# HYDROLOGY

## Introduction

This section of the report contains an overview of the project hydrology which is based on the review of hydrology of Updated Feasibility Study Report by Technoquarry Consults (P.) Ltd. and hydrological analysis by HCE.

An accurate assessment of long-term hydrology is essential to any hydropower project. The longer the hydrological records, more reliable are the estimation of design parameters for the project. In the case of ungauged (i.e., either limited or no stream flow records) river, direct measurements of hydrological parameters are not available, so, it is necessary to look at catchments that have similar catchment characteristics and meteorological records for the estimation of the hydrological data.

The hydrological study of the project area comprises the desk study, field investigation, collection of hydrological and meteorological data from nearby project area, and various literature reviews. Briefly the hydrological study covers the following:

* Review of previous study report and other related literature review,
* Assessment of the best suitable nearby gauging stations,
* Catchment area delineation,
* Collection of updated hydro-meteorological data,
* Estimation and updating of flow hydrograph based on updated data,
* Estimation and update of flow duration curve,
* Estimation and update of extreme flood,
* Updating of extreme flood

## Catchment Characteristics

Myagdi Khola is a perennial snow fed river originating from Dhaulagiri Himalayan Range. It is one of the major tributaries of Kali Gandaki River which is one of the major rivers of the Narayani Basin. The Myagdi Khola catchment is located in Myagdi district, Dhaulagiri Zone, Gandaki Province of Nepal.

Myagdi Khola originates from eastern side of the Dhaulagiri Himalayan Range. The river flows from north-east to south-west and joins with Kunaban Khola at Dovan. The Kunaban Khola also originates from western side of the Dhaulagiri Himalayan Range. Myagdi Khola, after its junction with Kunaban Khola, flows almost towards the south and again flows towards the south-west after its junction with Sinkos Khola located at about 1.25 km downstream from Jeltun Village. Then, the river joins with Mudi Khola (main tributary of Myagdi Khola) at near Khibang Village and Dar Khola near Solaban Village from which the river flows towards the south-east and joins with Kaligandaki Nadi at downstream of Beni Bazar.

The upper part of the catchment is covered with large glaciers which contribute to sustained flow during the dry season. The catchment has no any glacier lake. More than 90% of the catchment lies above 3000m, a favorable condition for higher degree of base flow throughout the year and less flood hazards. As per Physiographical Region, the catchment lies in between the High Mountain (2,000-2,500 m) and High Himalaya (2,500-8,848 m). The catchment area at the proposed intake sites of Myagdi Khola HPP (MKHPP) is shown in the satellite image below.

|  |
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| Plate ‑: Myagdi Khola HPP catchment area at proposed intake site in satellite image |

Myagdi River is a gauged river, and it has a hydrometric station located near Mangalghat (404.7) with published stream flow records from 1976-2015. Since the data in the beginning years is sparse, 30 years of flow data from the year 1985-2015 have been used for the station 404.7. The catchment area plays vital role in all the methods used for the hydrological estimation. Hence, the catchment area needs to be calculated precisely.

Catchment area has been calculated by catchment delineation using GIS. The 90 m SRTM DEM data covering the Project area was taken from SRTM data source http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp. Catchment area of Myagdi Khola at the proposed intakes of project, at Myagdi and Kunaban Khola have been recalculated by this method.

The recalculated catchment area at the intake of Myagdi Khola is 210.1 km2 and at the intake of Kunaban Khola is 95.0 km2.It means that total area contributing to the headworks of Myagdi Khola HPP is 305.1 km2. The catchment area calculated in the previous UFSR of Myagdi Khola HPP was 305 km2 and in previous UFSR of Myagdi khola(by Technoquarry) was 306 km2. As, the catchment area calculated in different phases of study is comparable, the catchment area of 305.1 km2 has been considered for the intake. Hence, the total catchment area considered for MKHPP at intake is 305.1 km2 and at tailrace is 346.5 km2.

The catchment area at the proposed intake and tailrace of MKHPP is shown in Table 1‑1 and Table 1‑2. The elevation wise catchment area at the proposed intake of MKHPP is shown in Figure 1‑1.

Table ‑: Hypsometric data of the catchment at intake of MKHPP

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Elevation (masl)** | **Myagdi Intake** | | **Kunaban Intake** | | **Total Area Contributing to Intake at MKHPP** | |
| **Area (km2)** | **%** | **Area (km2)** | **%** | **Area (km2)** | **%** |
| >5000 | 128.9 | 61.4% | 56.8 | 59.7% | 185.7 | 60.9% |
| 5000-3000 | 78.1 | 37.2% | 35.0 | 36.9% | 113.1 | 37.1% |
| <3000 | 2.98 | 1.4% | 3.24 | 3.4% | 6.22 | 2.0% |
| Total | 210.1 | 100.0% | 95.0 | 100.0% | **305.1** | 100.0% |

Table ‑: Hypsometric data of the catchment at tailrace of MKHPP

|  |  |  |
| --- | --- | --- |
| **Elevation (masl)** | **Tailrace of MKHPP** | |
| **Area (km2)** | **%** |
| >5000 | 186.8 | 53.9% |
| 5000m-3000 | 134.63 | 38.9% |
| <3000 | 25.03 | 7.2% |
| Total | **346.5** | 100.0% |

|  |
| --- |
| Figure ‑: Elevation wise area distribution of MKHPP catchments at intake sites of Myagdi and Kunaban |

The hypsometric data of the catchment of Myagdi khola HPP shows that above 50% of the catchment at the intake lies above 5000 m elevation which means the catchment is highly influenced by snow contribution.

## Climate

Since, the catchment of Myagdi Khola has wide variation in elevation, its climatic condition varies with altitude. As per climatic zone of Nepal, the catchment lies in between cool (2,000-3,000m) zone having mean annual air temperature of 10°to 15°C and arctic (4,500-5,000m) zone having mean annual air temperature of 0°to 2.5°C. The catchment at upper reach is surrounded by High Himalayan, thus having an arctic climate zone and the lower reach below the catchment has warm temperate climate zone having mean annual air temperature of 15° to 20°C.

The High Mountain Range in the north essentially forms a barrier forcing the monsoon brought about by orographic effects to pour down south of this range. Rainfall intensity varies throughout the catchment according to the degree of exposure with maximum intensities occurring on the south facing slopes. Rainfall intensity also varies in the catchment with elevation. In general, the amount of precipitation is highest in the south at the lower elevations and gradually decreases to the north with increase in elevation.

Winter precipitation in the region is sparse and falls as snow on the higher peaks. The period from October to November represents a general climatic transition to winter conditions. Rainfall is rare during this period. From the end of January until May, the region becomes progressively warmer. The permanent snow line is at El. 5000 m. From March onwards the snow line shifts upwards resulting in a gradual increase in river flows due to snowmelt.

## Available Data

## Hydrological Data

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| Figure ‑: Nearby river gauging stations considered for Myagdi Khola |

Proposed intake sites of the Myagdi Khola does not have any long-term stream flows record. However, there is a gauging station no. 404.7 established by the department of Hydrology and Meteorology along the Myagdi Khola at Mangalaghat which is approximately 33km downstream from the proposed intake of Myagdi Khola HPP. Similarly, in the vicinity of the project area toward the east, there are also other five gauging stations (406.5, 428, 430, 438 and 439.7) having time series of data more than 20 years. These stations have been considered for the purpose of regional hydrological analysis. The western side of the catchment does not have any gauging stations having similar physiographic characteristics. The characteristics of these gauging stations are presented in Table 1‑3: Hydrometric Stations located near the project catchment and their locations in Figure 1‑2.

Table ‑: Hydrometric Stations located near the project catchment

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **S. N** | **Station** | **River** | **Location** | **Elevation (m)** | **Data Record** | | **Catchment Area**  **(km2)** |
|  |  | **Length** | **Period** |
| 1 | 404.7 | Myagdi Khola | Mangalaghat | 914 | 39 | 1976 - 2015 | 1067.71 |
| 2 | 406.5 | Modi Khola | Nayapul | 701 | 39 | 1976 - 2015 | 558.09 |
| 3 | 428 | Mardi Khola | Lahachowk | 915 | 41 | 1974 - 2015 | 139.50 |
| 4 | 430 | Seti Nadi | Phoolbari | 830 | 20 | 1964 - 1984 | 537.01 |
| 5 | 438 | Madi Nadi | Shisaghat | 457 | 45 | 1963 - 2008 | 847.12 |
| 6 | 439.7 | Marsyandi Nadi | Bimalnagar | 354 | 28 | 1987 - 2015 | 4055.12 |

Modi Khola, Seti Nadi and Madi Nadi originate from Annapurna Himalayan Range whereas, Myagdi Khola originates from Dhaulagiri Himalayan Range and Marsyandi Nadi originates from Annapurna Himalayan Range and Manaslu Himal. Mardi Khola is a tributary of Seti Nadi. Since Dhaulagiri Himalayan Range, Annapurna Himalayan Range and Manaslu Himal are nearest to each other; their physiographic characteristics can be considered to be similar. The daily flow data of adopted gauge stations have been included in Annex A of this report.

## Gauge installation and data recording

Discharges have been measured in Myagdi Khola at four different locations by current meter. The location is:

Table ‑: Location of Discharge measurement in Myagdi Khola

|  |  |  |  |
| --- | --- | --- | --- |
| **S.N.** | **Location** | **Longitude** | **Latitude** |
| 1 | Upstream of confluence at Myagdi Khola (Headworks at Myagdi Khola) | 83°23'39.96" | 28°37'52.58" |
| 2 | Upstream of confluence at Kunaban Khola (Headworks at Kunaban Khola) | 83°22'6.61" | 28°37'59.30" |
| 3 | Downstream of Confluence at Dovan | 83°23'40.67" | 28°37'40.55" |
| 4 | Jeltung, near PH location of MKHPP | 83°23'10.02" | 28°34'5.95" |

The measured discharge received till date, at the downstream of confluence at Dovan are used for the comparison with adopted flow for MKHPP. These measured flows are shown in Table 1‑4 below. Also, an Automatic Water Level Recorder (AWLR) has been installed in the confluence area, which is used to measure water depth. The available discharges and stages measured as shown in Table 1‑5 have been used to create a rating curve for Myagdi Khola as shown in Figure 1‑3.

