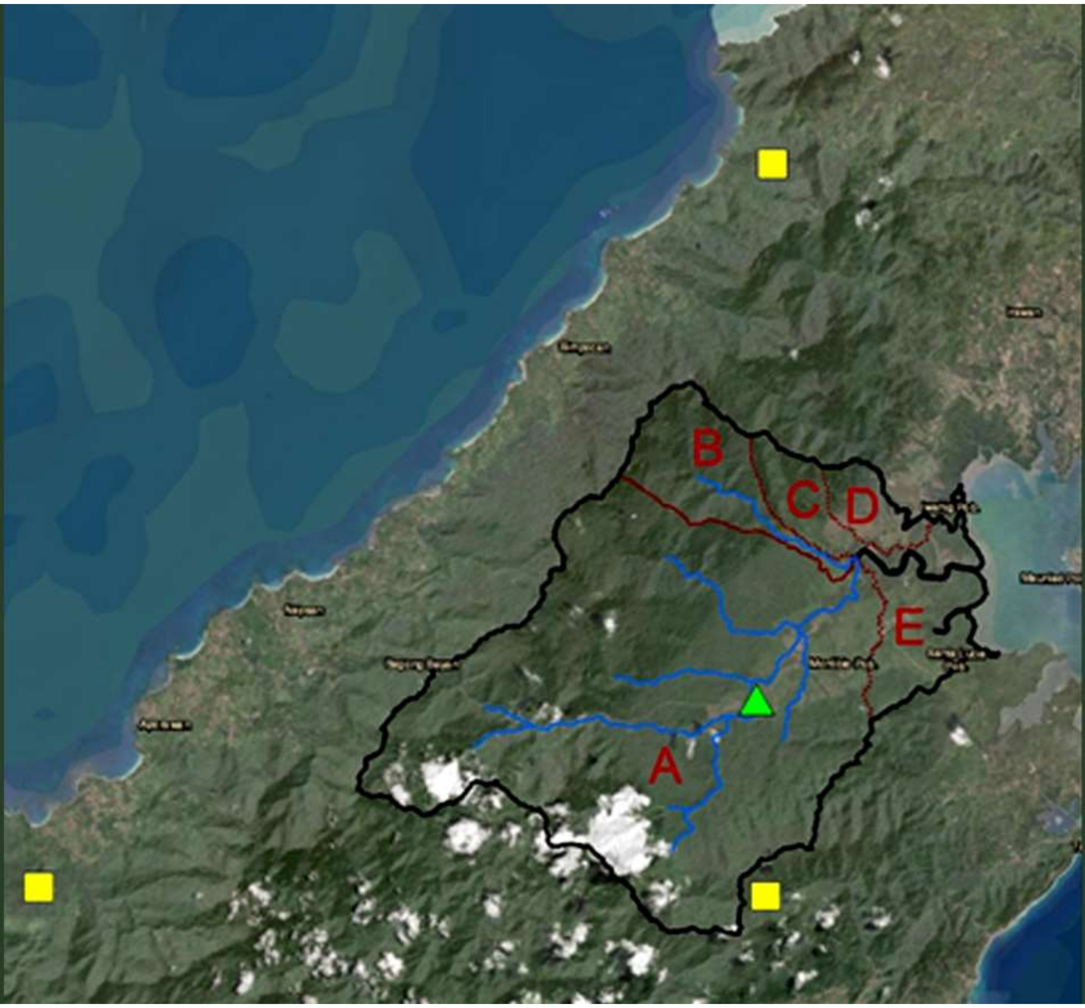

USAID SAFE WATER

MONTIBLE CATCHMENT HYDROLOGIC REPORT

PUERTO PRINCESA CITY

December 2020

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List of Acronyms

APHRODITE	Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation of the Water Resources
BOD	Bureau of Design
BRS	Bureau of Research and Standards
DOST-PAGASA	Department of Science and Technology – Philippine Atmospheric, Geophysical and Astronomical Services Administration
DPWH	Department of Public Works and Highways
FDC	Flow Duration Curve
GHG	Greenhouse gases
GIS	Geographic Information System
InSAR	Interferometric Synthetic Aperture Radar
JICA	Japan International Cooperation Agency
MGB	Mines and Geosciences Bureau
MO	Manila Observatory
NAMRIA	National Mapping and Resource Information Authority
QGIS	Quantum Geographic Information System
RCP	Representative Concentration Pathway
RS	Remote Sensing
SA-OBS	Observational Gridded Dataset for Southeast Asia

SECTION 1: SURFACE WATER

1.1 Basin Information

The Montible River is one of the major rivers in Palawan, located in central Palawan approximately 3 kilometers west of Puerto Princesa City in aerial distance. It has a total drainage area of 253.8 km^2 with five identified sub-catchments (Figure 1.1), hereafter referred to as sub-catchments A (192.5 km^2), B (21.8 km^2), C (14.1 km^2), D (7.8 km^2), and E (17.6 km^2). The main channel of Montible River is situated in sub-catchment A while the rest of the sub-catchments are tributaries at the downstream reaches of the river. The headwaters originate from the southern and western portions of the river basin characterized by mountainous landscapes, which rapidly transitions into a flatter terrain as the river flows northeast towards Puerto Princesa Bay.

The climate in the Montible River Basin is generally categorized as Type 3 under the modified Coronas classification, which has no pronounced wet and dry seasons but has a relatively dry weather from NovPRODUCTION ember to April and wet during the rest of the year (Figure 1.1). Baseline climate data (from 1976 to 2005) provided by the Manila Observatory indicate a mean annual rainfall of approximately 1,369 mm with a monthly minimum of 19.4 mm in April and a maximum of 187.3 mm in October. Meanwhile, the mean annual temperature is 26.0°C with a minimum of 25.4°C in September and a maximum of 27.0°C in April and May.

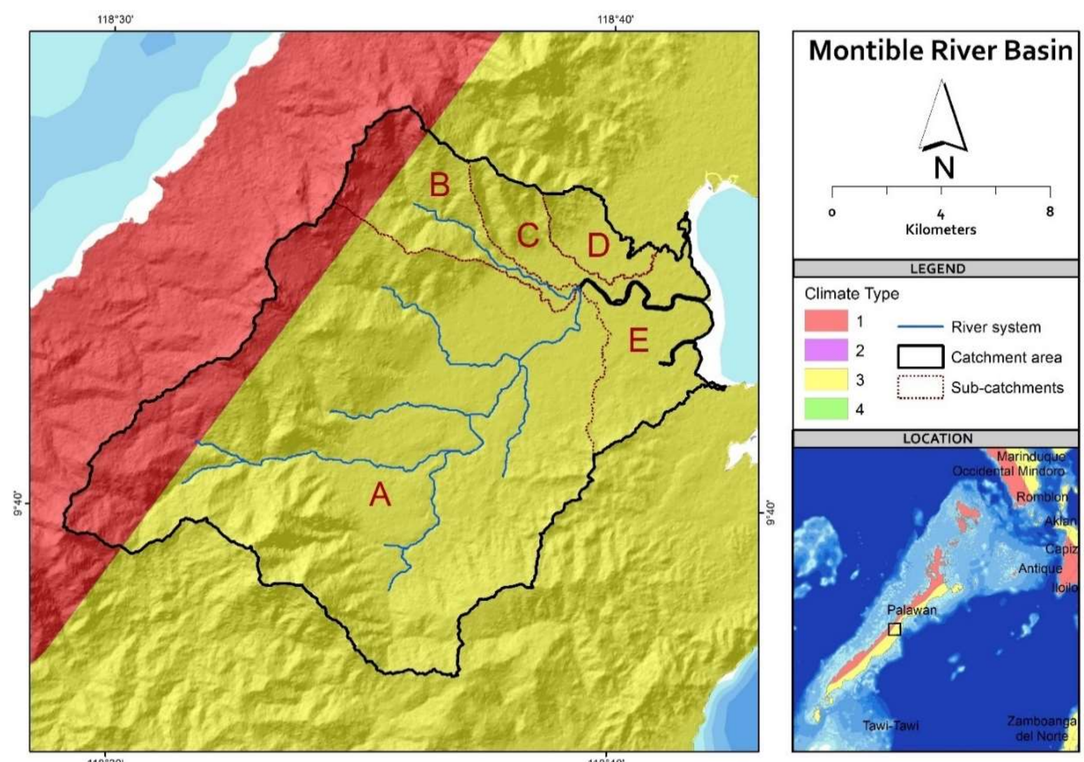

FIGURE 1.1 MAP OF MONTIBLE RIVER BASIN SHOWING THE FIVE SUB-CATCHMENTS (A TO E) AND THE CLIMATE TYPE BASED ON THE MODIFIED CORONAS CLASSIFICATION

1.2 Historical Discharge

The Montible River is one of the Philippine rivers monitored by the Department of Public Works and Highways - Bureau of Design (DPWH-BOD). The stream gauge is located at Montible Bridge II along Puerto Princesa South Road Junction – Napsan – Apurawan Road, Barangay Iwahig, Puerto Princesa City, Palawan (Figure 1.2). The gauging station is situated within sub-catchment A and has a drainage area of 105 km^2, which represents 41% of the entire catchment (Figure 1.3). Daily streamflow data is available for the years 2010-2017.

The following supplementary information is published with the DPWH-BOD data:

Station Code:	R04B.013
Location:	Iwahig, Puerto Princesa, Palawan
Coordinates:	9° 41' 28", 118° 37' 18"
Used Rating Table dated:	Monday, September 2, 2019

FIGURE 1.2. GOOGLE STREET VIEW IMAGE OF MONTIBLE RIVER AT MONTIBLE BRIDGE II ALONG PUERTO PRINCESA SOUTH ROAD JUNCTION – NAPSAN – APURAWAN ROAD

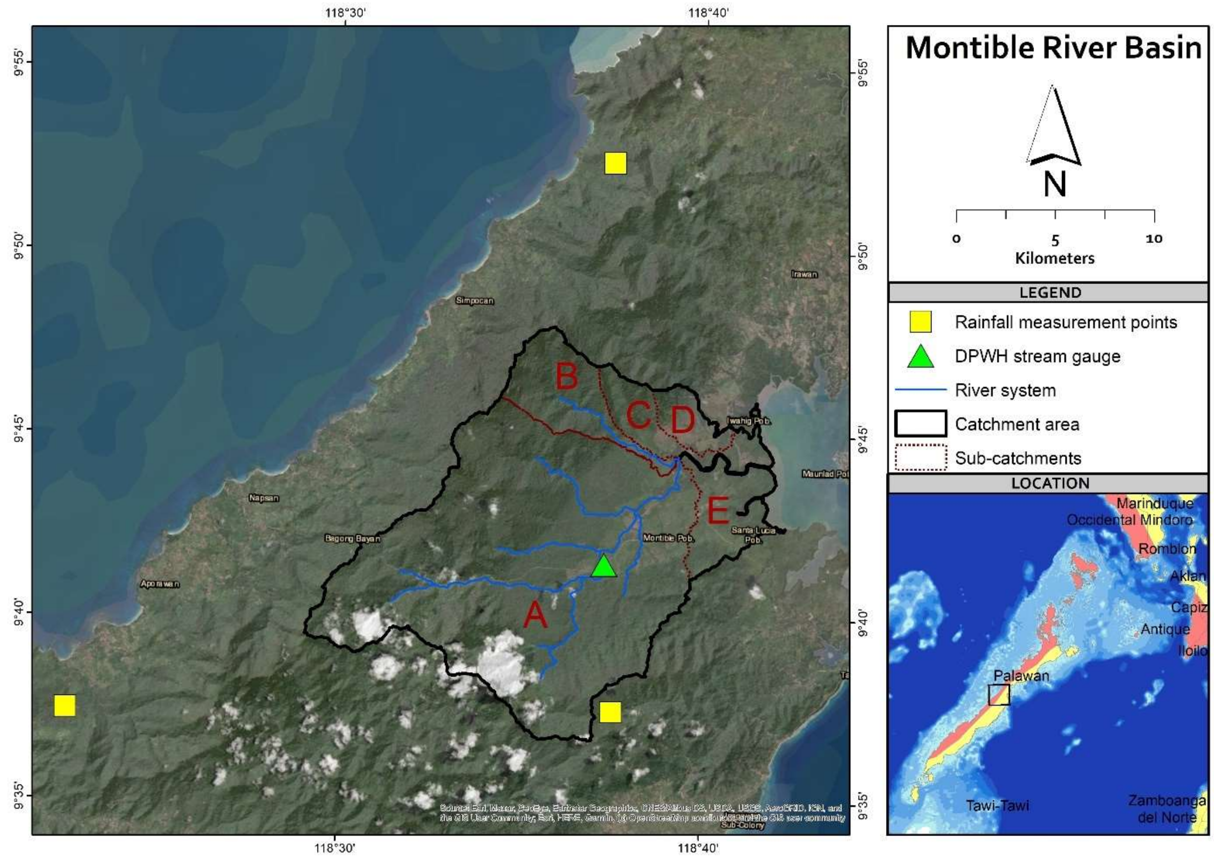

FIGURE 1.3. MAP SHOWING THE LOCATION OF THE MONTIBLE RIVER GAUGE AND THE RAINFALL MEASUREMENT POINTS (PROVIDED BY THE MANILA OBSERVATORY)

On average, the lowest flows are observed in April with a mean daily discharge of 0.89 $m^3 s^{-1}$ while the maximum flows are observed in January with a mean daily discharge of 1.32 $m^3 s^{-1}$ (Figure 1.4). Within the data record, the maximum daily flow was recorded on the 13th of October 2016 at 31.0 $m^3 s^{-1}$ with a corresponding exceedance percentage (i.e., percent of time that this magnitude is equaled or exceeded) of 0.04%. Meanwhile, the minimum daily discharge was recorded on the 12th of December 2012 at 0.56 $m^3 s^{-1}$, corresponding to a 99.96% exceedance percentage.

The entire flow regime of Montible River recorded at the DPWH gauging station is shown in Figure 1.4. The median flow or the discharge that is equaled or exceeded at least 50% of the time (i.e., Q_{50}) is 0.96 $m^3 s^{-1}$, which could be roughly considered as a proxy to the average flow of the river. High flows or discharge values that are equaled or exceeded not more than 20% of the time (i.e., $Q \geq Q_{20}$), start at 1.13 $m^3 s^{-1}$, while extreme flows (i.e., $Q \geq Q_1$) have a magnitude of 3.09 $m^3 s^{-1}$ at the minimum. On the other hand, low flows (i.e., $Q \leq Q_{80}$) start at 0.87 $m^3 s^{-1}$.

