Asia. *Atmospheric Research.* **254**.

Kurniadi A and Weller E (2022). Evaluation of Coupled Model Intercomparison Project Phase 6 model-simulated extreme precipitation over Indonesia. *International Journal of Climatology.*

Li J and Chen D (2022). Future precipitation changes in three key sub-regions of East Asia: the roles of thermodynamics and dynamics. *Climate Dynamics.* **59** pp 1377-1398.

Liu C -Y A -R -R (2020). Assessment of satellite precipitation product estimates over Bali Island. *Atmospheric Research.* **244**.

Norconsult (2019). *Mentarang Induk Feasibility Study.* NorPower Sdn Bhd, Kuching, Sarawak, Malaysia

Perrin C, Michel C and Andréassian V (2003). Improvement of a parsimonious model for streamflow simulation. *Journal of Hydrology*, **279** pp 275-289. doi:10.1016/S0022-1694(03)00225-7

Pimonsree S and Kamworapan S (2023). Evaluation of CMIP6 GCMs performance to simulate precipitation over Southeast Asia. *Atmospheric Research,* **282**.

Sa'adi Z and Rohmat F (2022). Spatiotemporal Rainfall Projection in Majalaya basin, West Java,. *Research Square,* pp. 1-32.

SMEC (2014). *Baram Hydroelectric Project Hydrology Review and Update.* SMEC, Kuala Lumpur, Malaysia

Wiwoho B S (2021). Validation of Three Daily Satellite Rainfall Products in a Humid Tropic Watershed, Brantas, Indonesia: Implications to Land Characteristics and Hydrological Modelling. *Hydrology,* **8**.