Table ‑: Summary of Measured discharge at downstream of Confluence of Myagdi and Kunban (at Dovan)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Months** | **Measured Discharge(m3/s)** | | | |
| **Daily** | **Average** | **Minimum** | **Maximum** |
| Baishakh | 7.157, 12.31, 7.25, 8.15 | **8.72** | **7.157** | **12.31** |
| Jestha | 17.08 | **17.08** | **17.08** | **17.08** |
| Asar |  |  |  |  |
| Shrawan | 32.54, 28.48 | **30.51** | **28.48** | **32.54** |
| Bhadra | 29.18, 30.57 | **29.88** | **29.18** | **30.57** |
| Asoj |  |  |  |  |
| Kartik |  |  |  |  |
| Mangsir | 5.325 | **5.33** | **5.325** | **5.325** |
| Paush | 4.652, 3.39, 4.612 | **4.22** | **3.39** | **4.652** |
| Magh | 3.465, 3.512, 4.206, 4.016, 3.928 | **3.83** | **3.465** | **4.206** |
| Falgun | 4.134, 4.292, 4.297, 4.897, 4.373, 4.249, 3.939, 3.11 | **4.31** | **3.11** | **4.897** |
| Chaitra | 5.965, 5.618, 5.665, 5.858, 9.03 | **6.43** | **5.618** | **9.03** |

Table ‑: Summary of available stage and discharge data at downstream of confluence of Myagdi and Kunban (at Dovan)

|  |  |  |
| --- | --- | --- |
| **Date** | **Discharge (m3/s)** | **Stage (m)** |
| 16 Poush 2076 | 3.39 | 0.46 |
| 1 Falgun 2076 | 3.11 | 0.45 |
| 16 Chaitra 2076 | 9.03 | 0.66 |
| 11 Baisakh 2077 | 12.31 | 0.85 |
| 1 Jestha 2077 | 17.08 | 1.24 |
| 10 Baisakh 2078 | 7.25 | 0.75 |
| 17 Baisakh 2078 | 8.15 | 0.78 |
| 16 Shrawan 2078 | 32.54 | 3.19 |
| 17 Shrawan 2078 | 28.48 | 2.92 |
| 15 Bhadra 2078 | 29.18 | 3.05 |
| 16 Bhadra 2078 | 30.57 | 3.1 |

|  |
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| Figure ‑: Stage Discharge (Rating) curve for Myagdi Khola HPP developed from available data till date |

The rating curve has been prepared with very limited data so it is recommended to perform continuous measurements of discharge and stage in the desired project area. At least 2 years’ data is required to develop a reliable rating curve. Furthermore, the rating curve has been prepared from dry season flow only, hence two rating curves including wet season flow should be developed.

The equation of the rating curve is given by,

Where α stage in the river when there is no discharge in river, Q is discharge in river in m3/s, G is height of water in m, Cr and β are the calibration parameters.

The equation of the rating curve after calibration is found to be,

## Meteorological Data

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| Figure ‑: Nearby meteorological stations considered for Myagdi Khola |

Precipitations data are important to know the weather condition of the project site as well as to derive the hydrological parameters. There are no established rainfall stations within Myagdi Khola catchment. The rainfall data from the stations located in the vicinity of the Myagdi catchment have been collected from DHM. Also, the rainfall stations in the vicinity of the gauging stations considered for the hydrological analysis of Myagdi Khola have been collected from DHM. All the rainfall stations considered during the analysis are presented in Table 1‑6 and their locations are shown in Figure 1‑4. Although the span of data record available has been stated in the table below, there are many missing data. Also, some stations have years in between with no data. The mean monthly precipitation data have been included in Annex A of this report.

Table ‑: Metrological stations laying in the vicinity of the catchment

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **S. N** | **Stn No.** | **Stn. Name** | **Latitude** | **Longitude** | **Elevation (masl)** | **Data Record, available** | **Annual Precipitation, mm** |
| 1 | 604 | Thakmarpha | 28.75 | 83.7 | 2566 | 1967-2020 | 401 |
| 2 | 605 | Baglung | 28.26 | 83.6 | 984 | 1978-2014 | 1870 |
| 3 | 606 | Tatopani | 28.48 | 83.65 | 1243 | 1978-2008 | 1577 |
| 4 | 607 | Lete | 28.63 | 83.6 | 2384 | 1970-2021 | 1310 |
| 5 | 608 | Ranipauwa (M.Nath) | 28.81 | 83.88 | 3609 | 1978-2013 | 260 |
| 6 | 609 | Beni Bazar | 28.35 | 83.56 | 835 | 1979-2008 | 1544 |
| 7 | 616 | Gurja Khani | 28.6 | 83.21 | 2530 | 1979-2014 | 1887 |
| 8 | 619 | Ghorepani | 28.4 | 83.73 | 2742 | 1975-2010 | 2804 |
| 9 | 621 | Darbang | 28.38 | 83.4 | 1160 | 1989-2010 | 1979 |
| 10 | 627 | Kuhun | 28.38 | 83.48 | 1550 | 1992-2010 | 1539 |
| 11 | 628 | Muna | 28.5 | 83.3 | 1970 | 1992-2010 | 2479 |
| 12 | 629 | Baghara | 28.56 | 83.38 | 2330 | 1992-2020 | 2919 |
| 13 | 801 | Jagat (Setibas) | 28.36 | 84.9 | 1334 | 1979-2008 | 1202 |
| 14 | 802 | Khudi Bazar | 28.28 | 84.36 | 832 | 1979-2008 | 3381 |
| 15 | 804 | Pokhara Airport | 28.21 | 84 | 827 | 1979-2008 | 3921 |
| 16 | 806 | Larke Samdo | 28.66 | 84.61 | 3650 | 1978-2010 | 966 |
| 17 | 807 | Kunchha | 28.13 | 84.35 | 855 | 1979-2008 | 2589 |
| 18 | 808 | Bandipur | 27.93 | 84.41 | 965 | 1979-2008 | 1766 |
| 19 | 809 | Gorkha | 28 | 84.61 | 1097 | 1979-2008 | 1656 |
| 20 | 813 | Bhadaure Deurali | 28.26 | 83.81 | 1600 | 1985-2008 | 4051 |
| 21 | 814 | Lumle | 28.3 | 83.8 | 1740 | 1979-2008 | 5459 |
| 22 | 815 | Khairini Tar | 28.03 | 84.1 | 500 | 1979-2008 | 2348 |
| 23 | 816 | Chame | 28.55 | 84.23 | 2680 | 1979-2012 | 918 |
| 24 | 817 | Damauli | 27.96 | 84.28 | 358 | 1979-2008 | 1806 |
| 25 | 818 | Lamachaur | 28.26 | 83.96 | 1070 | 1979-2008 | 4191 |
| 26 | 820 | Manang Bhot | 28.66 | 84.01 | 3420 | 1979-2012 | 430 |
| 27 | 821 | Ghandruk | 28.38 | 83.8 | 1960 | 1976-2010 | 3254 |
| 28 | 823 | Gharedhunga | 28.2 | 84.61 | 1120 | 1979-2010 | 3019 |
| 29 | 824 | Siklesh | 28.36 | 84.1 | 1820 | 1979-2008 | 3773 |
| 30 | 829 | Sallyan | 28.26 | 83.75 | 100 | 1992-2010 | 3851 |
| 31 | 830 | Pamdur | 28.26 | 83.78 | 1160 | 1992-2010 | 5012 |

## Basin rainfall

Annual average basin rainfall of the catchments has been recalculated from the rainfall stations presented in Table 1‑6 using interpolation methods of IDW, Thiessen Polygon and creating Isohyets and from Natural neighbor method. Result of the analysis is presented hereunder in Table 1‑7.

Table ‑: Basin average annual rainfall

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Catchment** | **Basin average Annual Precipitation (mm)** | | | | |
| **Annual Average of satellite data** | **IDW** | **Theissen Polygon** | **Isohyetal (Kriging)** | **Natural Neighbour** |
| Myagdi khola @ Mangalaghat (404.7) | 1757 | 2108 | 2245 | 2146 | 1878 |
| Modikhola @ Nayapul (406.5) | 3145 | 3058 | 2745 | 2609 | 2550 |
| Mardikhola @ Lahachowk (428.0) | 4302 | 3827 | 3791 | 3748 | 3403 |
| Seti khola @ Phoolbari (430.0) | 3250 | 3446 | 3300 | 3174 | 3022 |
| Madi Khola @ Shisaghat (438.0) | 2822 | 3180 | 3196 | 3086 | 3080 |
| Marshyandi khola @ Bimalnagar (439.7) | 1705 | 1870 | 1615 | 1685 | 1556 |
|  |  |  |  |  |  |
| Myagdi Intake | 1544 | 1792 | 2016 | 1835 | 1154 |
| Kunaban Intake | 2403 | 2112 | 2515 | 2190 | 1452 |
| Myagdi Khola HPP \_intake | 1629 | 1952 | 2171 | 2013 | 1303 |
| Myagdi Khola HPP \_tailrace | 1629 | 1958 | 2261 | 2001 | 1339 |
| **Remarks** |  |  |  | **Adopted** |  |

Due to less dense precipitation stations near catchment area, IDW cannot give the correct result as compared to isohyetal method. Theissen polygon does not consider the impact of all the stations in the proximity. Natural neighbour method is highly sensitive to the spatial pattern of the data locations. Hence, the result from isohyetal method is adopted as it also includes the effects of local features. The detailed calculation has been included in Annex A of this report.

## Long term mean monthly flow

The daily flow data and long term mean monthly flow is to be derived from indirect methods. Mean monthly flow adopted in the updated feasibility study of MKHPP by Technoquarry has been crosschecked with the flow estimated from current updated feasibility study by HCE. A minor difference has been noticed between the flow adopted in the previous UFSR and current UFSR study. In the previous report, the catchment area from DHM had been considered for the calculation, whereas in the current study, the catchment area has been recalculated using 90m SRTM DEM. The mean monthly flow has been recalculated from various methods in this updated feasibility study. In this review, updated data up to 2015 has been considered while in previous study, flow data up to 2006 was considered.

Flow measurement data available till date, at the downstream of confluence, at Dovan have also been used to validate the adopted mean monthly flow for MKHPP. The adopted mean monthly flow will be further validated with the measured flow data after getting more data as the flow measurement has been ongoing since April 2015.

The brief description of the methods adopted to calculate the mean monthly flow and comparison of the results from these methods are given in following sub-sections.

## Catchment Correlation

Since there is no availability of hydrological data of the project area, an attempt was made to correlate the flows using the area ratio from the flows with Myagdi Khola at Mangalaghat in previous Updated Feasibility Study. In this study, Catchment correlation has been performed with other six nearby gauging stations as well. The catchment parameters of intake at Myagdi, intake at kunaban and total of these two catchments are tabulated in Table 1‑8 for comparison of the catchment characteristics.