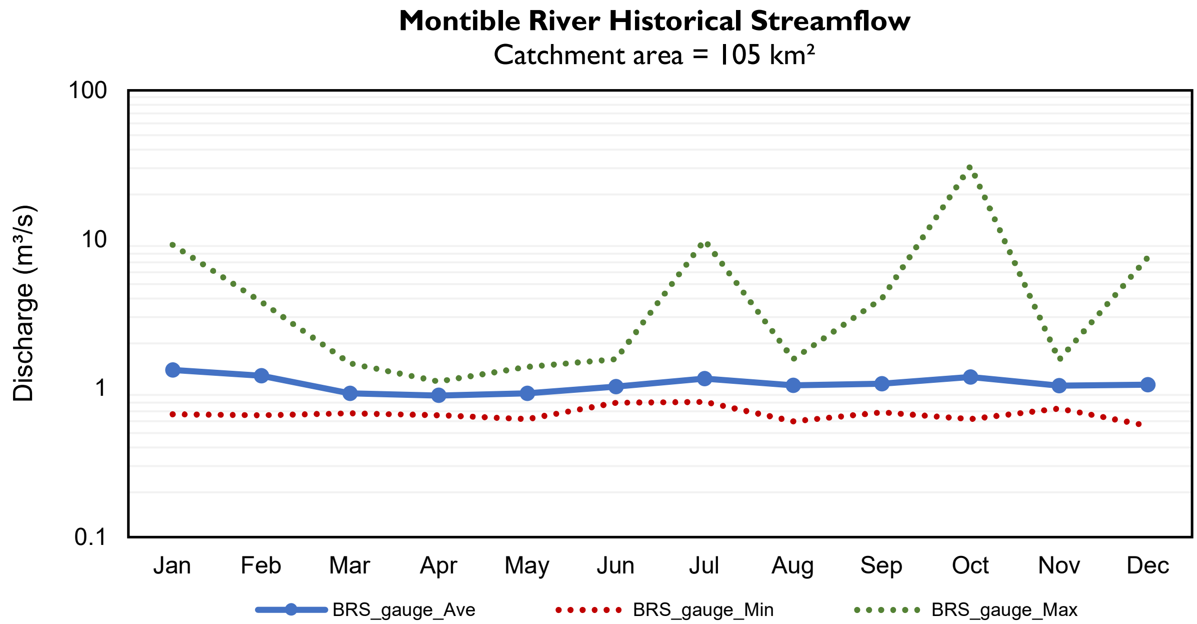

FIGURE 1.4. MONTHLY FLOWS OF MONTIBLE RIVER AT THE DPWH GAUGING STATION

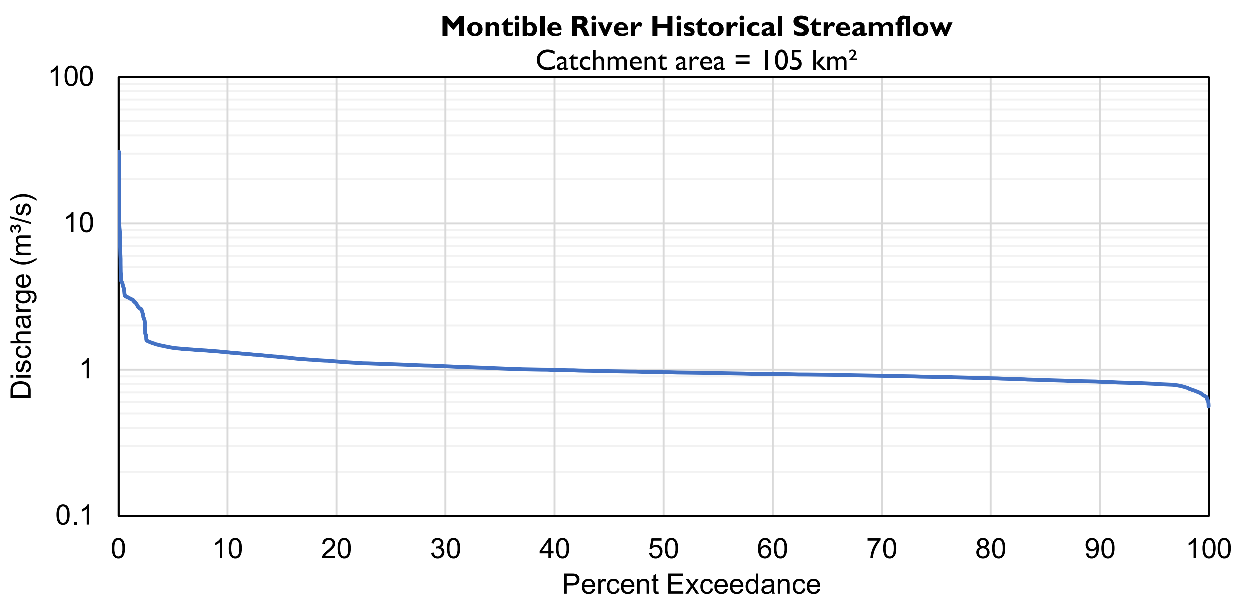

FIGURE 1.5. FLOW DURATION CURVE OF MONTIBLE RIVER AT THE DPWH GAUGING STATION

1.3 Flow Analysis

The flow duration curve is a graphical representation of the flow regime of a stream that shows the percent of time specific discharges were equaled or exceeded during a given period. Flow duration curves (FDCs) are widely used in hydrological and engineering studies related to water resources management. It is a valuable tool for designing irrigation, hydropower, and water supply systems.

In this study, the entire range of stream discharge – from low flows to flood flows – for the whole Montible River Basin (with a total catchment area of 253.8 km^2) was projected using FDCs. The high flow section of the FDC (i.e., $Q \leq Q_{20}$) is important for hydropower and flood modeling purposes while the low flow section (i.e., $Q \geq Q_{80}$) is used to predict future flows available for water supply.

Three (3) techniques were utilized to create FDCs:

1) Discharge derivation by catchment area transposition;
2) Rainfall – discharge analysis using the rational method; and,
3) Multiple river correlation of rivers in Palawan using regression analyses involving exponential, linear, logarithmic, and power regressions.

Rainfall data provided by the Manila Observatory and stream flow data from DPWH were used for the flow duration analysis. The details and results of the methods used are described in the succeeding sections.

Method 1: Discharge derivation by catchment area transposition

Method 1 makes use of the catchment area transposition analysis, wherein the flow characteristics of a gauged river are related to the subject river as expressed by the equation:

$$Q = Q_{gauged} * (A/A_{gauged})$$

Where Q is the discharge of the study area (m^3 s^{-1}), Q_{gauged} is the recorded discharge of the gauged river (m^3 s^{-1}), A is the catchment area of the study area (m^2), and A_{gauged} is the catchment area of the gauged river (m^2). Ideally, the gauged river to be selected as reference should have a robust streamflow record with good data quality and should also bear similar characteristics with the study area including topography, land use, and climate. In this study, the reference river that was used is the Montible River itself, specifically its gauged upstream sub-catchment. For this reason, this technique will likely provide the most reliable flow analysis results among all methods used in the study. The results of Method 1 are summarized in Table 1.1.

TABLE 1.1. RESULTS OF CATCHMENT AREA TRANSPOSITION FOR THE MONTIBLE RIVER BASIN

Date	Q ($m^3 s^{-1}$)		Rank	Flow exceedance
	Montible River (105 km^2)	Montible River Basin (254 km^2)		
06/01/2013	9.16	22.14	3	$Q_{0.1}$
02/02/2012	3.09	7.47	28	Q_1
14/07/2010	1.43	3.46	131	Q_5
23/07/2010	1.31	3.17	294	Q_{10}
05/08/2010	1.13	2.73	584	Q_{20}
13/06/2010	1.05	2.54	879	Q_{30}
28/04/2010	1.00	2.42	1,117	Q_{40}
04/07/2010	0.96	2.32	1,436	Q_{50}
19/04/2010	0.93	2.25	1,773	Q_{60}
14/05/2010	0.91	2.20	1,985	Q_{70}
29/03/2010	0.87	2.10	2,303	Q_{80}
24/04/2010	0.83	2.01	2,546	Q_{90}
23/09/2010	0.80	1.93	2,709	Q_{95}
26/08/2011	0.70	1.69	2,816	Q_{99}
26/10/2011	0.62	1.50	2,839	$Q_{99.9}$

Method 2: Rainfall – discharge analysis using the rational method

Method 2 utilizes the Rational equation to estimate discharge at the site given its catchment area and precipitation data:

$$Q = ciA$$

Where Q is the discharge of the study area ($m^3 s^{-1}$), *c* is the runoff coefficient, i is the rainfall intensity (mm $month^{-1}$) and A is the catchment area (m^2). Originally, the equation is designed to calculate peak discharge at a certain rainfall intensity, usually in mm hr^{-1}, wherein the time of concentration is factored in. In this study, the equation is utilized in a straightforward manner - using total monthly precipitation instead to allow direct derivation of mean monthly discharge without the need for a time of concentration.

Monthly rainfall data from 1976 to 2005 was prepared by the Manila Observatory using observed data from DOST-PAGASA and APHRODITE. Average values from the gridded rainfall measurement points were used in this method. A runoff coefficient of 0.5 was selected for months with lower rainfall (i.e., January to April) and 0.20 for months with higher rainfall (i.e., May to December) based on the general characteristics of the river basin and the actual streamflow trends. These values are typically used for cultivated/timbered Philippine watersheds with moderate slope and for agricultural/unpaved open areas, respectively (Table 1.2). The influence of other catchment features (e.g., slope, soil type, land use) and hydrological processes (e.g., infiltration, evapotranspiration) are implicitly accounted for in the runoff coefficient. It is important to note that the adopted approach is highly simplified and is demonstrated primarily for the purpose of comparison with the results of other methods. Nevertheless, this technique is useful in discharge estimation using coarse-resolution datasets/measurements like in the current study. The results of Method 2 are summarized in Table 1.3.

TABLE 1.2. RUNOFF COEFFICIENTS USED IN THE PHILIPPINES PUBLISHED IN THE DESIGN GUIDELINES CRITERIA AND STANDARDS, VOL. I (MPWH, 1987, IN DPWH AND JICA, 2003)

Surface Characteristics	Runoff coefficient
Lawn, gardens, meadows, and cultivated lands	0.05-0.25
Parks, open spaces including unpaved surfaces and vacant lots	0.20-0.30
Suburban districts with few buildings	0.25-0.35
Residential districts not densely built	0.30-0.55
Residential districts densely built	0.50-0.75
Watershed having steep gullies and not heavily timbered	0.50-0.70
Watershed having moderate slope, cultivated, and heavily timbered	0.45-0.55
Suburban areas	0.34-0.45
Agricultural areas	0.15-0.25

TABLE 1.3. RESULTS OF THE RAINFALL-DISCHARGE ANALYSIS FOR THE MONTIBLE RIVER BASIN

Year	Month	Precipitation (mm)	Q (m^3 s^{-1})	Rank	Flow exceedance
2003	10	252.4	4.94	4	Q_1
1993	10	218.8	4.29	18	Q_5
2005	10	197.3	3.86	36	Q_{10}
1994	3	71.8	3.52	73	Q_{20}
1994	8	164.6	3.22	109	Q_{30}
1976	8	152.4	2.99	145	Q_{40}
1996	6	135.1	2.65	181	Q_{50}
1997	6	112.0	2.19	217	Q_{60}
2003	5	90.0	1.76	253	Q_{70}
1999	1	28.7	1.40	289	Q_{80}
2001	3	19.1	0.93	325	Q_{90}
1995	2	15.4	0.75	343	Q_{95}
1980	3	8.2	0.40	358	Q_{99}
1976	3	7.1	0.35	360	$Q_{99.9}$

Method 3: Multiple river correlation of rivers in Palawan using regression analyses

Method 3 adopts multi-river regression analyses wherein the discharge and drainage area of gauged rivers are correlated using different regression techniques such as linear, logarithmic, power, and exponential, and are then used to derive the flow characteristics of the subject river. Ideally, the rivers of reference should (a) be in close proximity to the study area (i.e., within a 50-km radius), (b) have similar climate and catchment characteristics, (c) have clearly defined catchment areas and consistent streamflow records, and (d) have lower and higher catchment areas compared with the study area. However, it is challenging, if not impossible to find reference rivers that fulfill all the qualifications. In this study, three rivers in Palawan were deemed most suitable to use as reference (Table 1.4), meeting all of the criteria except for proximity - these rivers are located beyond 50 km but within 100 km from the river basin. The coefficient of determination (r^2) was calculated for each analysis. Subsequently, this metric was used to assess the precision of the predicted discharge to the regression trends exhibited by the reference rivers, wherein $r^2 \geq 0.7$ was considered as good correlation. The results of Method 3 are summarized in Table 1.5.

TABLE 1.4. LIST OF PALAWAN RIVERS USED AS REFERENCE IN THE REGRESSION ANALYSES

Reference	Coordinates	Location	Catchment area	Streamflow data record
Iraan	*10° 25' 48.94", 119° 22' 25.21"*	Brgy. Sto. Tomas, Roxas	11.37 km^2	2010-2014, 2017
Caramay	*10° 10' 59.15", 119° 13' 29.63"*	Brgy. Caramay, Roxas	94.62 km^2	2010-2017
Batang-Batang	*09° 13' 35.93", 118° 19' 27.65"*	Brgy. Urduja, Narra	170.00 km^2	2010-2018

TABLE 1.5. RESULTS OF THE REGRESSION ANALYSES FOR THE MONTIBLE RIVER BASIN. VALUES IN RED DENOTE $R^2 < 0.7$

Q ($m^3 s^{-1}$)				Flow exceedance
Linear regression	Logarithmic regression	Exponential regression	Power regression	
92.71	91.76	98.31	89.02	$Q_{0.1}$
8.81	9.41	8.08	9.27	Q_1
6.59	4.40	-	8.11	Q_5
5.28	3.41	5.70	2.70	Q_{10}
3.43	2.27	4.82	2.18	Q_{20}
2.70	1.79	4.55	1.86	Q_{30}
2.03	1.35	3.39	1.44	Q_{40}
1.53	1.02	2.32	1.05	Q_{50}

1.13	0.78	1.68	0.80	Q_{60}
0.90	0.63	1.32	0.66	Q_{70}
0.76	0.53	1.28	0.60	Q_{80}
0.56	0.40	1.10	0.48	Q_{90}
0.44	0.31	0.90	0.38	Q_{95}
0.29	0.22	-	-	Q_{99}
0.24	0.21	0.28	0.23	$Q_{99.9}$

The flow regime projections for the Montible River Basin using various discharge estimation techniques are shown in Figure 1.6. Among all the methods used, the exponential regression analysis yielded the highest values in the high flow section of the FDCs while the area transposition technique yielded the highest values in the low flow section. The latter also predicted the lowest values in the high flow section, while the logarithmic regression analysis projected the lowest values in the low flow section. High flows ($Q \geq Q_{20}$) are expected to start at 2.18 m^3 s^{-1}, while extreme flows ($Q \geq Q_1$) have a magnitude of at least 7.47 m^3 s^{-1}. The median flow is expected to be within the range of 1.02-2.32 m^3 s^{-1} but could reach up to 5.65 m^3 s^{-1} as predicted by the rainfall-discharge analysis. Discharge values less than 2.10 m^3 s^{-1} could already be considered low flow ($Q \leq Q_{80}$) as suggested by the area transposition analysis.

The projected monthly flows for the river basin are also shown in Figure 1.7. Similar with the monthly trends observed in the historical streamflow data from the DPWH gauging station, the lowest mean flows are observed in April at 2.16 m^3 s^{-1} while the highest mean daily flows occur in October at 2.87 m^3 s^{-1}. The flow regimes for each sub-catchment are summarized in the Tables A-F in the Appendix section. Monthly flow statistics (average, minimum, and maximum discharge) for the entire basin and each sub-catchment are reported in Tables G and H in the Appendix section.