Table ‑: Catchment parameters

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Elevation (masl)** | **Myagdi Intake** | | **Kunaban Intake** | | **Total Catchment contributing to Intake of MKHPP** | |
| **Area (km2)** | **%** | **Area (km2)** | **Area (km2)** | **%** | **%** |
| >5000 | 128.9 | 61.4% | 56.8 | 59.7% | 185.7 | 60.9% |
| 5000-3000 | 78.1 | 37.2% | 35.0 | 36.9% | 113.1 | 37.1% |
| <3000 | 2.98 | 1.4% | 3.24 | 3.4% | 6.22 | 2.0% |
| Total | **210.1** | 100.0% | **95.0** | 100.0% | **305.1** | 100.0% |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Elevation (masl)** | **Myagdi khola @ Mangalaghat (404.7)** | | **Modi khola @ Nayapul (406.5)** | | **Mardi khola @ Lahachowk (428.0)** | | **Seti khola @ Phoolbari (430.0)** | | **Madi Khola @ Shisaghat (438.0)** | | **Marshyandi khola @ Bimalnagar (439.7)** | |
|  | **Area (km2)** | **%** | **Area (km2)** | **%** | **Area (km2)** | **%** | **Area (km2)** | **%** | **Area (km2)** | **%** | **Area (km2)** | **%** |
| >5000 | 206.4 | 19.3% | 117.8 | 21.1% | 0.4 | 0.3% | 48.7 | 9.1% | 62.0 | 7.3% | 1157.6 | 28.5% |
| 5000-3000 | 338.9 | 31.7% | 174.4 | 31.2% | 26.0 | 18.6% | 181.5 | 33.8% | 164.5 | 19.4% | 1557.5 | 38.4% |
| <3000 | 522.4 | 48.9% | 265.9 | 47.6% | 113.1 | 81.1% | 306.7 | 57.1% | 620.6 | 73.3% | 1340.0 | 33.0% |
| Total | 1067.7 | 100.0% | 558.1 | 100.0% | 139.5 | 100.0% | 537.0 | 100.0% | 847.1 | 100.0% | 4055.1 | 100.0% |

The catchment of Myagdi Khola HPP at intake (Myagdi and Kunaban Khola) and nearby gauging stations considered for hydrological analysis has been shown in Figure 1‑2 above.

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The catchment of Myagdi Khola HPP which comprises of Myagdi Khola Intake and Kunaban Khola Intake has been correlated with the catchment of the DHM’s gauging station no. 404.7 along the Myagdi Khola at Mangalaghat to generate the mean daily flows at proposed intake site of Myagdi Khola HPP. The similar procedure has been followed to correlate with other five nearby catchments (mentioned in section 1.4.1). The calculated long-term mean daily flows in English Calendar has been converted into Nepali Calendar based on 2077 BS and finally, mean daily flows in the corresponding Nepali month were averaged to calculate the long-term mean monthly flow. The summary of mean monthly flow at the intake of Myagdi Khola, Kunaban Khola and intake of MKHPP (sum of Myagdi intake and Kunaban intake) from catchment correlation method with six gauging stations have been tabulated in Table 1‑9, Table 1‑10, and Table 1‑11 respectively.

Table ‑: Long-term mean monthly flows by catchment correlation (CAR) at Myagdi Khola Intake

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Month** | **Mean monthly flow at the intake of Myagdi Khola by CAR with** | | | | | |
| **Myagdi khola @ Mangalaghat (404.7)** | **Modi khola @ Nayapul (406.5)** | **Mardi khola @ Lahachowk (428.0)** | **Seti khola @ Phoolbari (430.0)** | **Madi Khola @ Shisaghat (438.0)** | **Marshyandi khola @ Bimalnagar (439.7)** |
| *CAR Coefficient* | **0.09** | **0.17** | **0.68** | **0.18** | **0.11** | **0.02** |
| Baisakh | 4.03 | 5.56 | 4.58 | 5.64 | 5.27 | 3.43 |
| Jestha | 8 | 10.67 | 8.84 | 9.75 | 10.31 | 7.18 |
| Ashar | 25.63 | 38.79 | 41.48 | 32.77 | 34.72 | 22.22 |
| Shrawan | 45.41 | 82.1 | 76.39 | 57.6 | 54.01 | 33.89 |
| Bhadra | 38.12 | 56.08 | 71.66 | 47.49 | 48.31 | 31.24 |
| Ashoj | 17.34 | 25.28 | 34.89 | 29.56 | 23.89 | 15.31 |
| Kartik | 7.94 | 10.18 | 13.71 | 12.6 | 10.68 | 6.74 |
| Mangsir | 4.75 | 6.57 | 7.43 | 7.65 | 6.54 | 4.05 |
| Poush | 3.45 | 4.84 | 5.54 | 5.47 | 4.82 | 3 |
| Magh | 2.79 | 3.89 | 4.62 | 4.56 | 4.04 | 2.48 |
| Falgun | 2.5 | 3.43 | 4.25 | 4.2 | 3.7 | 2.34 |
| Chaitra | 2.86 | 3.79 | 4.09 | 4.37 | 3.91 | 2.45 |
| **Average** | **13.6** | **20.9** | **23.1** | **18.5** | **17.5** | **11.2** |

Table ‑: Long-term mean monthly flows by catchment correlation (CAR) at Kunaban Khola Intake

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Month** | **Mean monthly flow at the intake of Kunaban Khola by CAR with** | | | | | |
| **Myagdi khola @ Mangalaghat (404.7)** | **Modi khola @ Nayapul (406.5)** | **Mardi khola @ Lahachowk (428.0)** | **Seti khola @ Phoolbari (430.0)** | **Madi Khola @ Shisaghat (438.0)** | **Marshyandi khola @ Bimalnagar (439.7)** |
| *CAR Coefficient* | **0.29** | **0.55** | **2.19** | **0.57** | **0.36** | **0.08** |
| Baisakh | 1.82 | 2.51 | 2.07 | 2.55 | 2.38 | 1.55 |
| Jestha | 3.62 | 4.83 | 4 | 4.41 | 4.67 | 3.25 |
| Ashar | 11.6 | 17.55 | 18.77 | 14.83 | 15.71 | 10.05 |
| Shrawan | 20.55 | 37.15 | 34.57 | 26.06 | 24.44 | 15.34 |
| Bhadra | 17.25 | 25.38 | 32.42 | 21.49 | 21.86 | 14.13 |
| Ashoj | 7.84 | 11.44 | 15.79 | 13.38 | 10.81 | 6.93 |
| Kartik | 3.59 | 4.61 | 6.21 | 5.7 | 4.83 | 3.05 |
| Mangsir | 2.15 | 2.97 | 3.36 | 3.46 | 2.96 | 1.83 |
| Poush | 1.56 | 2.19 | 2.51 | 2.48 | 2.18 | 1.36 |
| Magh | 1.26 | 1.76 | 2.09 | 2.06 | 1.83 | 1.12 |
| Falgun | 1.13 | 1.55 | 1.92 | 1.9 | 1.68 | 1.06 |
| Chaitra | 1.29 | 1.71 | 1.85 | 1.98 | 1.77 | 1.11 |
| **Average** | **0.29** | **0.55** | **2.19** | **0.57** | **0.36** | **0.08** |

Table ‑: Long-term mean monthly flows by catchment correlation (CAR) for MKHPP intake (sum of Table 1‑9 and Table 1‑10)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Month** | **Mean monthly flow at the MKHPP Intake by CAR with** | | | | | |
| **Myagdi khola @ Mangalaghat (404.7)** | **Modi khola @ Nayapul (406.5)** | **Mardi khola @ Lahachowk (428.0)** | **Seti khola @ Phoolbari (430.0)** | **Madi Khola @ Shisaghat (438.0)** | **Marshyandi khola @ Bimalnagar (439.7)** |
| *CAR Coefficient* | **0.2** | **0.38** | **1.51** | **0.39** | **0.25** | **0.05** |
| Baisakh | 5.85 | 8.07 | 6.65 | 8.19 | 7.65 | 4.98 |
| Jestha | 11.62 | 15.5 | 12.84 | 14.16 | 14.98 | 10.43 |
| Ashar | 37.22 | 56.34 | 60.24 | 47.6 | 50.43 | 32.28 |
| Shrawan | 65.96 | 119.24 | 110.96 | 83.67 | 78.45 | 49.23 |
| Bhadra | 55.37 | 81.46 | 104.08 | 68.98 | 70.17 | 45.37 |
| Ashoj | 25.18 | 36.72 | 50.68 | 42.94 | 34.7 | 22.24 |
| Kartik | 11.53 | 14.79 | 19.92 | 18.31 | 15.51 | 9.79 |
| Mangsir | 6.90 | 9.55 | 10.8 | 11.11 | 9.49 | 5.88 |
| Poush | 5.00 | 7.03 | 8.04 | 7.95 | 7.00 | 4.35 |
| Magh | 4.06 | 5.65 | 6.72 | 6.62 | 5.86 | 3.6 |
| Falgun | 3.63 | 4.98 | 6.17 | 6.11 | 5.38 | 3.39 |
| Chaitra | 4.15 | 5.5 | 5.94 | 6.35 | 5.68 | 3.55 |
| **Average** | **19.71** | **30.4** | **33.59** | **26.83** | **25.44** | **16.26** |

## Regional Regression Analysis

The regional analysis method has been used to estimate mean flow series at the proposed intake site. In this method, the long term mean monthly flow has been estimated from the relationship obtained between the monthly flow of each month of the known stations and their respective catchment area.

The regression analysis is carried out between the monthly flow of the known stations for each month and their respective catchment area and the equation obtained is as follows:

Y=aX^b

Where

Y=Mean monthly flow for each month at the proposed intake site

X=Catchment area at the intake site, Km2

a and b= constants generated from the graph

The gauging stations considered for the development of regional regression equation between mean monthly flow and the catchment area are presented in Table 1‑12.

Table ‑: Details of stations considered for regional regression

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **SN.** | **Station** | **River** | **Location** | **Data Record** | **Catchment Area (Km2)** |
| 1 | 404.7 | Myagdi | Mangalaghat | 1976-2015 | 1067.71 |
| 2 | 406.5 | Modi | Nayapul | 1976-2015 | 558.09 |
| 3 | 428.0 | Mardi | Lahachowk | 1974-2015 | 139.50 |
| 4 | 430.0 | Seti | Phoolbari | 1964-1984 | 537.01 |
| 5 | 438.0 | Madi | Shisaghat | 1963 - 2008 | 847.12 |
| 6 | 439.7 | Marshyandi | Bimalnagar | 1987 - 2015 | 4055.12 |

For all reference six gauging stations in the vicinity of the project area, available daily flows of the corresponding day in the corresponding year were averaged to calculate the long-term mean daily flow. The calculated long-term mean daily flows in English Calendar were converted into Nepali Calendar based on 2077 BS and then, mean daily flows in the corresponding Nepali month were averaged to calculate the long-term mean monthly flow as tabulated in Table 1‑13.

Table ‑: Long-term mean monthly flow of the reference gauging stations

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Month** | **Myagdi Khola (404.7)** | **Modi Khola (406.5)** | **Mardi Khola (428)** | **Seti Nadi (430)** | **Madi Nadi (438)** | **Marsyandi Nadi (439.7)** |
| C.A, km2 | 1067.71 | 558.09 | 139.50 | 537.01 | 847.12 | 4055.12 |
| Baishakh | 20.49 | 14.76 | 3.04 | 14.42 | 21.25 | 66.14 |
| Jesth | 40.68 | 28.35 | 5.87 | 24.93 | 41.60 | 138.64 |
| Ashar | 130.27 | 103.07 | 27.55 | 83.79 | 140.05 | 429.03 |
| Shrawan | 230.85 | 218.14 | 50.74 | 147.28 | 217.84 | 654.34 |
| Bhadra | 193.80 | 149.02 | 47.59 | 121.42 | 194.84 | 603.12 |
| Ashoj | 88.13 | 67.17 | 23.18 | 75.59 | 96.35 | 295.69 |
| Kartik | 40.37 | 27.05 | 9.11 | 32.22 | 43.06 | 130.19 |
| Mangsir | 24.16 | 17.46 | 4.94 | 19.56 | 26.36 | 78.19 |
| Poush | 17.51 | 12.86 | 3.68 | 11.65 | 19.45 | 57.84 |
| Magh | 14.21 | 10.34 | 3.07 | 14.00 | 16.28 | 47.86 |
| Falgun | 12.69 | 9.12 | 2.82 | 10.75 | 14.94 | 45.09 |
| Chaitra | 14.54 | 10.06 | 2.72 | 11.18 | 15.76 | 47.23 |
| **Average** | **20.49** | **14.76** | **3.04** | **14.42** | **21.25** | **66.14** |

The calculated long-term mean monthly flows against total catchment area of the corresponding reference gauging stations were plotted on a log scale for each month of the year (Baishakh to Chaitra). The regression equations along with the corresponding coefficient of correlation R2, thus obtained, for each month were used to estimate the long-term mean monthly flow at the proposed intake site of Myagdi Khola, Kunaban Khola and intake of MKHPP as presented in Table 1‑14, Table 1‑15, and Table 1‑16 respectively.

Table ‑: Long-term mean monthly flows at Myagdi Khola intake from regional regression analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Month** | **Regression Equation** | **Value of R2** | **Discharge (m3/s)** |
| Baishakh | Y=0.045X^0.8935 | 0.9736 | 5.34 |
| Jestha | Y=0.0707X^0.9249 | 0.9837 | 9.93 |
| Ashar | Y=0.5568X^0.8028 | 0.9848 | 40.73 |
| Shrawan | Y=1.488X^0.7387 | 0.9618 | 77.25 |
| Bhadra | Y=1.1954X^0.7465 | 0.99 | 64.7 |
| Ashoj | Y=0.6394X^0.7353 | 0.9792 | 32.6 |
| Kartik | Y=0.2101X^0.7752 | 0.9831 | 13.25 |
| Mangsir | Y=0.1072X^0.7998 | 0.9775 | 7.71 |
| Poush | Y=0.0723X^0.8079 | 0.9869 | 5.43 |
| Magh | Y=0.0729X^0.7866 | 0.9544 | 4.89 |
| Falgun | Y=0.0579X^0.8031 | 0.9745 | 4.24 |
| Chaitra | Y=0.0512X^0.8301 | 0.9793 | 4.33 |

Note: Y=long-term mean monthly flow in m3/s and X=drainage area in km2.

In above table, the values of R2 are more than 0.90 for each month. Thus, it shows a good fit between the data and the generated regression equations for each month can give reliable results.

Table ‑: Long-term mean monthly flows of Kunaban Khola Intake from regional regression analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Month** | **Regression Equation** | **Value of R2** | **Discharge (m3/s)** |
| Baishakh | Y=0.045X^0.8935 | 0.9736 | 2.63 |
| Jestha | Y=0.0707X^0.9249 | 0.9837 | 4.77 |
| Ashar | Y=0.5568X^0.8028 | 0.9848 | 21.55 |
| Shrawan | Y=1.488X^0.7387 | 0.9618 | 43.01 |
| Bhadra | Y=1.1954X^0.7465 | 0.99 | 35.79 |
| Ashoj | Y=0.6394X^0.7353 | 0.9792 | 18.20 |
| Kartik | Y=0.2101X^0.7752 | 0.9831 | 7.17 |
| Mangsir | Y=0.1072X^0.7998 | 0.9775 | 4.09 |
| Poush | Y=0.0723X^0.8079 | 0.9869 | 2.86 |
| Magh | Y=0.0729X^0.7866 | 0.9544 | 2.62 |
| Falgun | Y=0.0579X^0.8031 | 0.9745 | 2.24 |
| Chaitra | Y=0.0512X^0.8301 | 0.9793 | 2.24 |

Note: Y=long-term mean monthly flow in m3/s and X=drainage area in km2.

In above table, the values of R2 are more than 0.90 for each month. Thus, it shows a good fit between the data and the generated regression equations for each month can give reliable results.

Table ‑: Long-term mean monthly flows at MKHPP intake from regional regression analysis (sum of Table 1‑14 and Table 1‑15)

|  |  |
| --- | --- |
| **Month** | **Discharge (m3/s)** |
| Baishakh | 7.45 |
| Jestha | 14.02 |
| Ashar | 54.96 |
| Shrawan | 101.78 |
| Bhadra | 85.48 |
| Ashoj | 42.90 |
| Kartik | 17.70 |
| Mangsir | 10.40 |
| Poush | 7.34 |
| Magh | 6.55 |
| Falgun | 5.72 |
| Chaitra | 5.91 |

## Adopted Long-term Mean Monthly Flow

*In Previous Updated Feasibility Study (by Technoquarry)*

In the previous updated feasibility study (by Techno-quarry), the mean monthly flow was calculated using CAR with Mangalaghat and from regional regression analysis using the long term mean monthly flow of nearby stations: 404.7, 406.5, 428, 430, 438, and 439.7. The long-term mean monthly flows calculated from the catchment correlation with Myagdi Khola (404.7) were on lower side whereas the same flows calculated using regional regression analysis of reference six gauging stations were on higher side.

The reasons for lower value from the catchment correlation with Myagdi Khola (404.7) were due to:

* location (42Km downstream from proposed intake site) and
* large catchment area of the DHM’s gauging station 404.7 (3.5 times the catchment of the proposed intake site).

98% of the catchment at proposed intake site of Myagdi Khola HPP lies above 3000m which means the catchment is highly influenced by snow contribution. Regional regression analysis is one of the commonly précised method for estimating mean monthly flow which gives reasonable acceptable result and can be adopted where there are no other better alternatives or direct data is not available from the concerned river. Therefore, to be in conservative side, average of these two methods was recommended to calculate the long-term mean monthly flow at proposed intake site of the MKHPP as presented in Table 1‑17.

Table ‑: Adopted long-term mean monthly flow at MKHPP intake in previous UFSR

|  |  |  |  |
| --- | --- | --- | --- |
| **Month** | **CAR with Myagdi Khola (404.7)** | **Regional regression analysis** | **Adopted Discharge (Average)** |
| Baishakh | 5.18 | 6.82 | 6.00 |
| Jestha | 9.17 | 12.42 | 10.80 |
| Ashar | 32.8 | 52.44 | 42.62 |
| Shrawan | 62.34 | 100.53 | 81.44 |
| Bhadra | 52.39 | 83.75 | 68.07 |
| Asoj | 23.27 | 43 | 33.14 |
| Kartik | 10.33 | 17.23 | 13.78 |
| Mangsir | 5.91 | 9.81 | 7.86 |
| Poush | 4.36 | 7.09 | 5.73 |
| Magh | 3.55 | 5.78 | 4.67 |
| Falgun | 3.2 | 5.14 | 4.17 |
| Chaitra | 3.61 | 5.3 | 4.46 |
| **Average** | **18.01** | **29.11** | **23.56** |

*In Present Updated Feasibility Study (by HCE)*

PPA agreement has already been done for Myagdi Khola HPP based on previous UFSR. The flow adopted in PPA agreement for MKHPP has been tabulated in Table 1‑18 below. In this updated feasibility study, long term mean monthly flow for MKHPP has been estimated using CAR, PCAR and regional regression method referring nearby gauging stations as tabulated in Table 1‑12. As out of six-gauge stations considered, station 404.7 is located at Myagdi Khola, the long term mean monthly flow estimated from CAR and PCAR using this station has been tabulated below for comparison. Also, regression analysis using the reference six gauging stations considered are presented in Table 1‑18 below. The available daily measured data at Dovan (confluence of Myagdi and Kunaban), tabulated in Table 1‑4 above have also been presented in the table below for comparison. Along with the comparison table, these long term monthly average flow data have been plotted in a graph with the measured flow data as shown in Plate 1‑6 below.

Table ‑: Comparison of long-term mean monthly flow at intake of MKHPP (Myagdi intake+ Kunaban intake)

| **Month** | **PPA** | **Present Updated Feasibility Study** | | | **Measured Discharge @ Dovan** | | **Adopted Flow (PPA flow)** | **Remarks** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **CAR** | **PCAR** | **Regional analysis** | **Daily** | **Avg.** |
| Baisakh | 6.09 | 5.85 | 5.49 | 7.45 | 7.157, 12.31, 7.25, 8.15 | 8.72 | 6.09 | Measured discharges are on higher side compared to adopted flow. |
| Jestha | 11.8 | 11.62 | 10.90 | 14.02 | 17.08 | 17.08 | 11.8 | Measured discharge is on higher side compared to adopted flow. Also, the adopted flow is comparable to the flow calculated from CAR. |
| Ashar | 45.42 | 37.22 | 34.91 | 54.96 |  |  | 45.42 |  |
| Shrawan | 73.28 | 65.96 | 61.87 | 101.78 | 32.54, 28.48 | 30.51 | 73.28 |  |
| Bhadra | 65.41 | 55.37 | 51.94 | 85.48 | 29.18, 30.57 | 29.88 | 65.41 |  |
| Ashoj | 36.1 | 25.18 | 23.62 | 42.90 |  |  | 36.1 |  |
| Kartik | 13.49 | 11.53 | 10.82 | 17.70 |  |  | 13.49 |  |
| Mangsir | 7.11 | 6.90 | 6.48 | 10.40 | 5.325 | 5.325 | 7.11 | The adopted flow is comparable to the flow calculated from CAR and on the higher side by 32%-34% in comparison to the average of available measured flow. More measured data are needed for validation. |
| Poush | 5.56 | 5.00 | 4.69 | 7.34 | 4.652, 3.39, 4.612 | 4.218 | 5.56 |
| Magh | 4.54 | 4.06 | 3.81 | 6.55 | 3.465, 3.512, 4.206, 4.016, 3.928 | 3.8254 | 4.54 | The adopted flow is comparable to the flow calculated from CAR and on the higher side by 19% in comparison to the average of available measured flow. More measured data are needed for validation. |
| Falgun | 4.36 | 3.63 | 3.40 | 5.72 | 4.134, 4.292, 4.297, 4.897, 4.373, 4.249, 3.939, 3.11 | 4.31 | 4.36 | Adopted flow is comparable to the measured flow. |
| Chaitra | 4.41 | 4.15 | 3.90 | 5.91 | 5.965, 5.618, 5.665, 5.858, 9.03 | 6.43 | 4.41 | Adopted flow is comparable to the flow calculated from CAR and on the lower side compared to the measured flow. |
| **Avg.** | **23.13** | **19.71** | **18.49** | **30.02** |  |  | **23.13** |  |

|  |
| --- |
| Plate ‑: Mean monthly hydrograph comparison at the intake of MKHPP |
| Plate ‑: Adopted Mean monthly hydrograph at the intake of MKHPP |

The long term mean monthly flow at the intake of MKHPP has been compared in Table 1‑11 and also graphically represented in Plate 1‑6 above. The adopted mean monthly flow for dry months is mostly comparable to the available measured data. Also, they are comparable with the mean monthly flow calculated using CAR with Stn. 404.7 in this Updated Feasibility Study. Hence, the mean monthly flow as considered in PPA and previous feasibility study shall be continued in this updated feasibility study.