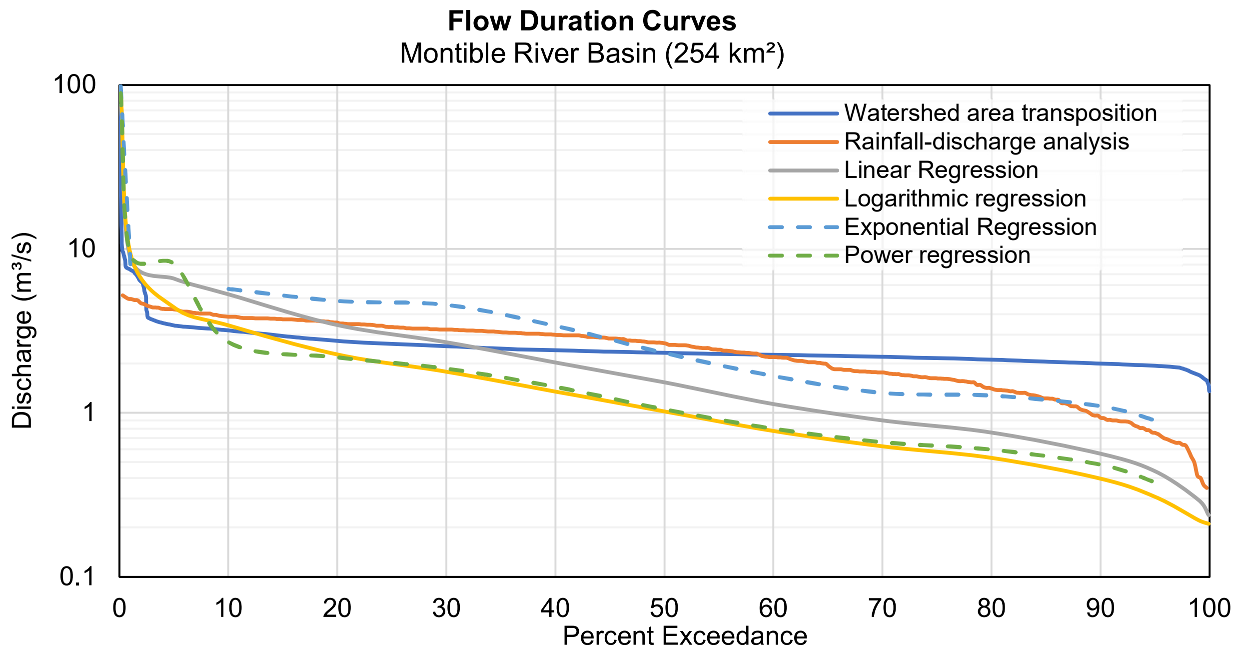

FIGURE 1.6. FLOW DURATION CURVES FOR THE MONTIBLE RIVER BASIN AS PREDICTED BY VARIOUS ESTIMATION TECHNIQUES. DASHED LINES INDICATE INCOMPLETE FLOW DURATION CURVES AS ERRONEOUS DISCHARGE VALUES PREDICTED BY THE EXPONENTIAL AND POWER REGRESSION ANALYSES WERE EXCLUDED

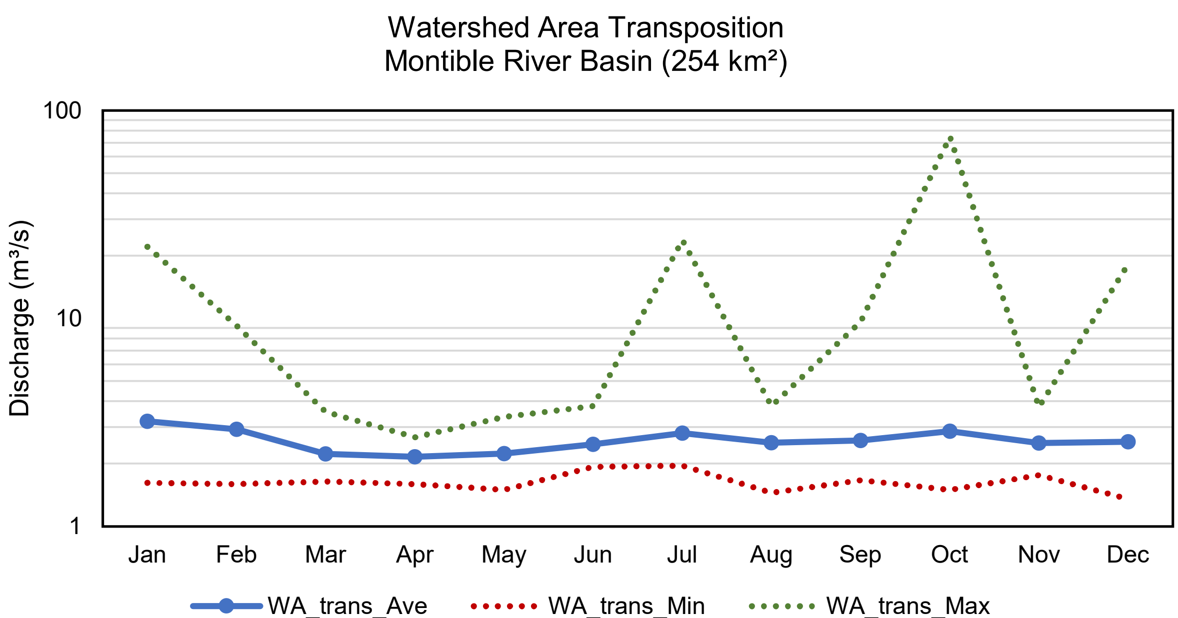

FIGURE 1.7. PROJECTED MONTHLY FLOWS IN THE MONTIBLE RIVER BASIN FOR THE CURRENT PERIOD. DISCHARGE VALUES WERE PROJECTED USING HISTORICAL STREAMFLOW DATA FROM THE DPWH GAUGING STATION FROM 2010-2017 THROUGH WATERSHED AREA TRANSPOSITION

1.4 Projection of future flows under different climate scenarios

The Intergovernmental Panel on Climate Change has developed different future scenarios to simulate the impact of greenhouse gas (GHG) emissions on climate. These scenarios are described by the representative concentration pathways (RCP) that are further classified based on the level of end-of-century radiative forcing. Two scenarios were used in this study: (a) RCP4.5 (representing 4.5 W/m^2 forcing increase relative to pre-industrial conditions) and (b) RCP8.5 (representing 8.5 W/m^2 forcing increase). In other words, RCP4.5 is used to predict changes in the climate assuming intermediate GHG emissions, while RCP8.5 is used to model high GHG effects.

The Manila Observatory has provided bias-adjusted monthly temperature and precipitation values under these two scenarios. Rainfall-discharge analysis was conducted for two future periods, from 2006 to 2035 (i.e., 2020s) and from 2036 to 2065 (i.e., 2050s) Potential hydrological impacts can then be assessed by comparing the baseline flows to the predicted future flows.

The future flow exceedance values and the percentage change for the Montible River Basin are reflected in Table 1.6. For the 2020s period, the RCP4.5 scenario predicts flow reduction in the entire flow regime except at Q_1 (no change) and Q_{90}-Q_{99} (+3% to +31%). Most noteworthy is the flow reduction at $Q_{99.9}$ (-30%). In other words, although observed flows at 90-99% of the time will be greater than the baseline values, the water supply is generally expected to decrease especially at the lowest flows. Meanwhile, the RCP8.5 scenario predicts a more drastic water availability situation, with significant flow reductions across the flow regime especially at Q_{99} (-22%) and $Q_{99.9}$ (-39%). In contrast, Q_1 and Q_{90} are projected to increase by 9% and 18%, respectively, implying greater extreme flows and higher discharge observed at 90% of the time compared with the baseline.

In the 2050s, the RCP4.5 scenario generally predicts flow reduction (-3% to -23%) except for Q_{90} (no change) and Q_{99} (+9%). A similar but more extreme trend is projected using the RCP8.5 scenario, with significant flow reduction across the flow regime (-1% to -31%) but with considerable increase at Q_{90} (+5%) and Q_{99} (+18%). Both scenarios indicate that although the observed discharge values at 90% and 99% of the time are higher compared with the baseline, water supply is expected to significantly decrease in the 2050s.

TABLE 1.6. FLOW EXCEEDANCE VALUES (IN $M^3 S^{-1}$) OF FUTURE FLOWS (2006-2035 AND 2036-2065) WITH RESPECT TO THE BASELINE (1976-2005). VALUES IN RED INDICATE NEGATIVE CHANGE FROM THE BASELINE VALUES

Flow exceedance	1976-2005	2006-2035				2036-2065			
	Baseline	RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
	Q (m^3/s)	Q (m^3/s)	Change	Q (m^3/s)	Change	Q (m^3/s)	Change	Q (m^3/s)	Change
Q_1	4.94	4.95	0%	5.39	9%	4.79	-3%	4.91	-1%
Q_5	4.29	4.15	-3%	4.30	0%	3.90	-9%	3.95	-8%
Q_{10}	3.86	3.72	-4%	3.72	-4%	3.49	-10%	3.56	-8%
Q_{20}	3.52	3.28	-7%	3.21	-9%	3.05	-13%	3.06	-13%
Q_{30}	3.22	3.00	-7%	2.92	-9%	2.79	-13%	2.71	-16%
Q_{40}	2.99	2.75	-8%	2.61	-12%	2.47	-17%	2.39	-20%

Q_{50}	2.65	2.42	-8%	2.38	-10%	2.21	-16%	2.11	-20%
Q_{60}	2.19	2.14	-2%	2.05	-6%	1.87	-15%	1.86	-15%
Q_{70}	1.76	1.79	2%	1.68	-5%	1.57	-11%	1.56	-12%
Q_{80}	1.40	1.41	0%	1.37	-2%	1.29	-8%	1.25	-11%
Q_{90}	0.93	0.98	5%	1.10	18%	0.93	0%	0.98	5%
Q_{95}	0.75	0.77	3%	0.73	-4%	0.72	-5%	0.72	-4%
Q_{99}	0.40	0.52	31%	0.31	-22%	0.43	9%	0.47	18%
$Q_{99.9}$	0.35	0.24	-30%	0.21	-39%	0.27	-23%	0.24	-31%

The predicted monthly flow statistics (average, minimum, and maximum discharge) in the 2020s are shown in Figures 1.8-1.9, while Figures 1.10-1.11 show the monthly flows in the 2050s period. In the 2020s, the RCP4.5 scenario predicts minimal changes in the monthly flows compared with the baseline, except in February (higher mean discharge) and in July (lower mean discharge). The same trend is observed using the RCP8.5 scenario, but with April having lower average flows as well. In the 2050s, RCP4.5 predicts considerable flow reduction in all months except in January, February, and September. Lastly, RCP8.5 projects lower discharge throughout year with respect to the baseline except in February.

The future flow projections for each sub-catchment are summarized in Tables I-L in the Appendix section. The predicted monthly statistics for the two future periods under the RCP4.5 and RCP8.5 scenarios are likewise shown in Tables M and N in the Appendix section, respectively.