## Riparian Release

For growing socioeconomic activities around the project area and also from environmental point of view, the project has to release minimum downstream flow to maintain the natural ecosystem. The downstream release is critical especially in those months when the river flow is less than the design flow. As the downstream release has more impact on the energy production of the project, the trade-off between the river ecosystem and energy cost is very important.

Myagdi Khola Hydropower Project (MKHPP) is conceived as a run-of river type project. The long-term mean monthly flow for driest month, Falgun at the intake of MKHPP is 4.36 m3/s. As per prevailing environment act of Nepal, the downstream release should be 10% of minimum long-term mean monthly flow, i.e., 0.436m3/s will be released downstream as the riparian release for aquatic life.

## Flow Duration Curve (FDC) and Design Discharge

The FDC is a probability discharge curve that shows the percentage of time; a particular flow is equaled or exceeded. In a run-off-the-river hydropower project, it is useful to know the variation of flow over the year to make ease to select the most appropriate turbine configuration as well as for project optimization.

In this updated feasibility study, FDC has been derived from catchment correlation and regional regression method.

## Catchment Correlation

The generated mean daily flows at the proposed intake site of MKHPP from catchment correlation with the DHM’s gauging stations considered (as mentioned in Table 1‑3 above) have been used to calculate the long-term mean daily flows. And based on the generated mean daily flows, flow duration curve has been developed whose values are tabulated in Table 1‑19 below:

Table ‑: Flow duration curve of MKHPP from catchment correlation

| **% Exceedence** | **Derived from daily data generated at Myagdi HPP using CAR with stations** | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **404.7** | **406.5** | **428** | **430** | **438** | **439.7** |
| 1% | 120.56 | 185.38 | 218.69 | 128.58 | 145.69 | 75.98 |
| 5% | 79.15 | 108.23 | 131.13 | 86.92 | 91.47 | 55.37 |
| 10% | 55.72 | 82.00 | 99.50 | 73.85 | 67.34 | 45.44 |
| 15% | 43.71 | 67.21 | 78.29 | 65.90 | 55.10 | 38.74 |
| 20% | 34.29 | 53.73 | 59.26 | 53.68 | 46.46 | 31.36 |
| 25% | 25.83 | 40.34 | 43.74 | 38.52 | 37.09 | 24.77 |
| 30% | 18.23 | 27.11 | 29.96 | 26.30 | 27.16 | 18.13 |
| 35% | 13.46 | 19.02 | 21.19 | 20.74 | 19.19 | 13.09 |
| **40%** | **10.86** | **14.87** | **15.51** | **16.87** | **14.91** | **10.31** |
| 45% | 8.97 | 12.08 | 12.15 | 13.52 | 12.10 | 8.35 |
| 50% | 7.63 | 10.22 | 10.52 | 11.19 | 10.34 | 6.85 |
| 55% | 6.66 | 9.07 | 9.29 | 10.11 | 9.07 | 5.89 |
| 60% | 5.81 | 8.20 | 8.49 | 8.98 | 8.10 | 5.19 |
| 65% | 5.09 | 7.54 | 7.74 | 8.35 | 7.38 | 4.71 |
| 70% | 4.63 | 6.89 | 7.11 | 7.84 | 6.81 | 4.33 |
| 75% | 4.26 | 6.29 | 6.67 | 7.10 | 6.37 | 3.96 |
| 80% | 3.89 | 5.79 | 6.10 | 6.65 | 5.94 | 3.68 |
| 85% | 3.60 | 5.46 | 5.60 | 6.14 | 5.47 | 3.43 |
| 90% | 3.34 | 5.02 | 4.81 | 5.61 | 5.04 | 3.26 |
| 95% | 3.03 | 4.41 | 3.90 | 4.85 | 4.43 | 3.05 |
| 100% | 1.32 | 2.90 | 0.06 | 0.97 | 2.28 | 1.67 |

## Regional Regression Analysis

The flow duration curves of the reference six gauging stations have been developed based on available mean daily flows and tabulated in Table 1‑20 below.

Table ‑: Flow duration curve of the reference gauging stations from regional regression

| **Probability of Exceedence (%)** | **Myagdi Khola (404.7)** | **Modi Khola (406.5)** | **Mardi Khola (428)** | **Seti Nadi (430)** | **Madi Nadi (438)** | **Marsyangdi Nadi (439.7)** |
| --- | --- | --- | --- | --- | --- | --- |
| 5% | 277.00 | 198.00 | 59.96 | 153.00 | 254.00 | 736.00 |
| 10% | 195.00 | 150.00 | 45.50 | 130.00 | 187.00 | 604.00 |
| 15% | 152.99 | 122.95 | 35.80 | 116.00 | 153.00 | 515.00 |
| 20% | 120.00 | 98.30 | 27.10 | 94.50 | 129.00 | 416.80 |
| 25% | 90.40 | 73.80 | 20.00 | 67.80 | 103.00 | 329.25 |
| 30% | 63.80 | 49.59 | 13.70 | 46.30 | 75.41 | 240.94 |
| 35% | 47.10 | 34.80 | 9.69 | 36.50 | 53.30 | 174.00 |
| **40%** | **38.01** | **27.20** | **7.09** | **29.70** | **41.40** | **137.00** |
| 45% | 31.40 | 22.10 | 5.55 | 23.80 | 33.60 | 111.00 |
| 50% | 26.70 | 18.70 | 4.81 | 19.70 | 28.70 | 91.10 |
| 55% | 23.32 | 16.60 | 4.25 | 17.80 | 25.18 | 78.30 |
| 60% | 20.35 | 15.00 | 3.88 | 15.80 | 22.50 | 69.01 |
| 65% | 17.80 | 13.80 | 3.54 | 14.70 | 20.50 | 62.60 |
| 70% | 16.20 | 12.60 | 3.25 | 13.80 | 18.90 | 57.50 |
| 75% | 14.90 | 11.50 | 3.05 | 12.50 | 17.70 | 52.60 |
| 80% | 13.60 | 10.60 | 2.79 | 11.70 | 16.50 | 48.90 |
| 85% | 12.60 | 9.99 | 2.56 | 10.80 | 15.20 | 45.60 |
| 90% | 11.70 | 9.18 | 2.20 | 9.88 | 14.00 | 43.30 |
| 95% | 10.60 | 8.06 | 1.78 | 8.54 | 12.30 | 40.50 |

For each values of the probability of exceedence (5% to 95%), the discharges against total catchment area of the corresponding reference gauging stations were plotted on a log scale. The regression equations along with the corresponding coefficient of correlation R2, thus obtained, for each values of the probability of exceedence were used to develop the flow duration curve at the proposed intake site of MKHPP as presented in Table 2‑24.

Table ‑: Flow duration curve at the intake of MKHPP from regional regression analysis

| **Probability of Exceedence (%)** | **Regression Equation** | **Value of R2** | **Discharge (m3/s)** |
| --- | --- | --- | --- |
| 5% | Y=1.5804X^0.7437 | 0.9899 | 111.27 |
| 10% | Y=1.1303X^0.7549 | 0.9921 | 84.81 |
| 15% | Y=0.8426X^0.7702 | 0.9858 | 69.02 |
| 20% | Y=0.6006X^0.7879 | 0.9808 | 54.43 |
| 25% | Y=0.3903X^0.8111 | 0.9810 | 40.40 |
| 30% | Y=0.2346X^0.8345 | 0.9819 | 27.75 |
| 35% | Y=0.1668X^0.8379 | 0.9823 | 20.11 |
| **40%** | **Y=0.1144X^0.8579** | **0.9809** | **15.47** |
| 45% | Y=0.0859X^0.8689 | 0.9818 | 12.37 |
| 50% | Y=0.0792X^0.8555 | 0.9830 | 10.56 |
| 55% | Y=0.0746X^0.6863 | 0.9798 | 3.78 |
| 60% | Y=0.0718X^0.7437 | 0.9786 | 5.05 |
| 65% | Y=0.0677X^0.7549 | 0.9728 | 5.08 |
| 70% | Y=0.0628X^0.7702 | 0.9700 | 5.14 |
| 75% | Y=0.06X^0.7879 | 0.9711 | 5.44 |
| 80% | Y=0.0543X^0.8111 | 0.9680 | 5.61 |
| 85% | Y=0.0491X^0.8345 | 0.9680 | 5.80 |
| 90% | Y=0.0372X^0.8379 | 0.9679 | 4.48 |
| 95% | Y=0.0247X^0.8579 | 0.9714 | 3.33 |

Note: Y=Discharge in m3/s and X=drainage area in km2.

In above table, the values of R2 are more than 0.90 for each value of the probability of exceedence. Thus, it shows a good fit between the data and the generated regression equations for each value of the probability of exceedence can give reliable results.

## Adopted Flow Duration Curve

*In Previous Updated Feasibility Study (by Technoquarry)*

In the previous updated feasibility study (by Techno-quarry), the flow duration curve at proposed intake site of the Myagdi Khola HPP was developed from catchment correlation with Myadi Khola (404.7) and regression analysis of the reference six gauging stations. The flow duration curve developed from catchment correlation with Myagdi Khola (404.7) were found to be on lower side whereas, the same curve developed from regional regression analysis of the reference six gauging stations were found to be on higher side. The reasons for lower value from the catchment correlation with Myagdi Khola (404.7) are the same as explained in Section 1.6.3. Therefore, to be in safe side, average of these two methods was recommended for use at proposed intake site and tailrace site of the project as tabulated in Table 1‑22.

Table ‑: Adopted Flow duration curve at MKHPP intake in previous UFSR

| **Probability of exceedence** | **CAR with Myagdi Khola (404.7)**  **(I)** | **Regional regression analysis   (II)** | **Adopted  (Average of I & II)** |
| --- | --- | --- | --- |
| 5% | 75.67 | 107.66 | 91.67 |
| 10% | 52.56 | 82.65 | 67.61 |
| 15% | 40.84 | 66.93 | 53.89 |
| 20% | 31.92 | 54.00 | 42.96 |
| 25% | 24.46 | 40.89 | 32.68 |
| 30% | 17.34 | 27.80 | 22.57 |
| 35% | 12.93 | 19.64 | 16.29 |
| **40%** | **10.29** | **14.73** | **12.50** |
| 45% | 8.37 | 11.58 | 9.98 |
| 50% | 7.04 | 9.90 | 8.47 |
| 55% | 6.16 | 8.62 | 7.39 |
| 60% | 5.23 | 7.69 | 6.46 |
| 65% | 4.62 | 7.07 | 5.85 |
| 70% | 4.18 | 6.57 | 5.38 |
| 75% | 3.85 | 6.06 | 4.96 |
| 80% | 3.58 | 5.59 | 4.59 |
| 85% | 3.33 | 5.10 | 4.22 |
| 90% | 3.08 | 4.60 | 3.84 |
| 95% | 2.83 | 3.91 | 3.37 |

*Present Updated Feasibility Study (by HCE)*

In this UFSR, two methods namely catchment correlation and regional regression analysis of the reference gauging stations (as mentioned in Table 1‑3 above) have been used for developing flow duration curve of MKHPP in order to find the 40% dependable flow.

The flow duration curve at proposed intake site of the Myagdi Khola developed from catchment correlation with Myagdi Khola (404.7) and regression analysis of the reference six gauging stations are presented in Table 1‑23. Also, the FDC adopted in previous UFSR for intake at MKHPP have been tabulated in the same table for comparison.

Table ‑: Comparison of developed flow duration curve at intake of MKHPP

| **Probability of exceedence** | **Adopted FDC in previous UFSR** | **FDC calculated in present UFSR** | |
| --- | --- | --- | --- |
| **CAR with Myagdi Khola (404.7)** | **Regional regression analysis** |
| 5% | 91.67 | 79.15 | 111.27 |
| 10% | 67.61 | 55.72 | 84.81 |
| 15% | 53.89 | 43.71 | 69.02 |
| 20% | 42.96 | 34.29 | 54.43 |
| 25% | 32.68 | 25.83 | 40.40 |
| 30% | 22.57 | 18.23 | 27.75 |
| 35% | 16.29 | 13.46 | 20.11 |
| 40% | **12.50** | **10.86** | **15.47** |
| 45% | 9.98 | 8.97 | 12.37 |
| 50% | 8.47 | 7.63 | 10.56 |
| 55% | 7.39 | 6.66 | 3.78 |
| 60% | 6.46 | 5.81 | 5.05 |
| 65% | 5.85 | 5.09 | 5.08 |
| 70% | 5.38 | 4.63 | 5.14 |
| 75% | 4.96 | 4.26 | 5.44 |
| 80% | 4.59 | 3.89 | 5.61 |
| 85% | 4.22 | 3.60 | 5.80 |
| 90% | 3.84 | 3.34 | 4.48 |
| 95% | 3.37 | 3.03 | 3.33 |

Above table shows that the flow duration curve developed from catchment correlation with Myagdi Khola (404.7) are found to be on lower side whereas, the same curve developed from regional regression analysis of the reference six gauging stations are found to be on higher side. The reasons for lower value from the catchment correlation with Myagdi Khola (404.7) are the same as explained in comparison of the long-term mean monthly flows.

Regional regression analysis is one of the commonly practiced method for developing flow duration curve which gives reasonable acceptable result and can be adopted where there are no other better alternatives or direct data is not available from the concerned river. The 40% exceedence flow adopted in previous UFSR was 12.50 m3/s. In this UFSR, the 40 % exceedence flow calculated from CAR with station 404.7 is 10.86 m3/s and from regional regression method is 15.47 m3/s. The adopted design flow in previous UFSR i.e. 12.50 m3/s is obtained at 36.6 % exceedence flow from CAR with Stn. 404.7 and at 44.7% exceedence flow from regional regression method based on present UFS. The average of these two methods gives the 40% exceedence flow as 13.135 m3/s which is higher than that adopted in previous UFSR (12.50 m3/s). Hence, the FDC in previous UFSR has been adopted at the proposed intake site of MKHPP in this updated feasibility study where the design discharge at 40 % exceedence flow at the intake of MKHPP is 12.50 m3/s.

## Flood Flow

Temporary structures like the cofferdams will be designed to resist flood events with a rather short recurrence interval, e.g. 5 to 20 years whereas, design of the permanent structures like diversion weir, intake, drainage works, canal or pipe crossings, powerhouse and tailrace etc. have to be considered the 1 in 100 year to 1 in 10,000-year flood events depending on the risk involved. The selection of the design flood involves considerations as given below:

* Effect of overtopping on the structure
* Cost of structure reconstruction
* Potential loss of life and cost of downstream damage
* Cost of loss of revenue while the structure is out of commission

Since there is no flood data at proposed weir site of the Myagdi Khola, preliminary assessment of peak flows at the intake site was conducted during the previous updated feasibility study with the catchment correlation method from Myagdi at Mangalaghat, Stn 404.7 and from regional regression analysis. The design flood has been re-calculated in this study with the updated data for the refinement of the project hydrology. The extreme floods of various year return periods have been estimated in this study from following methods:

## Catchment Correlation Method

This method is one of the most widely used method in the estimation of extreme flood for ungauged catchment. The flood flows for different return periods at the intake site and powerhouse site of MKHPP were transposed using catchment area ratio. Three frequency analysis: the Gumbel’s method (GEV), Log-Pearson Type III method (LP III) and the Log-normal method (LN) have been used for the review and updating of the design flood. These methods have been commonly used in the flood frequency analysis of the Nepalese river system.

Since the annual instantaneous peak flow series at Myagdi khola is not available, the flood frequency analysis has to be carried out with the reference station instantaneous flood data. The instantaneous flood flow series from Myagdi Khola at Mangalaghat including other similar nature nearby gauging stations have been used for the flood frequency analysis. The flood frequency analysis carried out on the annual flood series generated at the intake site of Myagdi Khola, Kunaban Khola, at intake site of MKHPP and at tailrace site of MKHPP with reference to the historical stream flow records observed at gauging stations 404.7 i.e. Myagdi Khola at Mangalaghat have been shown in Table 1‑24, Table 1‑25, Table 1‑26, and Table 1‑27 respectively below. The extreme flow data is available for the period of 1976 to 2015 for the gauging station at Mangalaghat.

Table ‑24: Estimate of Flood at Intake of Myagdi Khola from various frequency analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Return Period** | **CAR with Myagdi @ Mangalghat** | | |
| **GEV** | **LPIII** | **LN** |
| 2 | 115 | 115 | 114 |
| 5 | 153 | 152 | 159 |
| 10 | 178 | 171 | 188 |
| 20 | 202 | 187 | 217 |
| 50 | 233 | 203 | 254 |
| **100** | **256** | **214** | **283** |
| 200 | 279 | 223 | 312 |
| 500 | 310 | 233 | 351 |
| 1000 | 333 | 239 | 381 |

Table 1‑25: Estimate of Flood at Kunaban Khola from various frequency analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Return Period** | **CAR with Myagdi @ Mangalghat** | | |
| **GEV** | **LPIII** | **LN** |
| **2** | 50 | 50 | 50 |
| **5** | 66 | 66 | 69 |
| **10** | 77 | 74 | 82 |
| **20** | 88 | 81 | 94 |
| **50** | 101 | 88 | 110 |
| **100** | **111** | **93** | **123** |
| **200** | 121 | 97 | 135 |
| **500** | 134 | 101 | 152 |
| **1000** | 144 | 104 | 165 |

Table 1‑26: Estimate of Flood at intake site of MKHPP from various frequency analysis (sum of Table 1‑24 and Table 1‑25)

|  |  |  |  |
| --- | --- | --- | --- |
| **Return Period** | **CAR with Myagdi @ Mangalghat** | | |
| **GEV** | **LPIII** | **LN** |
| 2 | 161 | 161 | 160 |
| 5 | 214 | 213 | 222 |
| 10 | 249 | 240 | 264 |
| 20 | 283 | 262 | 304 |
| 50 | 326 | 285 | 356 |
| **100** | **358** | **299** | **396** |
| 200 | 391 | 311 | 436 |
| 500 | 434 | 325 | 491 |
| 1000 | 466 | 334 | 533 |

Table 1‑27: Estimate of Flood at tailrace site of MKHPP from various frequency analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Return Period** | **CAR with Myagdi @ Mangalghat** | | |
| **GEV** | **LPIII** | **LN** |
| 2 | 191 | 191 | 190 |
| 5 | 254 | 252 | 263 |
| 10 | 295 | 284 | 313 |
| 20 | 335 | 310 | 360 |
| 50 | 387 | 338 | 422 |
| **100** | **425** | **355** | **470** |
| 200 | 464 | 370 | 518 |
| 500 | 514 | 386 | 582 |
| 1000 | 553 | 397 | 632 |

Comparative study of the distribution based on the fitting of observed and computed values have been done and Gumbel method has given the best fit curve, however other distributions are acceptable as well. Therefore, the result given by GEV has been adopted. The detail calculation is available in Annex A.

## Regional Regression Analysis

In this method, instantaneous maximum flow data from 6 gauging stations (Table 1‑28) in the same region of the project was collected and their individual frequency analysis was carried out. Then, regression equations were developed between the catchment area and T-year return period. The results of flood flow of different return periods obtained from this method at intake site of Myagdi Khola, Kunaban Khola and intake site of MKHPP are presented in Table 1‑29 and at tailrace site of MKHPP are presented in Table 1‑30.

Table ‑: DHM Gauging stations considered in the regression analysis of extreme flood with catchment area

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **S.N.** | **Station name** | **Station No.** | **Total Area, km2** | **Area Below 5000 masl, km2** | **Area Above 5000 masl, km2** | **Area Below 3000 masl, km2** |
| 1 | Myagdi | 404.7 | 1067.71 | 861.29 | 206.41 | 522.39 |
| 2 | Modi | 406.5 | 558.09 | 440.26 | 117.82 | 265.91 |
| 3 | Mardi | 428 | 139.50 | 139.08 | 0.42 | 113.08 |
| 4 | Seti | 430 | 537.01 | 488.26 | 48.75 | 306.73 |
| 5 | Madi | 438 | 847.12 | 785.09 | 62.02 | 620.56 |
| 6 | Marshyandi | 439.7 | 4055.12 | 2897.47 | 1157.65 | 1340.00 |

Table ‑: Estimated flood at intake Site of Myagdi Khola, Kunaban Khola and intake site of MKHPP using Regional Regression Analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Return period** | **Regional Regression analysis method (m3/s)** | | |
| **Myagdi Khola** | **Kunaban Khola** | **Intake site of MKHPP** |
|
| 2 | 219 | 129 | 280 |
| 5 | 357 | 222 | 445 |
| 10 | 449 | 286 | 555 |
| 20 | 537 | 347 | 659 |
| 50 | 652 | 427 | 795 |
| **100** | **738** | **488** | **897** |
| 200 | 824 | 548 | 998 |
| 500 | 937 | 628 | 1132 |
| 1000 | 1023 | 689 | 1233 |

Table ‑: Estimated flood at Tailrace Site of MKHPP using Regional Regression Analysis

|  |  |
| --- | --- |
| **Return period, Yrs** | **Myagdi PH** |
| **Regional Regression Myagdi KHPP** |
| 2 | 304.92 |
| 5 | 480.37 |
| 10 | 596.19 |
| 20 | 707.17 |
| 50 | 850.73 |
| **100** | **958.25** |
| 200 | 1065.36 |
| 500 | 1206.64 |
| 1000 | 1313.39 |

## Adopted Flood Flow

*Previous Updated Feasibility Study (by Technoquarry)*

In the previous updated feasibility study (by Techno-quarry), the flood discharges at proposed intake and tailrace site of the Myagdi Khola HPP was developed from catchment correlation with Myadi Khola (404.7) and regression analysis of the reference six gauging stations. The flood discharge from catchment correlation with Myagdi Khola (404.7) were found to be on lower side whereas, the same curve developed from regional regression analysis of the reference six gauging stations were found to be on higher side. The reasons for lower value from the catchment correlation with Myagdi Khola (404.7) are the same as explained in Section 1.6.3. Therefore, to be in safe side, average of these two methods was recommended for use at proposed intake site and tailrace site of MKHPP as tabulated in Table 1‑31 .