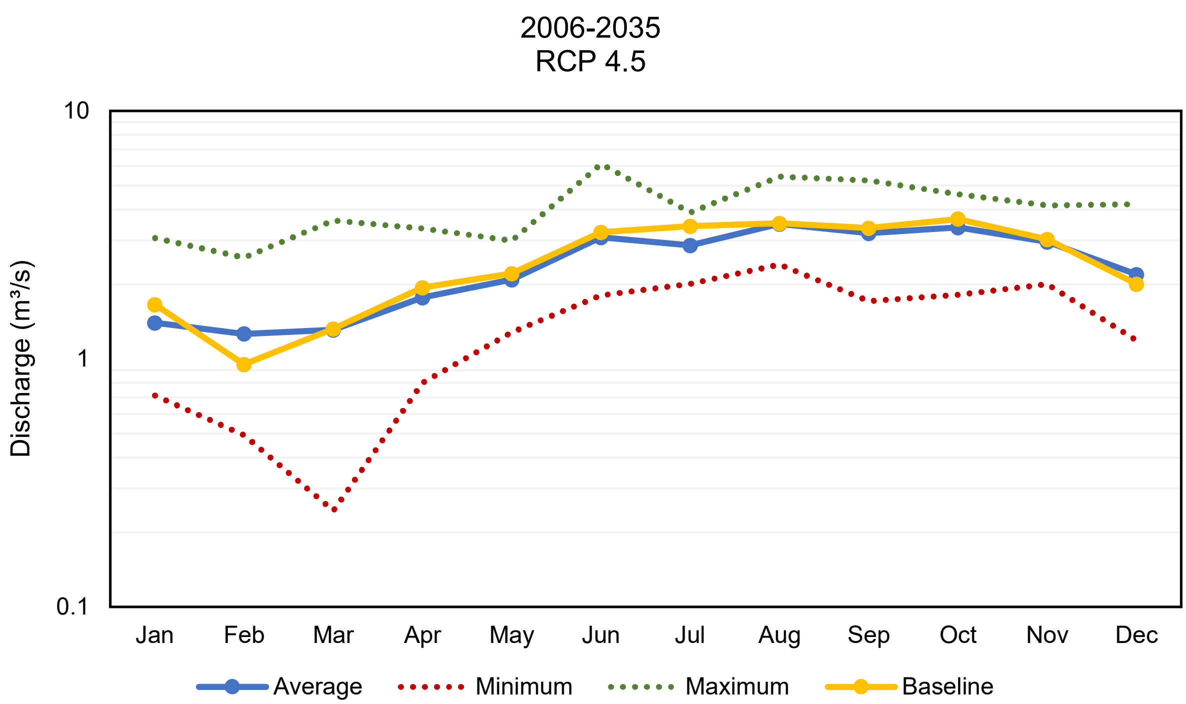

FIGURE 1.8. PREDICTED MONTHLY FLOWS FROM 2006 TO 2035 FOR THE MONTIBLE RIVER BASIN USING THE RCP 4.5 SCENARIO

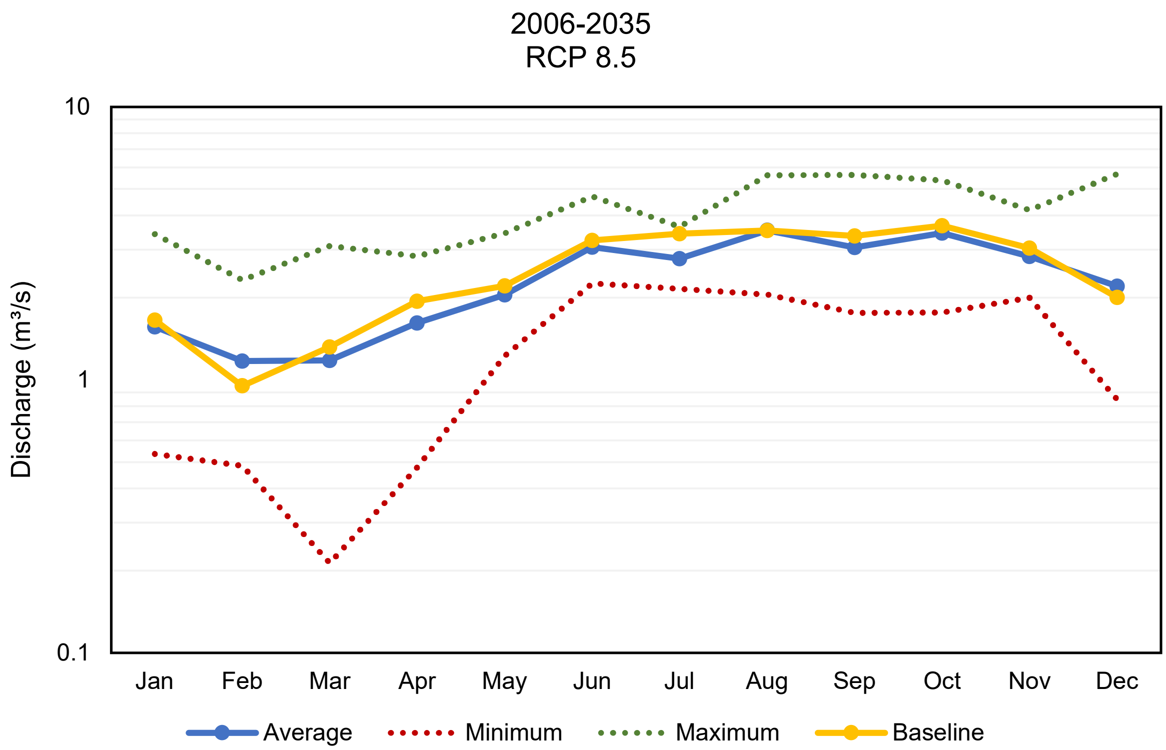

FIGURE 1.9. PREDICTED MONTHLY FLOWS FROM 2036 TO 2065 FOR THE MONTIBLE RIVER BASIN USING THE RCP 4.5 SCENARIO

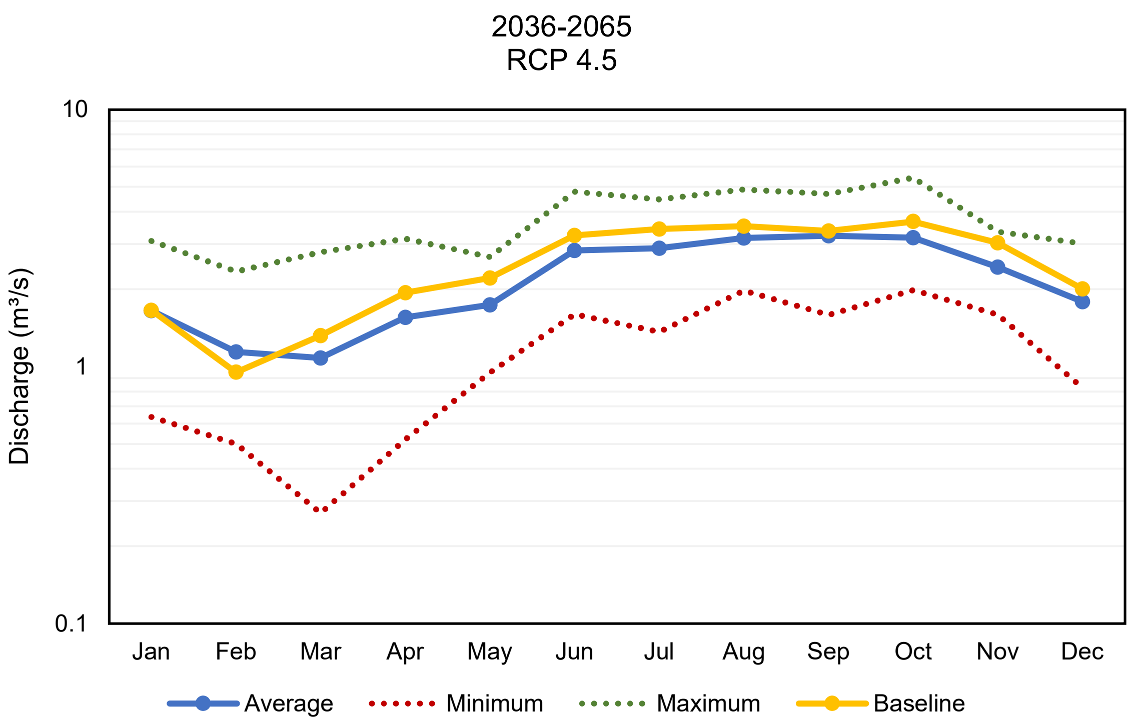

FIGURE 1.10. PREDICTED MONTHLY FLOWS FROM 2006 TO 2035 FOR THE MONTIBLE RIVER BASIN USING THE RCP 8.5 SCENARIO

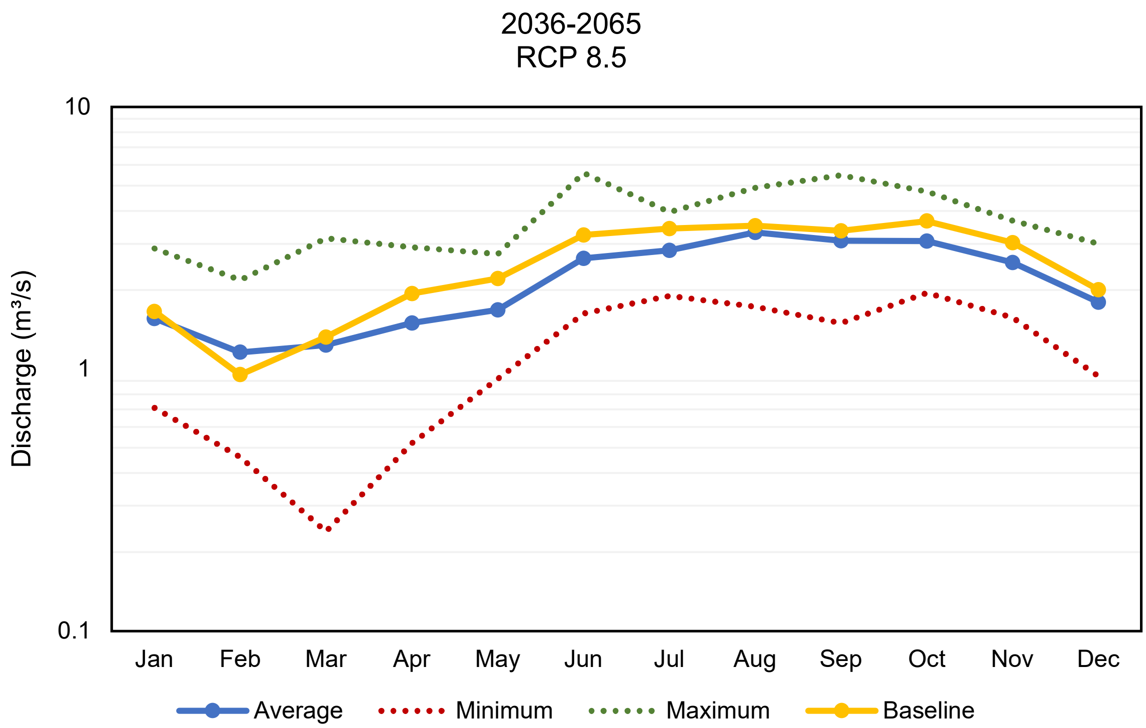

FIGURE 1.11. PREDICTED MONTHLY FLOWS FROM 2036 TO 2065 FOR THE MONTIBLE RIVER BASIN USING THE RCP 8.5 SCENARIO

1.5 Field Validation

Field validation and local stakeholders' training were conducted in Montible catchment in Palawan on February 3 to 6, 2021. Table P in the Appendix section shows the summary of location of the sampling sites, field photo with site description, water quality *in situ* measurements, and measured water discharge. A total of eight (8) sites were sampled while training was done on February 4-5, 2021 in which the participants joined the field team in all sites.

Three sampling sites could be considered as most relevant for validation. The midstream sampling site at the dam near Montible Bridge II (9°41'25.6", 118°37'22.2") represents the catchment area of Montible River at the BRS gauging station, where the measured discharge (2.79 $m^3 s^{-1}$) represents high flow that is equaled or exceeded at least 20% of the time, i.e., $Q_{10} > Q > Q_{20}$ according to the historical streamflow data. Meanwhile, the midstream sampling site at Montible river inside the Montible Subcolony (9°43'25.28", 118°39'4.05") is situated near the outlet of sub-catchment A, and the measured discharge of 2.96 $m^3 s^{-1}$ represents very high flows that is equaled or exceeded at least 5% of the time, i.e., $Q_1 > Q > Q_5$, as suggested by the watershed area transposition. Lastly, the downstream site at Iwahig Bridge along Puerto Princesa South Road (9°44'0.0", 118°41'0.9") represents the outlet of the whole Montible catchment. However, discharge was not measured during fieldwork due to back flow (high tide) and only the area and back flow rate was measured that is not a representative of the river discharge.

SECTION 2: GROUNDWATER

2.1 Potential Groundwater Recharge Areas

Groundwater recharge, or the process that describes the flow of water from surface sources (e.g., direct from precipitation, streamflow) to the aquifers deep beneath the ground, is still a significant source of freshwater (30%) around the world. In the Philippines, the average proportion of precipitation that ultimately infiltrates as groundwater is between 15-25%, primarily varying based on the prevailing geology and land cover of a particular area. In alluvial areas in humid tropics, the proportion of rainfall ultimately infiltrating shallow aquifers may be as high as 40-45% (Kotchoni et al., 2018).

Although a substantial amount of freshwater is stored as groundwater, finding and developing this resource require significant investments in the exploration of potential groundwater sources. Numerous techniques have been developed over the years to directly and indirectly measure the amount of groundwater entering aquifers. As Yeh et al. (2009) pointed out, on-site hydrogeological investigations and geophysical surveys generally downplay large-scale processes contributing to the dynamics of groundwater recharge. Most of the time, these and other similar techniques rely on just a single (or a few) parameter to estimate recharge.

We identified the geology of the area, topographic slope, drainage density, and land cover as the controlling variables influencing groundwater recharge as used and verified by Shaban et al. (2006), Yeh et al. (2009), Kourgialas and Karatzas (2015), Deepa et al. (2016), and Senanayake et al. (2016). Accordingly, we adopted their approach in using Geographic Information System (GIS) and Remote Sensing (RS) to integrate these variables.

These areas were delineated on the basis of four factors: drainage density, slope gradient, surface lithology, and land cover. The weight of these factors are based on the influence they have on one another. The groundwater recharge potential map was derived from previous maps using spatial analysis functions and is presented in Figure 2.1. Figure 2.2 illustrates a flowchart representing the methodology of this investigation and the inter-influence of these factors used in determining their corresponding weights. Each primary variable was assigned a numerical weight, signifying its relative importance in promoting infiltration and percolation of water towards the ground. Geology was assigned 34%, land cover with 25%, slope with 25%, and drainage density with 16%; with these weight distribution modified and adapted from Shaban et al., (2006) and Yeh et al., (2009). Subclasses of each primary variable were also allocated with weights according to their likely influence on groundwater recharge.

Zones were classified whether they have very low, low, moderate, high, or very high potential for groundwater recharge. For example, around 40-50% of the total amount of recharge are capable of infiltrating towards the aquifers in very high recharge areas. Conversely, in poor recharge areas less than 5% of estimated recharge is expected to ultimately feed the aquifers. Potential recharge of the areas were classified into five zones: very low recharge for areas with values of 0-20; low recharge areas (20-40) moderate recharge for areas with values of 40-60; good recharge for areas with values of 60-80; and values between 80-100 for very high recharge zones.

The points of these factors were identified by classifying and ranking them on the basis of their influence on the groundwater potential. Using spatial analysis, the factors were then added together, and the potential groundwater recharge zones were demarcated. For the determination of the weights of factors, major and minor inter-influences were compared. A major effect or influence equates to one point, while a minor effect or influence equates to a half point. From these the drainage density factor has a weight of 1, lithology has a weight of 2, and both land cover and slope gradient have weights of 1.5. Normalizing these to a hundred points, these weights may be obtained: 16 for drainage density, 34 for lithology, 25 for land cover, and 25 for slope gradient.

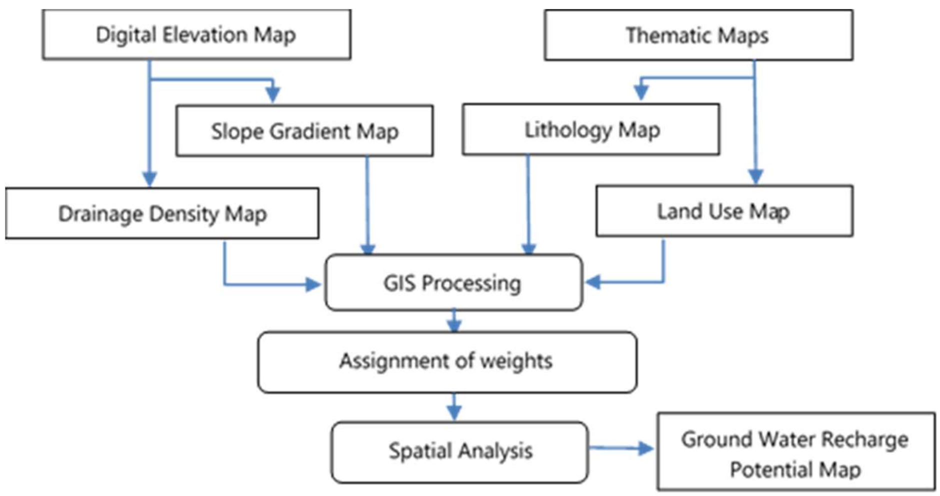

FIGURE 2.1. FLOWCHART FOR DETERMINING POTENTIAL GROUNDWATER RECHARGE ZONES

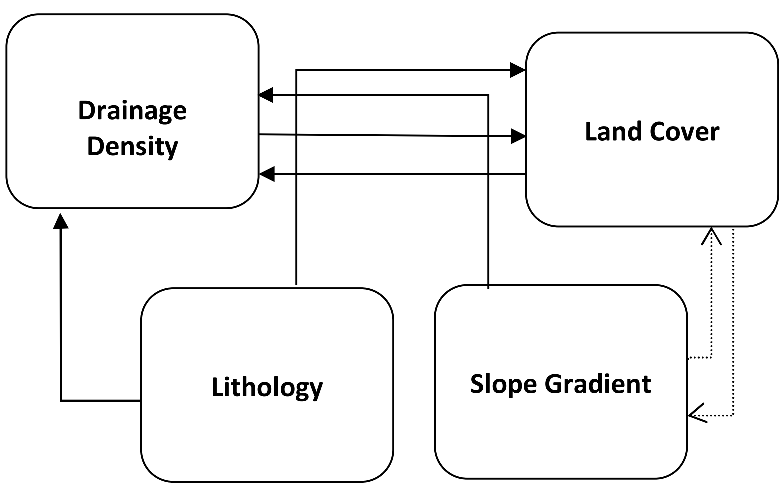

FIGURE 2.2. RELATIONSHIP AMONG VARIABLES (SOLID LINES INDICATE MAJOR EFFECTS, WHILE DASHED LINES REPRESENT MINOR EFFECTS)

A. Drainage Density

Drainage Density is defined as the number of channels in a given sub-catchment per unit area. It is a measure of how well or poorly drained a given sub-catchment is. This has bearing on planning purposes such as delineating areas where groundwater infiltration occurs. The same areas may also be flood-prone areas during the rainy season. Its value may be calculated as the quotient of total length of a channel in a basin and the area of the catchment basin. For this report, drainage density was computed as the ratio between the total length (m) of streams and the total area (sq. km.) of a sub-catchment.

The drainage network and catchment basins of the Montible river basin (Figure 2.3) were provided by the Manila Observatory (MO). The drainage density values were calculated and assigned to each respective catchment basin.