Table ‑: Estimated flood at Intake Site of MKHPP during previous UFSR

|  |  |  |  |
| --- | --- | --- | --- |
| **Return period (yrs)** | **Design flood (m3/s)** | | |
| **CAR with Myagdi Khola (404.7)** | **Regional regression analysis** | **Adopted Flood (Average)** |
| 2 | 130.45 | 267.16 | 198.81 |
| 5 | 181.74 | 446.07 | 313.90 |
| 10 | 218.03 | 573.05 | 395.54 |
| 20 | 253.61 | 697.63 | 475.62 |
| 50 | 300.17 | 860.78 | 580.48 |
| **100** | **335.25** | **983.68** | **659.46** |
| 200 | 370.26 | 1106.38 | 738.32 |
| 500 | 416.50 | 1268.43 | 842.47 |
| 1000 | 451.46 | 1390.97 | 921.22 |

*Present Updated Feasibility Study (by HCE)*

In this UFSR, two methods namely catchment correlation and regional regression analysis of the reference gauging stations (as mentioned in Table 1‑3 above) have been used for estimating flood discharge of MKHPP.

The flood discharge estimated at the intake of MKHPP using Gumbel distribution method and regional regression method has been tabulated in Table 1‑32. Also, the adopted flood discharge in previous UFSR has been tabulated for comparison in the same table.

The flood discharge estimated at the intake of MKHPP has been tabulated in Table 1‑32 and tailrace of MKHPP has been tabulated in Table 1‑33.

Table ‑: Comparison of estimated flood at Intake Site of MKHPP in present UFSR

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Present UFSR** | | | **Previous UFSR**  **(Average of Gumbel and Regional Analysis)** | **Adopted Flood Discharge** |
| **Return Period** | **Gumbel** | **Regional Regression analysis** | **Average** |
| 2 | 161.29 | 280.23 | 220.76 | 198.81 | 220.76 |
| 5 | 214.06 | 445.33 | 329.69 | 313.90 | 329.69 |
| 10 | 249.00 | 554.58 | 401.79 | 395.54 | 401.79 |
| 20 | 282.51 | 659.38 | 470.94 | 475.62 | 470.94 |
| 50 | 325.89 | 795.02 | 560.46 | 580.48 | 560.46 |
| **100** | **358.40** | **896.67** | **627.54** | **659.46** | **627.54** |
| 200 | 390.79 | 997.96 | 694.38 | 738.32 | 694.38 |
| 500 | 433.52 | 1131.59 | 782.56 | 842.47 | 782.56 |
| 1000 | 465.82 | 1232.59 | 849.20 | 921.22 | 849.20 |

Table ‑: Adopted flood discharge at Tailrace Site of MKHPP in present UFSR

|  |  |  |  |
| --- | --- | --- | --- |
| **Return Period** | **Gumbel** | **Regional Regression analysis** | **Average** |
| 2 | 191.33 | 304.92 | 248.12 |
| 5 | 253.93 | 480.37 | 367.15 |
| 10 | 295.37 | 596.19 | 445.78 |
| 20 | 335.13 | 707.17 | 521.15 |
| 50 | 386.59 | 850.73 | 618.66 |
| **100** | **425.15** | **958.25** | 691.70 |
| 200 | 463.58 | 1065.36 | 764.47 |
| 500 | 514.27 | 1206.64 | 860.45 |
| 1000 | 552.58 | 1313.39 | 932.99 |

The flood estimated from the average of Catchment correlation with Myagdi Khola at Mangalaghat gauging station and Regional analysis of six reference gauge stations have been adopted for intake site of MKHPP (Intake of Myagdi and Kunaban) and tailrace site of MKHPP.

During the correlation of catchment area during CAR method and regional regression method for flood analysis, area below 5000 masl is usually considered as the runoff contribution from snow (above 5000 masl) is not significant. But, the catchment area at the intake of MKHPP, lying above 5000 masl is more than 60% of the total catchment area. Hence, the catchment correlation (for both CAR and regional regression) have been carried out for the total catchment area to calculate the design flood.

The average value of flood flows estimated from CAR and regional regression method for intake site of MKHPP is comparable to the flood flows adopted in the previous UFSR as shown in the Table 1‑32 above. In this Updated feasibility study also, the average flood flows of CAR and regional regression have been adopted for tailrace site of MKHPP. Considering the capacity of the project, the design flood at the intake and tailrace site of MKHPP has been taken for 100 years of return period which is **627.54** m3/s and **691.70 m3/s** respectively. The detail calculation is available in Annex A.

## Construction Flood/ Dry Period Flood

The annual period of November – May is considered in the estimation of the flood for the diversion during construction since the cost of diversion (i.e. coffer dams) becomes very high if it is constructed to stand during the monsoon. In order to prevent maximum flows during this period from entering the construction area, the diversion work has to be designed to withstand dry season flood. It is the usual practice and recommendation of the standards to consider dry period, 1 in 20 years return period flood for the diversion during the construction. Dry seasonal flood analysis has been carried out by two methods namely catchment correlation with Myagdi Khola (404.7) and regional flood frequency analysis.

## Catchment Correlation with Myagdi Khola (404.7) at Mangalaghat

In the current study, to carry out the dry season diversion flood frequency analysis, the derived inflow time series (1976-2015) at the intake site of MKHPP have been used. Information on recorded instantaneous flood peaks is not available at the intake site. Therefore, to estimate the ratio of instantaneous flood peaks to concurrent daily discharge, records of the Myagdi Khola at Mangalaghat (station no 404.7) has been used. From this gauging station, the ratio of daily average flood with the corresponding maximum instantaneous flood has been found to be nearly 1.1 and as depicted in Table 1‑34.

Table ‑: Ratio of annual maximum instantaneous flood event with max annual daily average flow

| **Year** | **Max instantaneous flood, m3/s** | **Maximum annual daily flow, m3/s** | **Ratio** |
| --- | --- | --- | --- |
|  | **(I)** | **(II)** | **(I)/(II)** |
| 1976 | 414 | 377 | 1.10 |
| 1977 | 578 | 450 | 1.28 |
| 1978 | 492 | 389 | 1.26 |
| 1979 | 470 | 411 | 1.14 |
| 1980 | 509 | 457 | 1.11 |
| 1981 | 682 | 674 | 1.01 |
| 1982 | 663 | 641 | 1.03 |
| 1983 | 682 | 615 | 1.11 |
| 1984 | 647 | 631 | 1.03 |
| 1985 | 647 | 524 | 1.23 |
| 1986 | 682 | 672 | 1.01 |
| 1987 | 655 | 549 | 1.19 |
| 1988 | 644 | 561 | 1.15 |
| 1989 | 926 | 759 | 1.22 |
| 1990 | 509 | 361 | 1.41 |
| 1991 | 394 | 323 | 1.22 |
| 1992 | 377 | 338 | 1.12 |
| 1993 | 560 | 434 | 1.29 |
| 1994 | 405 | 371 | 1.09 |
| 1995 | 445 | 431 | 1.03 |
| 1996 | 578 | 562 | 1.03 |
| 1997 | 180 | 160 | 1.13 |
| 1998 | 442 | 418 | 1.06 |
| 1999 | 568 | 546 | 1.04 |
| 2000 | 549 | 517 | 1.06 |
| 2001 | 843 | 746 | 1.13 |
| 2002 | 525 | 473 | 1.11 |
| 2003 | 32 | 307 | 0.10 |
| 2004 | 386 | 367 | 1.05 |
| 2005 | 258 | 238 | 1.08 |
| 2006 | 176 | 168 | 1.05 |
|  | **Average** |  | **1.09** |

As the maximum instantaneous flood data of station 404.7 is not available for the dry period maximum flow, ratio of **1.2** (slightly higher than the average ratio) has been used to estimate the instantaneous flood peaks at the intake site during dry period i.e. November to May. Then frequency analysis of the daily flood peaks during the period of November to May has been carried out by using Gumbel, Log normal and Log Pearson III distributions. The result from the Gumbel method is adopted as it has given the best fit curve. Estimated dry period flood data of different return period at the intake of MKHPP has been presented in Table 1‑35.

Table ‑: Estimated dry period diversion flood from Gumbel method using CAR with Myagdi at Mangalaghat

|  |  |  |  |
| --- | --- | --- | --- |
| **Return period** | **Construction flood/ Dry period discharges** | | |
| **Myagdi Khola** | **Kunaban Khola** | **At intake of MKHPP** |
| **I** | **II** | **I+II** |
| 2 | 8.26 | 4.46 | 13.15 |
| 5 | 10.62 | 5.74 | 16.92 |
| 10 | 12.19 | 6.58 | 19.42 |
| **20** | **13.69** | **7.39** | **21.81** |
| 50 | 15.64 | 8.45 | 24.91 |

Hence, as shown in the Table 1‑35, the dry period flood of magnitude **21.81** m3/s corresponding to 1 in 20 years return period has been estimated at the intake of MKHPP from this method. The detail calculation is available in Annex A.

## Regional Flood Frequency Analysis

For each reference gauging station, data series of yearly dry seasonal maximum flows have been developed from November to May. Finally using these flows, flood frequency analysis has been performed by Gumbel’s method (analytical and graphical) to estimate the construction flood for each gauging station as tabulated in Table 1‑36.