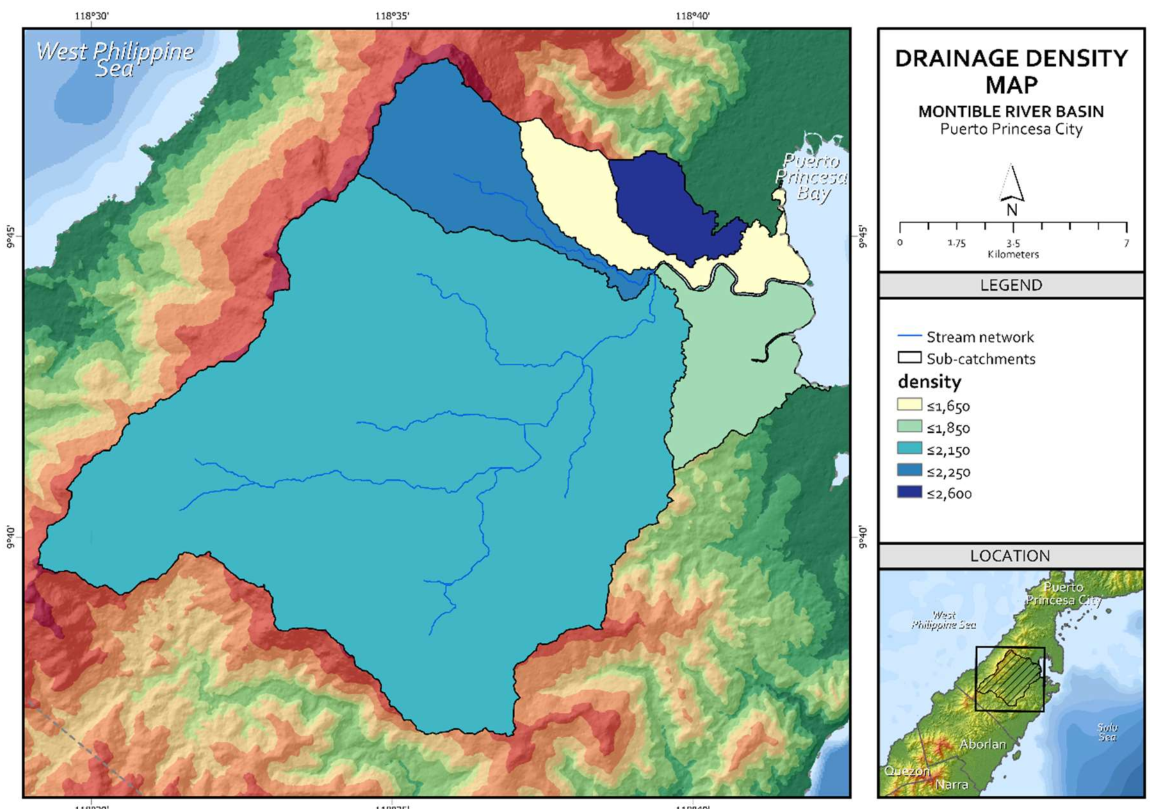

FIGURE 2.3. DRAINAGE DENSITY MAP OF MONTIBLE RIVER BASIN

B. Slope Gradient

The slope gradient influences groundwater recharge by dictating the behavior of rainfall as it flows above ground. As local rainfall is the main source of recharge, slope gradient determines the amount of water that effectively infiltrates the ground. Steep slopes result to little recharge because it causes rainwater to become runoff. On the other hand, gentler slope gradients provide enough time for water to eventually infiltrate the surface and reach the water table.

Slope gradient map (in degrees; Figure 2.4) was processed from the 5-meter resolution Interferometric Synthetic Aperture Radar (InSAR) digital elevation model using the slope function of QGIS. Hydrologic and topographic corrections, such as filling in sinks, were done before processing the data into its derivative products.

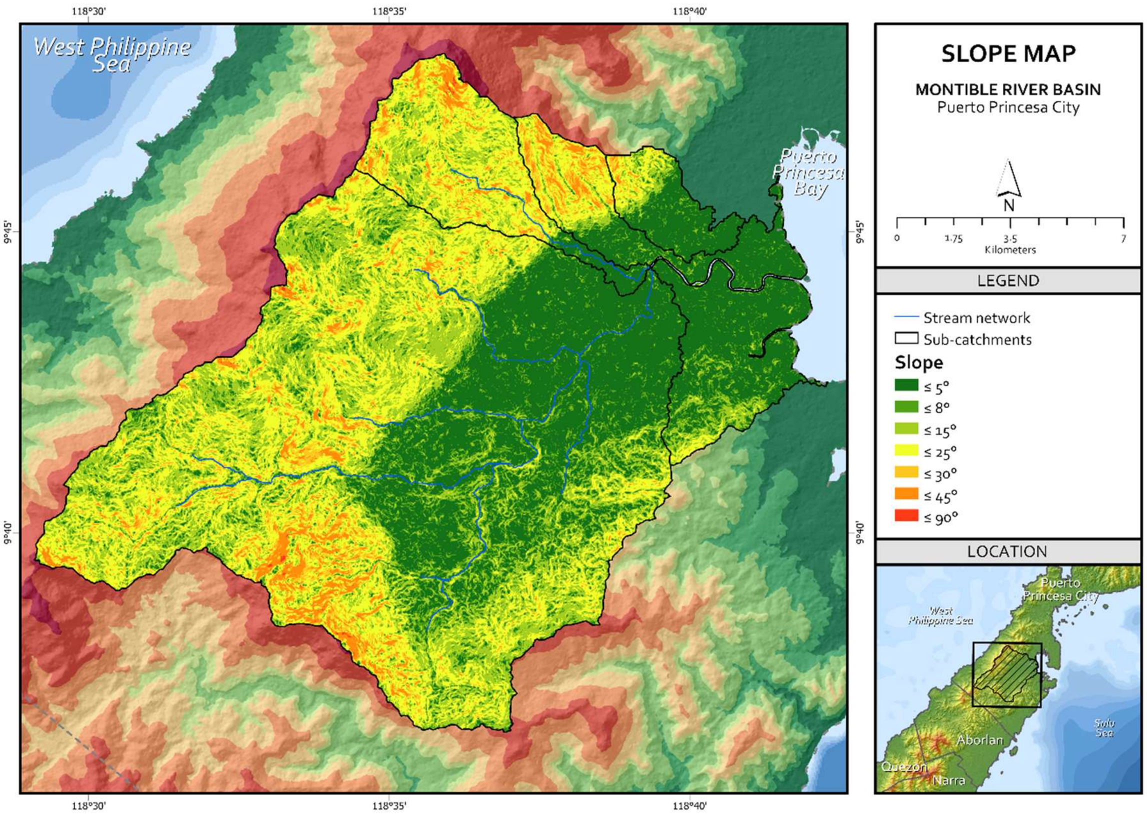

FIGURE 2.4. SLOPE MAP OF MONTIBLE RIVER BASIN

C. Land Cover

The land cover of a particular area partly determines the amount of infiltration of surface water to the water table. The land cover describes the extent of concreted residential areas, the type and extent of vegetation cover, the type of soil deposits, and the presence or absence of any water bodies. Concreted or built-up areas are zones with the least amount of infiltration due to the inability of surface water to penetrate concrete. On the other hand, areas with rich vegetation allow high amounts of infiltration due to the fact that the roots of these plants loosen the overlying rocks and soil- making it easier for water to percolate towards the water table. The type of vegetation present is also an important factor since vegetation with deep roots provide stronger infiltration as compared to vegetation with shallow roots. The amount of foliage in trees also affect recharge potential. Areas with thick foliage may provide a buffer for rainfall due to the droplets being intercepted by plant leaves. Thus, the underlying soil is provided with more time to soak up the rainfall. Furthermore, vegetation with a large area coverage prevents the direct evapotranspiration of water from the soil.

The 2020 land cover of the Montible river basin (Figure 2.5) used here were provided by the Manila Observatory, using Landsat 8 images after radiometric calibration and correction.

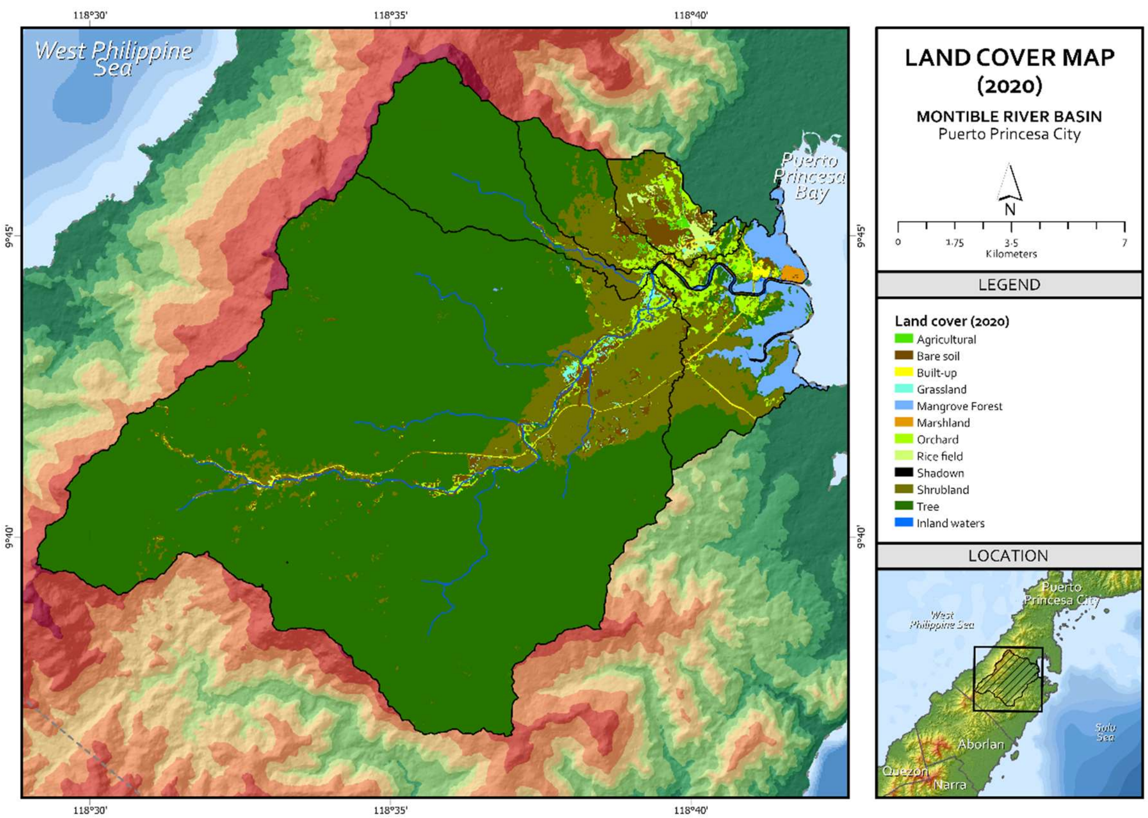

FIGURE 2.5. LAND COVER MAP (2020) OF MONTIBLE RIVER BASIN

D. Lithology

The lithology of the underlying rocks also influences the rate of infiltration to groundwater. Factors affecting the ranking of different lithologies are its porosity and permeability. In general, for sedimentary rocks, a larger grain size means a higher permeability. Meanwhile, for igneous and metamorphic rocks, the permeability is determined by the susceptibility of the rock to break or fracture- creating spaces within the rock for groundwater to fill up.

The lithology of the Montible river basin (Figure 2.6) was delineated and digitized from existing geologic maps of National Mapping and Resource Information Authority (NAMRIA) and the Mines and Geosciences Bureau (MGB). Weights for each lithologic unit were assigned based on the geologic age and texture of each unit. Thus, Quaternary alluvium and sandstones formed during Miocene were expected to facilitate infiltration and recharge of precipitation than claystones and igneous intrusions from Cretaceous, for example.

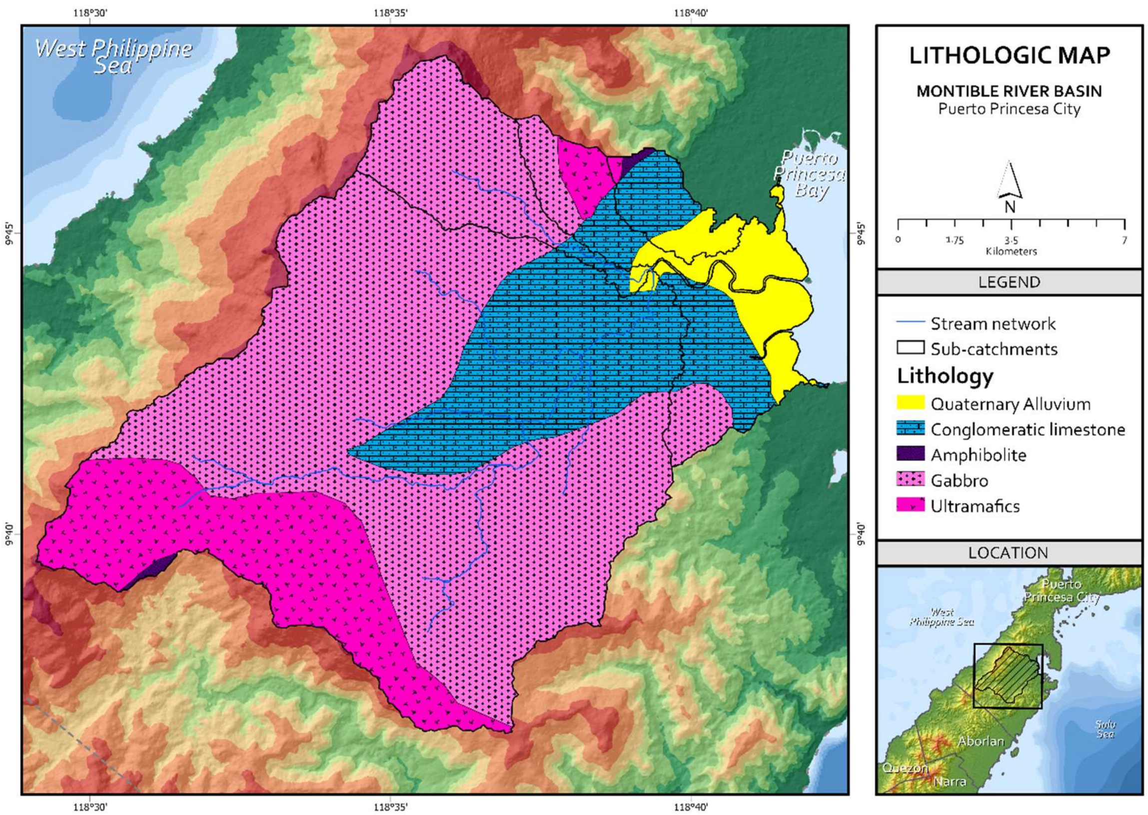

FIGURE 2.6. LITHOLOGIC MAP OF MONTIBLE RIVER BASIN

2.2 Determination of Potential Groundwater Recharge Areas

High to very high recharge areas in Montible river basin are mostly found further downstream of the river, along its floodplains at the southern part of Puerto Princesa City (Figure 2.7). Pockets of relatively high recharge areas are also found downstream of Central Peak and the Triple Top Range in southern sections of the city. Along the eastern flanks of the Anepahan Range, near the city's border with Aborlan, more incised morphological features and less sloping terrain, a significant zone of moderate to high recharge potential was also delineated. Recent deposits composed of conglomerates, sands, and silts along these alluvium plains along with a sizeable areas of conglomeratic limestone, found in these downstream areas, are conducive in promoting near vertical infiltration of precipitation and runoff from the surface. Consequently, the water table here is expected to be perennially shallow and groundwater should have short residence times. However, the rate groundwater recharge may be at times inconsistent due to the extensive limestone formation underlying a large part of the basin downstream.