Table ‑: Construction flood discharges of the reference gauging stations

| **Return period (yrs)** | **Myagdi Khola (404.7)** | **Modi Khola (406.5)** | **Mardi Khola (428)** | **Seti Nadi (430)** | **Madi Nadi (438)** | **Marsyandi Nadi (439.7)** |
| --- | --- | --- | --- | --- | --- | --- |
| 2 | 49.08 | 60.07 | 16.75 | 53.61 | 108.11 | 271.05 |
| 5 | 63.14 | 114.31 | 24.68 | 72.41 | 188.09 | 451.50 |
| 10 | 72.45 | 150.22 | 29.92 | 84.86 | 241.04 | 570.98 |
| 20 | 81.38 | 184.66 | 34.96 | 96.80 | 291.83 | 685.58 |
| 50 | 92.94 | 229.24 | 41.47 | 112.25 | 357.58 | 833.93 |

The maximum instantaneous flood data of the above stations used for regional flood analysis is not available for the dry period maximum flow. Therefore, the ratio of instantaneous flood peaks to concurrent daily discharge has been estimated using the records of the respective stations. Then frequency analysis of the daily flood peaks during the period of November to May has been carried out by using Gumbel, Log normal and Log Pearson III distributions. The result from the Gumbel method is used for regional flood analysis as it has given the best fit curve.

The regression analysis is carried out between the dry period maximum flow of the known stations for each return period and their respective catchment area and the equation obtained is as follows:

Y=aX^b

Where,

Y= Dry period maximum flow for each return period

X=Catchment area at the intake site, Km2

a and b= constants generated from the graph

Table ‑: Estimated dry period diversion flood at intake from Regional Regression

|  |  |  |  |
| --- | --- | --- | --- |
| **Return period** | **Construction flood/ Dry period discharges** | | |
| **At intake of Myagdi Khola** | **Kunaban Khola** | **At intake of MKHPP** |
| 2 | 24.41 | 13.06 | 32.76 |
| 5 | 36.85 | 19.35 | 49.90 |
| 10 | 44.90 | 23.43 | 60.98 |
| **20** | **52.56** | **27.32** | **71.52** |
| 50 | 62.42 | 32.32 | 85.09 |

## Adopted Construction Flood

*Previous Updated Feasibility Study (by Technoquarry)*

In the previous updated feasibility study (by Techno-quarry), the construction flood discharges at proposed intake site of the Myagdi Khola HPP was developed from catchment correlation with Myadi Khola (404.7) and regression analysis of the reference six gauging stations. The construction flood discharge from catchment correlation with Myagdi Khola (404.7) were found to be on lower side whereas, the same curve developed from regional regression analysis of the reference six gauging stations were found to be on higher side. The reasons for lower value from the catchment correlation with Myagdi Khola (404.7) are the same as explained in Section 2.6.3. Therefore, to be in safe side, average of these two methods was recommended for use at proposed intake site of MKHPP as tabulated in Table 1‑38. The adopted construction flood at the intake of MKHPP in the previous UFSR was 34.50 m3/s.

Table ‑: Estimated flood at Intake Site of MKHPP during previous UFSR

|  |  |  |  |
| --- | --- | --- | --- |
| **Return period (yrs)** | **Construction flood (m3/s)** | | |
| **CAR with Myagdi Khola (404.7)** | **Regional regression analysis** | **Adopted Construction Flood (Average)** |
| 2 | 10.57 | 19.77 | 15.17 |
| 5 | 14.38 | 32.02 | 23.20 |
| 10 | 17.09 | 40.72 | 28.90 |
| **20** | **19.74** | **49.26** | **34.50** |
| 50 | 23.22 | 60.44 | 41.83 |

*Present Updated Feasibility Study (by HCE)*

In this UFSR, two methods namely catchment correlation and regional regression analysis of the reference gauging stations (as mentioned in Table 1‑3 above) have been used for estimating dry period flood at the intake of Myagdi Khola and Kunaban Khola.

The construction flood estimated at the intake of MKHPP using Gumbel distribution method and regional regression method has been tabulated in Table 1‑39 below. Also, the adopted flood discharge in previous UFSR has been tabulated for comparison.

The construction flood estimated at the intake of MKHPP has been tabulated in Table 1‑39, the construction flood estimated from the average of CAR and regional regression method is comparable to the adopted construction flood in the previous UFSR. In this updated feasibility study, the average of CAR and regional regression has been adopted as the dry period flood/ construction flood at the intake of MKHPP. The adopted 20-year return period flood at the intake of MKHPP for construction period is **46.66** m3/s

Table ‑: Comparison of estimated construction flood at Intake Site of MKHPP in present UFSR

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Present UFSR** | | | **Previous UFSR**  **(Average of Gumbel and Regional Analysis)** | **Adopted Construction Flood** |
| **Return Period** | **Gumbel (CAR with Stn.404.7)** | **Regional Regression analysis** | **Average** |
| 2 | 13.15 | 32.76 | 22.96 | 15.17 | 22.96 |
| 5 | 16.92 | 49.90 | 33.41 | 23.20 | 33.41 |
| 10 | 19.42 | 60.98 | 40.20 | 28.90 | 40.20 |
| **20** | **21.81** | **71.52** | **46.66** | **34.50** | **46.66** |
| 50 | 24.91 | 85.09 | 55.00 | 41.83 | 55.00 |

## Low Flow

Low flow analysis has been carried out using the derived daily inflow series (1976-2015) of Myagdi Khola at the proposed intake site of Myagdi Khola and Kunaban Khola. The low flow at the intake site of MKHPP has been calculated by adding the low flow of Intake of Myagdi Khola and Kunaban Khola.

Using the daily flow series data, 1-day, 7-day, 15-day and 30-day average flow series has been developed to extract the corresponding duration minimum flows. Then using the minimum flow series data of 40 years (from 1976 to 2015), Weibull’s probability distribution functions were fitted to each minimum flow series. This is one of the recommended methods for calculating Low Flow Analysis which is widely used due to its reliability. The result has been presented in Table 1‑40, Table 1‑41, and Table 1‑42. The detail calculation is available inAnnex A.

Table ‑: Estimated low flow at intake site of Myagdi Khola

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Return period (T-year)** | **Minimum Daily flows, m3/s** | | | | **Remarks** |
| **1-day** | **7-day** | **15-day** | **30-day** |
| 2 | 2.01 | 2.08 | 2.16 | 2.30 | Adopted |
| 5 | 1.63 | 1.69 | 1.79 | 1.85 |  |
| 10 | 1.42 | 1.48 | 1.57 | 1.61 |  |
| 20 | 1.24 | 1.30 | 1.39 | 1.40 |  |
| 50 | 1.04 | 1.10 | 1.19 | 1.18 |  |
| 100 | 0.92 | 0.97 | 1.06 | 1.03 |  |

Table ‑: Estimated low flow at Kunaban Khola Intake

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Return period (T-year)** | **Minimum Daily flows, m3/s** | | | | **Remarks** |
| **1-day** | **7-day** | **15-day** | **30-day** |
| 2 | 0.91 | 0.94 | 0.98 | 1.04 | Adopted |
| 5 | 0.74 | 0.77 | 0.81 | 0.84 |  |
| 10 | 0.64 | 0.67 | 0.71 | 0.73 |  |
| 20 | 0.56 | 0.59 | 0.63 | 0.64 |  |
| 50 | 0.47 | 0.50 | 0.54 | 0.53 |  |
| 100 | 0.41 | 0.44 | 0.48 | 0.47 |  |

Table ‑: Estimated low flow at the intake site of MKHPP

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Return period (T-year)** | **Minimum Daily flows, m3/s** | | | | **Remarks** |
| **1-day** | **7-day** | **15-day** | **30-day** |
| 2 | 2.92 | 3.02 | 3.14 | 3.34 | Adopted |
| 5 | 2.36 | 2.46 | 2.59 | 2.69 |  |
| 10 | 2.06 | 2.15 | 2.29 | 2.34 |  |
| 20 | 1.80 | 1.89 | 2.03 | 2.04 |  |
| 50 | 1.51 | 1.60 | 1.73 | 1.71 |  |
| 100 | 1.33 | 1.41 | 1.54 | 1.50 |  |

This information of low flow has been used to know whether the plant will go beyond the lowest operating capacity of the plant’s single unit, thus by helping in the design of the turbine units. However, it will be costly to design the plant units considering the higher return period low flow as one of the criteria of turbine design. However, it is recommended to design the turbine units in such way that it will operate at minimum flow as 40% of the single unit design discharge with considerable decrease in efficiency. The detail calculation is available in Annex A.

## Glacier Lake Outburst Flood (GLOF)

Glacier lake outburst flood (GLOF) is a type of outburst flood that occurs when the dam containing a glacier lake fails. It causes loss of life and properties, considerable damages of downstream huge structures, destruction of cultivation land and change of natural ecosystem. Therefore, GLOF has to be considered for the design of river engineering structures located at downstream of hazardous glacier lakes.

Final report on Glacier Lakes and Glacial Lake Outburst Floods in Nepal prepared by ICIMOD (2011) shows that a total of 1,466 glacial lakes with a total area of 64.78 km2 lies in Nepal. Out of 1,466 glacier lakes, 116 glacier lakes with a total area of 9.538 km2 lie in the Gandaki basin. But, it does not show the presence of any glacier lake in catchment of the project.

Similarly, Nepal has experienced at least 24 GLOF events in the past. Among them, 14 are believed to have occurred in Nepal itself and 10 were the result of flood surge overspills across the China-Nepal border. Out of 24 GLOF events, 5 GLOF events had occurred in the Gandaki basin. But, it does not show the occurrence of any GLOF event in catchment of the project.

Moreover, 21 glacier lakes were identified as potentially critical glacier lakes in Nepal by ICIMOD (2011). Out of 21 lakes, 5 lakes lie in the Gandaki basin. But it does not show the identification of any potentially critical lakes in catchment of the project.

Topographic map of Nepal having index no. 2883 06 in 1:50,000 Scale also does not show the presence of any glacial lake in catchment of the project. Thus, the project is out of GLOF risk. However, monitoring of large glaciers in upper part of the catchment has to be recommended in the future for considering the formation of glacier lakes.

## Conclusions

Based on the above studies on hydrology, followings conclusions can be drawn for the design of hydropower project components;

* The design discharge has been adopted to be 12.5 m3/s.
* 100 years return period flood at the proposed intake and tailrace site of the project is 627.54 m3/s and 691.10 m3/s respectively.
* The construction flood of 1 in 20 years return period at the proposed intake site of the project is 44.66 m3/s.
* Similarly, based on the final report on Glacier Lakes and Glacial Lake Outburst Floods in Nepal prepared by ICIMOD (2011), the project does not have any glacier lake and hence, it is out of GLOF risk.

## Recommendations

For reliability of the adopted monthly flow at proposed intake site of the project, it is recommended for further work prior to the detail design as;

* Continuous measurement of the flows at intake site of the Myagdi Khola to obtain long-term time series of the flow data

Similarly, for improvement of the rating curve developed at weir axis and tailrace of the Myagdi Khola,

* the rating curve has to be developed based on the measured flow data in the future

Moreover, based on the final report on Glacier Lakes and Glacial Lake Outburst Floods in Nepal prepared by ICIMOD (2011), the project area is out of GLOF risk. However;

* Monitoring of large glaciers in upper part of the catchment has to be recommended in the future for considering the formation of glacier lakes.