Due to the lack of information of the subsurface geology of the area, the extent of the available aquifers exposed on the surface is currently not known. Aquifers present in the area may or may not be a continuous layer; several unconnected aquifers may be present at different depths. As an assumption in this report, aquifers are expected follow the boundary of the watersheds, especially on an alluvial valley bounded by defined topographic barriers and sedimentary features to its northeast. However, the boundaries to the north, west, and south are estimated to be less precise because igneous and metamorphic bodies do not follow a typical lateral groundwater flow like in sedimentary formations.

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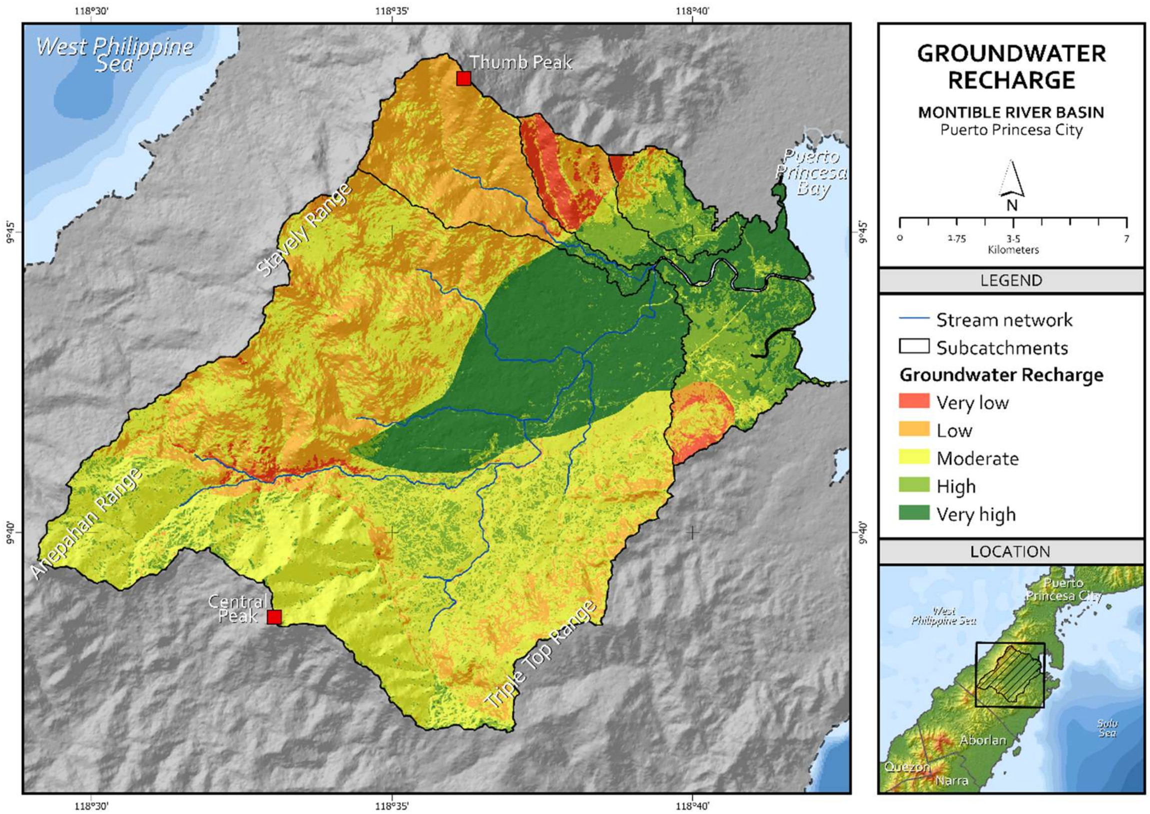

FIGURE 2.7. GROUNDWATER RECHARGE POTENTIAL MAP OF THE MONTIBLE RIVER BASIN

As expected, areas in the central-east parts of the basin have higher recharge potential than those in the upstream parts of the basin, especially in the nortwestern sections. The recharge potential of those areas may be further enhanced by decreasing the amount of run-off produced from these areas. One of the best way to decrease the amount of runoff is to increase the vegetative cover, inhibit construction of built-up areas, as well as discouraging the conversion of these lands to agricultural zones. Moderate recharge zones in the south-central parts (north of Central Peak) are characterized by shrublands. Buffers made up of grass and shrubs are efficient in decreasing the run-off velocities and filtering out particulates. Planting trees with deep root networks and high foliage also promote infiltration because they increase the permeability of the soil and they provide a buffer for rainwater as they reach the ground. For built-up areas, run-off may be redirected to a more permeable area to promote infiltration. Structures to detain water may also be constructed in these areas. Ponding areas such as swales and soak aways with sand beds help to further slow down run-off and spread the water over the basin. Infiltration basin and ditches are also helpful in collecting and spreading rainwater over a large area to increase soil-water contact. For areas with already high drainage densities, streambeds may be modified to increase the flowpath of water.

Between the baseline years of 1976 to 2005, the Montible river basin received around 1,365 mm of rainfall annually without distinct seasonal variations, typical of a Type 3 climate. Yearly precipitation rarely varies from around 1,355 mm in the southwestern areas of the basin (Anepahan Range) to around 1,382 mm in areas near Thumb Peak in the northwest. Due to the generally flat terrain of the river basin as well as the highly permeable lithologies in eastern sections of the basin, about 41% of rainfall is expected to infiltrate to the deeper aquifers in those areas. In some sub-catchments, the proportion of infiltrating rainfall decreases to about 19% in steeper, upstream areas near Thumb Peak, to as high as 41% in downstream areas in northern Puerto Princesa City. Although more than 40% of the annual rainfall is expected to infiltrate in downstream areas, no significant amount of rainfall is estimated to recharge the deeper aquifers there. Most of the infiltrating rainfall would ultimately be discharged into Puerto Princes Bay, and eventually to the Sulu Sea as submarine discharge.

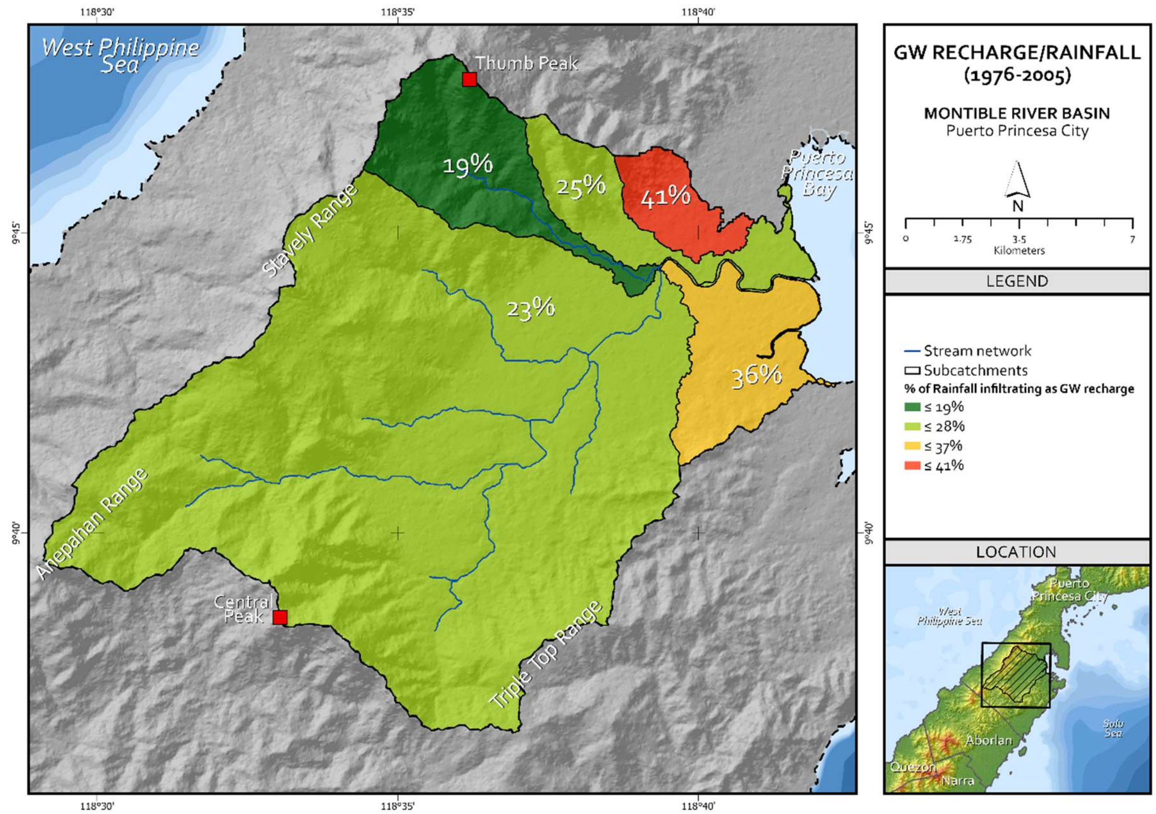

FIGURE 2.8. PROPORTION OF RAINFALL POTENTIALLY INFILTRATING AS GROUNDWATER RECHARGE IN MONTIBLE RIVER BASIN. LABELS INSIDE EACH SUB-CATCHMENT INDICATE THE AVERAGE PROPORTION OF RAINFALL INFILTRATING AS GROUNDWATER RECHARGE DURING THE BASELINE YEARS (1976-2005)

Based on these 2 scenarios of climate projections: RCP 4.5 (stabilization scenario) and RCP 8.5 (high-emissions/business as usual scenario) for the years 2006-2035 and 2036-2065, the expected volume of recharge is estimated to decrease by up to 13.2% at the end of 2065 (Table 2.1).

TABLE 2.1. PROJECTED VOLUME OF GROUNDWATER RECHARGE OF MONTIBLE RIVER BASIN BASED ON 2 CLIMATE CHANGE PROJECTIONS

SUB-BASIN	Baseline (1976-2005)	RCP 4.5 (2006-2035)	RCP 4.5 (2036-2065)	RCP 8.5 (2006-2035)	RCP 8.5 (2036-2065)
	Volume of recharge reported in Mm^3				
A	72,349,680	69,240,137	63,408,664	68,221,328	62,647,976
B	5,554,602	5,306,676	4,875,945	5,226,524	4,821,743
C	5,676,033	5,424,664	4,981,492	5,343,847	4,924,846
D	3,475,568	3,321,122	3,050,745	3,271,538	3,016,292
E	7,807,294	7,467,209	6,848,042	7,358,178	6,767,037
TOTAL	**94,863,177**	**90,759,808**	**83,164,888**	**89,421,415**	**82,177,894**

During the 1st scenario (RCP 4.5: 2006-2035), groundwater recharge is expected to decrease by up to 4.5% from the baseline years. A further decrease in groundwater recharge of up to 8.4% is estimated to occur during the next 30 years of the stabilization scenario (2036-2065). After 2065, a total of 12.4% decrease in volume of groundwater recharge from the baseline is projected to take place. For the high-emissions scenario (RCP 8.5: 2006-2035), groundwater recharge to the basin is expected to decrease by up to 5.9%, higher than what the stabilization scenario should predict. At the end of the next 30-year period, in 2065, up to 8.2% further decrease in the volume of groundwater recharge is anticipated to occur; translating to a total of up to 13.2% decrease from the baseline period.

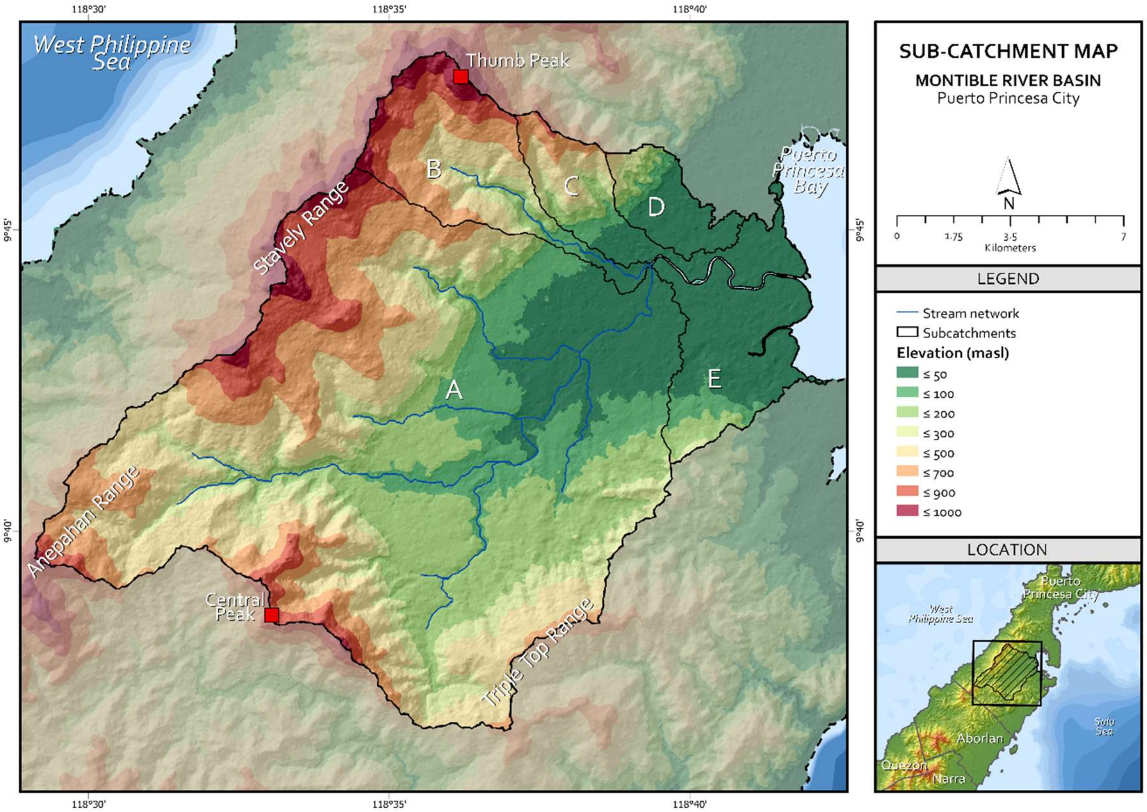

FIGURE 2.9. SUBCATCHMENTS OF MONTIBLE RIVER BASIN

To summarize, groundwater and surface water resources of Montible river basin are primarily fed by upstream areas, particularly Anepahan Range and Triple Top Range. Both climate change projections (RCP 4.5 & 8.5) tell us that monthly surface water flows will generally decrease, and groundwater recharge might decrease by up to 13.2% by the end of 2065. Thus, interventions and solutions, both nature-based and institutional measures to conserve water resources, must be prioritized in the areas identified above.

SECTION 3: POLICY RECOMMENDATIONS

Appendix O lists all the registered water permittees in the Montible River catchment. Apparently, the Puerto Princesa Water District has recently secured a water permit to extract 725 liters per second (LPS) from the river as part of the supply to the city of Puerto Princesa. Potentially, the water district can maximize this source by moving their proposed extraction point further downstream (9.740, 118.654) to capture the northern tributary of Montible River and increase the supply to >800LPS and move the diversion structure closer to Puerto Princesa City by 2.5km. Montible remains to be one of only two viable rivers near the City (the other being Irawan River) and therefore it is good that this supply has already been secured for the City's use. Still, the most important aspect of this supply is the management of its water quality. With still a fairly intact forest covering its catchment area, the utilization of this source will be cheaper if water quality is maintained through various stream management programs and land use policies that will protect its catchment in the future.

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Appendix

A. RESULTS OF THE WATERSHED AREA TRANSPOSITION FOR EACH SUB-CATCHMENT. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$.

Flow Exceedance	A	B	C	D	E
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
$Q_{0.1}$	16.79	1.91	1.23	0.68	1.54
Q_{1}	5.66	0.64	0.41	0.23	0.52
Q_{5}	2.62	0.30	0.19	0.11	0.24
Q_{10}	2.40	0.27	0.18	0.10	0.22
Q_{20}	2.07	0.24	0.15	0.08	0.19
Q_{30}	1.92	0.22	0.14	0.08	0.18
Q_{40}	1.83	0.21	0.13	0.07	0.17
Q_{50}	1.76	0.20	0.13	0.07	0.16
Q_{60}	1.70	0.19	0.12	0.07	0.16
Q_{70}	1.67	0.19	0.12	0.07	0.15
Q_{80}	1.59	0.18	0.12	0.06	0.15
Q_{90}	1.52	0.17	0.11	0.06	0.14
Q_{95}	1.47	0.17	0.11	0.06	0.13
Q_{99}	1.28	0.15	0.09	0.05	0.12
$Q_{99.9}$	1.14	0.13	0.08	0.05	0.10

B. RESULTS OF THE RAINFALL-DISCHARGE ANALYSIS FOR EACH SUB-CATCHMENT. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$. HIGHER RUNOFF COEFFICIENT VALUES WERE USED FOR MONTHS WITH LOWER RAINFALL (JAN-APR) WHILE LOWER COEFFICIENT VALUES WERE USED FOR MONTHS WITH HIGHER RAINFALL (MAY-DEC).

Flow Exceedance	**A**	**B**	**C**	**D**	**E**
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
	c = 0.20, 0.50	*c = 0.40, 0.70*	*c = 0.25, 0.55*	*c = 0.10, 0.25*	*c = 0.10, 0.25*
Q_1	3.75	0.85	0.48	0.08	0.17
Q_5	3.25	0.74	0.42	0.07	0.15
Q_{10}	2.93	0.67	0.38	0.06	0.13
Q_{20}	2.67	0.42	0.21	0.05	0.12
Q_{30}	2.44	0.55	0.31	0.05	0.11
Q_{40}	2.26	0.51	0.29	0.05	0.10
Q_{50}	2.01	0.46	0.26	0.04	0.09
Q_{60}	1.66	0.38	0.21	0.03	0.08
Q_{70}	1.34	0.30	0.17	0.03	0.06
Q_{80}	1.06	0.17	0.09	0.02	0.05
Q_{90}	0.71	0.11	0.06	0.01	0.03
Q_{95}	0.57	0.09	0.05	0.01	0.03
Q_{99}	0.30	0.05	0.02	0.01	0.01
$Q_{99.9}$	0.26	0.04	0.02	0.01	0.01

C. RESULTS OF THE LINEAR REGRESSION ANALYSIS FOR EACH SUB-CATCHMENT. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$.

Flow Exceedance	A	B	C	D	E
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
$Q_{0.1}$	89.03	78.79	78.33	77.95	78.54
Q_{1}	10.04	13.45	13.61	13.73	13.54
Q_{5}	5.46	2.32	2.17	2.06	2.24
Q_{10}	4.13	0.94	0.80	0.68	0.87
Q_{20}	2.66	0.53	0.43	0.35	0.47
Q_{30}	2.07	0.33	0.25	0.19	0.29
Q_{40}	1.57	0.27	0.21	0.16	0.24
Q_{50}	1.19	0.23	0.19	0.16	0.21
Q_{60}	0.89	0.21	0.18	0.15	0.19
Q_{70}	0.71	0.18	0.16	0.14	0.17
Q_{80}	0.59	0.13	0.11	0.10	0.12
Q_{90}	0.44	0.10	0.08	0.07	0.09
Q_{95}	0.34	0.07	0.06	0.05	0.06
Q_{99}	0.23	0.04	0.03	0.02	0.03
$Q_{99.9}$	0.19	-	-	-	-

D. RESULTS OF THE LOGARITHMIC REGRESSION ANALYSIS FOR EACH SUB-CATCHMENT. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$.

Flow Exceedance	A	B	C	D	E
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
$Q_{0.1}$	90.09	77.01	74.38	70.85	75.72
Q_1	9.88	13.58	14.32	15.32	13.94
Q_5	4.25	3.10	2.86	2.55	2.98
Q_{10}	3.20	1.53	1.19	0.74	1.36
Q_{20}	2.11	0.85	0.60	0.26	0.73
Q_{30}	1.65	0.58	0.37	0.08	0.48
Q_{40}	1.25	0.45	0.29	0.07	0.37
Q_{50}	0.95	0.37	0.25	0.10	0.31
Q_{60}	0.72	0.30	0.22	0.10	0.26
Q_{70}	0.58	0.25	0.18	0.09	0.22
Q_{80}	0.49	0.19	0.13	0.05	0.16
Q_{90}	0.37	0.13	0.09	0.02	0.11
Q_{95}	0.28	0.10	0.06	0.01	0.08
Q_{99}	0.20	0.06	0.03	-	0.04
$Q_{99.9}$	0.18	-	-	-	-

E. RESULTS OF THE EXPONENTIAL REGRESSION ANALYSIS FOR EACH SUB-CATCHMENT. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$.

Flow Exceedance	A	B	C	D	E
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
$Q_{0.1}$	92.46	77.96	77.36	76.87	77.63
Q_{1}	9.14	12.86	13.06	13.22	12.97
Q_{5}	-	-	-	-	-
Q_{10}	3.69	1.10	1.04	0.99	1.07
Q_{20}	2.81	0.63	0.58	0.55	0.60
Q_{30}	2.39	0.40	0.37	0.34	0.38
Q_{40}	1.80	0.31	0.29	0.27	0.30
Q_{50}	1.31	0.27	0.25	0.24	0.26
Q_{60}	0.99	0.23	0.21	0.20	0.22
Q_{70}	0.80	0.19	0.18	0.17	0.19
Q_{80}	0.71	0.14	0.13	0.12	0.13
Q_{90}	0.57	0.09	0.08	0.08	0.09
Q_{95}	0.45	0.06	0.06	0.05	0.06
Q_{99}	-	-	-	-	-
$Q_{99.9}$	0.19	-	-	-	-

F. RESULTS OF THE POWER REGRESSION ANALYSIS FOR EACH SUB-CATCHMENT. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$

Flow Exceedance	**A**	**B**	**C**	**D**	**E**
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
$Q_{0.1}$	87.31	74.98	72.71	69.78	73.86
Q_1	9.64	13.07	13.90	15.09	13.47
Q_5	8.04	7.51	7.41	7.28	7.46
Q_{10}	2.51	1.40	1.25	1.06	1.32
Q_{20}	1.94	0.77	0.64	0.50	0.71
Q_{30}	1.61	0.50	0.39	0.29	0.44
Q_{40}	1.24	0.38	0.30	0.22	0.34
Q_{50}	0.92	0.33	0.27	0.20	0.30
Q_{60}	0.71	0.27	0.23	0.17	0.25
Q_{70}	0.59	0.23	0.19	0.15	0.21
Q_{80}	0.52	0.16	0.13	0.10	0.15
Q_{90}	0.41	0.10	0.08	0.06	0.09
Q_{95}	0.31	0.08	0.06	0.04	0.07
Q_{99}	-	-	-	-	-
$Q_{99.9}$	0.18	0.04	0.03	0.02	0.03

G. MONTHLY DISCHARGE STATISTICS RECORDED AT THE DPWH GAUGING STATION (DRAINAGE AREA = 105 KM²) AND PREDICTED VALUES FOR THE WHOLE MONTIBLE CATCHMENT AND EACH SUB-CATCHMENT USING WATERSHED AREA TRANSPOSITION. VALUES ARE REPORTED IN $M^3 S^{-1}$.

Month	Montible (105 km²)			Montible (254 km²)			A (192.5 km²)			B (21.8 km²)			C (14.1 km²)			D (7.8 km²)			E (17.6 km²)		
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Jan	1.32	0.67	9.16	3.20	1.62	22.14	2.43	1.23	16.79	0.27	0.14	1.90	0.18	0.09	1.23	0.10	0.05	0.68	0.22	0.11	1.54
Feb	1.21	0.66	3.81	2.93	1.60	9.21	2.22	1.21	6.99	0.25	0.14	0.79	0.16	0.09	0.51	0.09	0.05	0.28	0.20	0.11	0.64
Mar	0.92	0.68	1.47	2.23	1.64	3.55	1.69	1.25	2.70	0.19	0.14	0.31	0.12	0.09	0.20	0.07	0.05	0.11	0.15	0.11	0.25
Apr	0.89	0.66	1.11	2.16	1.60	2.68	1.64	1.21	2.04	0.19	0.14	0.23	0.12	0.09	0.15	0.07	0.05	0.08	0.15	0.11	0.19
May	0.92	0.62	1.39	2.23	1.50	3.36	1.69	1.14	2.55	0.19	0.13	0.29	0.12	0.08	0.19	0.07	0.05	0.10	0.15	0.10	0.23
Jun	1.02	0.80	1.57	2.48	1.93	3.80	1.88	1.47	2.88	0.21	0.17	0.33	0.14	0.11	0.21	0.08	0.06	0.12	0.17	0.13	0.26
Jul	1.16	0.81	9.86	2.81	1.96	23.84	2.13	1.49	18.08	0.24	0.17	2.05	0.16	0.11	1.32	0.09	0.06	0.73	0.19	0.14	1.65
Aug	1.04	0.60	1.57	2.52	1.45	3.80	1.91	1.10	2.88	0.22	0.12	0.33	0.14	0.08	0.21	0.08	0.04	0.12	0.17	0.10	0.26
Sep	1.07	0.69	3.99	2.59	1.67	9.65	1.96	1.27	7.32	0.22	0.14	0.83	0.14	0.09	0.54	0.08	0.05	0.30	0.18	0.12	0.67
Oct	1.19	0.62	31.01	2.87	1.50	74.97	2.17	1.14	56.85	0.25	0.13	6.44	0.16	0.08	4.16	0.09	0.05	2.30	0.20	0.10	5.20
Nov	1.04	0.73	1.55	2.51	1.76	3.75	1.91	1.34	2.84	0.22	0.15	0.32	0.14	0.10	0.21	0.08	0.05	0.12	0.17	0.12	0.26
Dec	1.05	0.56	7.56	2.55	1.35	18.28	1.93	1.03	13.86	0.22	0.12	1.57	0.14	0.08	1.02	0.08	0.04	0.56	0.18	0.09	1.27

H. MONTHLY DISCHARGE STATISTICS PREDICTED FOR THE WHOLE MONTIBLE CATCHMENT AND EACH SUB-CATCHMENT USING RAINFALL-DISCHARGE ANALYSIS. VALUES ARE REPORTED IN $M^3 S^{-1}$.

Month	Montible (254 km²)			A (192.5 km²)			B (21.8 km²)			C (14.1 km²)			D (7.8 km²)			E (17.6 km²)		
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Jan	1.66	0.64	3.78	1.26	0.49	2.87	0.20	0.08	0.46	0.10	0.04	0.23	0.03	0.01	0.06	0.06	0.02	0.13
Feb	0.95	0.49	1.79	0.72	0.37	1.36	0.11	0.06	0.22	0.06	0.03	0.11	0.01	0.01	0.03	0.03	0.02	0.06
Mar	1.32	0.35	3.52	1.00	0.26	2.67	0.16	0.04	0.42	0.08	0.02	0.21	0.02	0.01	0.05	0.05	0.01	0.12
Apr	1.94	0.91	3.96	1.47	0.69	3.00	0.23	0.11	0.48	0.12	0.06	0.24	0.03	0.01	0.06	0.07	0.03	0.14
May	2.21	1.38	2.98	1.68	1.04	2.26	0.38	0.24	0.51	0.21	0.13	0.29	0.03	0.02	0.05	0.08	0.05	0.10
Jun	3.24	2.19	4.86	2.46	1.66	3.69	0.56	0.38	0.84	0.31	0.21	0.47	0.05	0.03	0.07	0.11	0.08	0.17
Jul	3.43	2.69	4.52	2.60	2.04	3.43	0.59	0.46	0.78	0.33	0.26	0.44	0.05	0.04	0.07	0.12	0.09	0.16
Aug	3.52	2.69	5.21	2.67	2.04	3.95	0.61	0.46	0.90	0.34	0.26	0.51	0.05	0.04	0.08	0.12	0.09	0.18
Sep	3.37	1.72	4.88	2.55	1.31	3.70	0.58	0.30	0.84	0.33	0.17	0.47	0.05	0.03	0.08	0.12	0.06	0.17
Oct	3.67	2.44	4.94	2.78	1.85	3.75	0.63	0.42	0.85	0.36	0.24	0.48	0.06	0.04	0.08	0.13	0.08	0.17
Nov	3.03	1.69	4.69	2.30	1.28	3.55	0.52	0.29	0.81	0.29	0.16	0.46	0.05	0.03	0.07	0.11	0.06	0.16
Dec	2.00	1.23	4.39	1.52	0.93	3.33	0.34	0.21	0.76	0.19	0.12	0.43	0.03	0.02	0.07	0.07	0.04	0.15

I. PREDICTED FUTURE FLOWS USING RCP4.5 FROM 2006-2035. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$. HIGHER RUNOFF COEFFICIENT VALUES WERE USED FOR MONTHS WITH LOWER RAINFALL (JAN-APR) WHILE LOWER COEFFICIENT VALUES WERE USED FOR MONTHS WITH HIGHER RAINFALL (MAY-DEC).

Flow exceedance	**A**	**B**	**C**	**D**	**E**
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
	c = 0.20, 0.50	*c = 0.40, 0.70*	*c = 0.25, 0.55*	*c = 0.10, 0.25*	*c = 0.10, 0.25*
Q_1	3.76	0.85	0.48	0.08	0.17
Q_5	3.15	0.71	0.40	0.06	0.14
Q_{10}	2.82	0.64	0.36	0.06	0.13
Q_{20}	2.49	0.56	0.32	0.05	0.11
Q_{30}	2.27	0.52	0.29	0.05	0.10
Q_{40}	2.08	0.47	0.27	0.04	0.10
Q_{50}	1.84	0.42	0.24	0.04	0.08
Q_{60}	1.63	0.37	0.21	0.03	0.07
Q_{70}	1.36	0.31	0.17	0.03	0.06
Q_{80}	1.07	0.17	0.09	0.02	0.05
Q_{90}	0.74	0.12	0.06	0.02	0.03
Q_{95}	0.59	0.09	0.05	0.01	0.03
Q_{99}	0.40	0.06	0.03	0.01	0.02
$Q_{99.9}$	0.19	0.03	0.01	0.00	0.01

J. PREDICTED FUTURE FLOWS USING RCP8.5 FROM 2006-2035. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$. HIGHER RUNOFF COEFFICIENT VALUES WERE USED FOR MONTHS WITH LOWER RAINFALL (JAN-APR) WHILE LOWER COEFFICIENT VALUES WERE USED FOR MONTHS WITH HIGHER RAINFALL (MAY-DEC).

Flow exceedance	A	B	C	D	E
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
	c = 0.20, 0.50	*c = 0.40, 0.70*	*c = 0.25, 0.55*	*c = 0.10, 0.25*	*c = 0.10, 0.25*
Q_1	4.08	0.93	0.52	0.08	0.19
Q_5	3.26	0.74	0.42	0.07	0.15
Q_{10}	2.82	0.64	0.36	0.06	0.13
Q_{20}	2.43	0.55	0.31	0.05	0.11
Q_{30}	2.21	0.50	0.28	0.05	0.10
Q_{40}	1.98	0.45	0.25	0.04	0.09
Q_{50}	1.80	0.41	0.23	0.04	0.08
Q_{60}	1.56	0.35	0.20	0.03	0.07
Q_{70}	1.27	0.20	0.10	0.03	0.06
Q_{80}	1.04	0.16	0.08	0.02	0.05
Q_{90}	0.83	0.13	0.07	0.02	0.04
Q_{95}	0.55	0.09	0.04	0.01	0.03
Q_{99}	0.24	0.04	0.02	0.00	0.01
$Q_{99.9}$	0.16	0.03	0.01	0.00	0.01

K. PREDICTED FUTURE FLOWS USING RCP4.5 FROM 2036-2065. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$. HIGHER RUNOFF COEFFICIENT VALUES WERE USED FOR MONTHS WITH LOWER RAINFALL (JAN-APR) WHILE LOWER COEFFICIENT VALUES WERE USED FOR MONTHS WITH HIGHER RAINFALL (MAY-DEC).

Flow exceedance	A	B	C	D	E
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
	c = 0.20, 0.50	*c = 0.40, 0.70*	*c = 0.25, 0.55*	*c = 0.10, 0.25*	*c = 0.10, 0.25*
Q_1	3.63	0.82	0.47	0.07	0.17
Q_5	2.96	0.67	0.38	0.06	0.14
Q_{10}	2.64	0.60	0.34	0.05	0.12
Q_{20}	2.32	0.53	0.30	0.05	0.11
Q_{30}	2.11	0.48	0.27	0.04	0.10
Q_{40}	1.87	0.30	0.15	0.04	0.09
Q_{50}	1.68	0.38	0.22	0.03	0.08
Q_{60}	1.42	0.32	0.18	0.03	0.07
Q_{70}	1.19	0.27	0.15	0.02	0.05
Q_{80}	0.98	0.16	0.08	0.02	0.04
Q_{90}	0.71	0.11	0.06	0.01	0.03
Q_{95}	0.55	0.09	0.04	0.01	0.02
Q_{99}	0.33	0.05	0.03	0.01	0.02
$Q_{99.9}$	0.20	0.03	0.02	0.00	0.01

L. PREDICTED FUTURE FLOWS USING RCP8.5 FROM 2036-2065. DISCHARGE VALUES ARE REPORTED IN $M^3 S^{-1}$. HIGHER RUNOFF COEFFICIENT VALUES WERE USED FOR MONTHS WITH LOWER RAINFALL (JAN-APR) WHILE LOWER COEFFICIENT VALUES WERE USED FOR MONTHS WITH HIGHER RAINFALL (MAY-DEC).

Flow exceedance	A	B	C	D	E
	192.5 km²	*21.8 km²*	*14.1 km²*	*7.8 km²*	*17.6 km²*
	c = 0.20, 0.50	*c = 0.40, 0.70*	*c = 0.25, 0.55*	*c = 0.10, 0.25*	*c = 0.10, 0.25*
Q_1	3.72	0.84	0.48	0.08	0.17
Q_5	3.00	0.68	0.38	0.06	0.14
Q_{10}	2.70	0.61	0.35	0.05	0.12
Q_{20}	2.32	0.53	0.30	0.05	0.11
Q_{30}	2.06	0.47	0.26	0.04	0.09
Q_{40}	1.82	0.41	0.23	0.04	0.08
Q_{50}	1.60	0.36	0.20	0.03	0.07
Q_{60}	1.41	0.32	0.18	0.03	0.06
Q_{70}	1.18	0.19	0.10	0.02	0.05
Q_{80}	0.95	0.22	0.12	0.02	0.04
Q_{90}	0.74	0.12	0.06	0.02	0.03
Q_{95}	0.55	0.09	0.04	0.01	0.03
Q_{99}	0.36	0.06	0.03	0.01	0.02
$Q_{99.9}$	0.18	0.03	0.01	0.00	0.01

M. MONTHLY DISCHARGE STATISTICS OF THE WHOLE MONTIBLE CATCHMENT AND EACH SUB-CATCHMENT IN THE BASELINE PERIOD (I.E., 1975-2005), 2020S (I.E., 2006-2035) AND 2050S (I.E., 2036-2065) USING RCP 4.5 SCENARIO. VALUES ARE REPORTED IN $M^3 S^{-1}$.

Montible (254 km²)									
Month	1976 - 2005 BASELINE RCP 4.5			2006 - 2035 RCP 4.5			2036 - 2065 RCP 4.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	1.66	0.64	3.78	1.40	0.71	3.07	1.65	0.64	3.09
Feb	0.95	0.49	1.79	1.26	0.49	2.56	1.14	0.50	2.35
Mar	1.32	0.35	3.52	1.31	0.24	3.62	1.08	0.27	2.79
Apr	1.94	0.91	3.96	1.77	0.80	3.35	1.55	0.52	3.14
May	2.21	1.38	2.98	2.09	1.28	3.00	1.74	0.95	2.67
Jun	3.24	2.19	4.86	3.09	1.81	6.11	2.83	1.60	4.79
Jul	3.43	2.69	4.52	2.87	2.01	3.89	2.89	1.37	4.47
Aug	3.52	2.69	5.21	3.50	2.40	5.43	3.16	1.98	4.89
Sep	3.37	1.72	4.88	3.21	1.71	5.25	3.23	1.59	4.70
Oct	3.67	2.44	4.94	3.39	1.81	4.62	3.17	1.99	5.43
Nov	3.03	1.69	4.69	2.96	2.00	4.15	2.44	1.60	3.35
Dec	2.00	1.23	4.39	2.19	1.19	4.21	1.79	0.83	3.01
A (192.5 km²)									
Month	BASELINE			2006 - 2035 RCP 4.5			2036 - 2065 RCP 4.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	1.26	0.49	2.87	1.06	0.54	2.33	1.25	0.48	2.34
Feb	0.72	0.37	1.36	0.96	0.37	1.94	0.86	0.38	1.78
Mar	1.00	0.26	2.67	0.99	0.19	2.74	0.82	0.20	2.11
Apr	1.47	0.69	3.00	1.34	0.61	2.54	1.18	0.39	2.38
May	1.68	1.04	2.26	1.58	0.97	2.28	1.32	0.72	2.02
Jun	2.46	1.66	3.69	2.34	1.37	4.64	2.14	1.21	3.63
Jul	2.60	2.04	3.43	2.17	1.52	2.95	2.19	1.04	3.39
Aug	2.67	2.04	3.95	2.66	1.82	4.12	2.40	1.50	3.71
Sep	2.55	1.31	3.70	2.43	1.30	3.98	2.45	1.20	3.56
Oct	2.78	1.85	3.75	2.57	1.38	3.50	2.40	1.51	4.12
Nov	2.30	1.28	3.55	2.24	1.52	3.15	1.85	1.21	2.54
Dec	1.52	0.93	3.33	1.66	0.90	3.19	1.35	0.63	2.28
	B (21.8 km²)								

Month	BASELINE			2006 - 2035 RCP 4.5			2036 - 2065 RCP 4.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	0.20	0.08	0.46	0.17	0.09	0.37	0.20	0.08	0.37
Feb	0.11	0.06	0.22	0.15	0.06	0.31	0.14	0.06	0.28
Mar	0.16	0.04	0.42	0.16	0.03	0.44	0.13	0.03	0.34
Apr	0.23	0.11	0.48	0.21	0.10	0.40	0.19	0.06	0.38
May	0.38	0.24	0.51	0.36	0.22	0.52	0.30	0.16	0.46
Jun	0.56	0.38	0.84	0.53	0.31	1.05	0.49	0.28	0.82
Jul	0.59	0.46	0.78	0.49	0.35	0.67	0.50	0.24	0.77
Aug	0.61	0.46	0.90	0.60	0.41	0.93	0.54	0.34	0.84
Sep	0.58	0.30	0.84	0.55	0.29	0.90	0.56	0.27	0.81
Oct	0.63	0.42	0.85	0.58	0.31	0.79	0.55	0.34	0.93
Nov	0.52	0.29	0.81	0.51	0.34	0.71	0.42	0.27	0.58
Dec	0.34	0.21	0.76	0.38	0.20	0.72	0.31	0.14	0.52
C (14.1 km^2)									
Month	BASELINE			2006 - 2035 RCP 4.5			2036 - 2065 RCP 4.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	0.10	0.04	0.23	0.09	0.04	0.19	0.10	0.04	0.19
Feb	0.06	0.03	0.11	0.08	0.03	0.16	0.07	0.03	0.14
Mar	0.08	0.02	0.21	0.08	0.01	0.22	0.07	0.02	0.17
Apr	0.12	0.06	0.24	0.11	0.05	0.20	0.09	0.03	0.19
May	0.21	0.13	0.29	0.20	0.12	0.29	0.17	0.09	0.26
Jun	0.31	0.21	0.47	0.30	0.18	0.59	0.27	0.16	0.47
Jul	0.33	0.26	0.44	0.28	0.20	0.38	0.28	0.13	0.43
Aug	0.34	0.26	0.51	0.34	0.23	0.53	0.31	0.19	0.48
Sep	0.33	0.17	0.47	0.31	0.17	0.51	0.31	0.15	0.46
Oct	0.36	0.24	0.48	0.33	0.18	0.45	0.31	0.19	0.53
Nov	0.29	0.16	0.46	0.29	0.19	0.40	0.24	0.16	0.33
Dec	0.19	0.12	0.43	0.21	0.12	0.41	0.17	0.08	0.29
D (7.8 km^2)									
Month	BASELINE			2006 - 2035 RCP 4.5			2036 - 2065 RCP 4.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	0.03	0.01	0.06	0.02	0.01	0.05	0.03	0.01	0.05

Feb	0.01	0.01	0.03	0.02	0.01	0.04	0.02	0.01	0.04
Mar	0.02	0.01	0.05	0.02	0.00	0.06	0.02	0.00	0.04
Apr	0.03	0.01	0.06	0.03	0.01	0.05	0.02	0.01	0.05
May	0.03	0.02	0.05	0.03	0.02	0.05	0.03	0.01	0.04
Jun	0.05	0.03	0.07	0.05	0.03	0.09	0.04	0.02	0.07
Jul	0.05	0.04	0.07	0.04	0.03	0.06	0.04	0.02	0.07
Aug	0.05	0.04	0.08	0.05	0.04	0.08	0.05	0.03	0.08
Sep	0.05	0.03	0.08	0.05	0.03	0.08	0.05	0.02	0.07
Oct	0.06	0.04	0.08	0.05	0.03	0.07	0.05	0.03	0.08
Nov	0.05	0.03	0.07	0.05	0.03	0.06	0.04	0.02	0.05
Dec	0.03	0.02	0.07	0.03	0.02	0.06	0.03	0.01	0.05
E (17.6 km^2)									
Month	BASELINE			2006 - 2035 RCP 4.5			2036 - 2065 RCP 4.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	0.06	0.02	0.13	0.05	0.02	0.11	0.06	0.02	0.11
Feb	0.03	0.02	0.06	0.04	0.02	0.09	0.04	0.02	0.08
Mar	0.05	0.01	0.12	0.05	0.01	0.13	0.04	0.01	0.10
Apr	0.07	0.03	0.14	0.06	0.03	0.12	0.05	0.02	0.11
May	0.08	0.05	0.10	0.07	0.04	0.10	0.06	0.03	0.09
Jun	0.11	0.08	0.17	0.11	0.06	0.21	0.10	0.06	0.17
Jul	0.12	0.09	0.16	0.10	0.07	0.14	0.10	0.05	0.16
Aug	0.12	0.09	0.18	0.12	0.08	0.19	0.11	0.07	0.17
Sep	0.12	0.06	0.17	0.11	0.06	0.18	0.11	0.06	0.16
Oct	0.13	0.08	0.17	0.12	0.06	0.16	0.11	0.07	0.19
Nov	0.11	0.06	0.16	0.10	0.07	0.14	0.08	0.06	0.12
Dec	0.07	0.04	0.15	0.08	0.04	0.15	0.06	0.03	0.10

N. MONTHLY DISCHARGE STATISTICS OF THE WHOLE MONTIBLE CATCHMENT AND EACH SUB-CATCHMENT IN THE BASELINE PERIOD (I.E., 1975-2005), 2020S (I.E., 2006-2035) AND 2050S (I.E., 2036-2065) USING RCP 8.5 SCENARIO. VALUES ARE REPORTED IN $M^3 S^{-1}$.

Montible (254 km^2)									
Month	1976 - 2005 BASELINE RCP 8.5			2006 - 2035 RCP 8.5			2036 - 2065 RCP 8.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	1.66	0.64	3.78	1.56	0.54	3.43	1.56	0.71	2.88
Feb	0.95	0.49	1.79	1.17	0.49	2.32	1.16	0.46	2.18
Mar	1.32	0.35	3.52	1.18	0.21	3.10	1.23	0.24	3.15
Apr	1.94	0.91	3.96	1.62	0.48	2.84	1.50	0.52	2.92
May	2.21	1.38	2.98	2.05	1.23	3.45	1.68	0.92	2.75
Jun	3.24	2.19	4.86	3.06	2.26	4.70	2.64	1.63	5.59
Jul	3.43	2.69	4.52	2.78	2.16	3.64	2.84	1.90	3.97
Aug	3.52	2.69	5.21	3.53	2.05	5.62	3.32	1.73	4.91
Sep	3.37	1.72	4.88	3.05	1.76	5.64	3.08	1.50	5.49
Oct	3.67	2.44	4.94	3.45	1.77	5.39	3.07	1.95	4.76
Nov	3.03	1.69	4.69	2.83	2.00	4.19	2.54	1.57	3.68
Dec	2.00	1.23	4.39	2.21	0.85	5.68	1.80	0.94	3.01

A (192.5 km^2)									
Month	BASELINE			2006 - 2035 RCP 8.5			2036 - 2065 RCP 8.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	1.26	0.49	2.87	1.18	0.41	2.60	1.18	0.54	2.18
Feb	0.72	0.37	1.36	0.89	0.37	1.76	0.88	0.35	1.66
Mar	1.00	0.26	2.67	0.89	0.16	2.35	0.93	0.18	2.39
Apr	1.47	0.69	3.00	1.23	0.36	2.15	1.13	0.40	2.21
May	1.68	1.04	2.26	1.55	0.93	2.61	1.27	0.70	2.08
Jun	2.46	1.66	3.69	2.32	1.71	3.56	2.00	1.24	4.24
Jul	2.60	2.04	3.43	2.11	1.64	2.76	2.15	1.44	3.01
Aug	2.67	2.04	3.95	2.68	1.56	4.26	2.52	1.31	3.72
Sep	2.55	1.31	3.70	2.31	1.33	4.28	2.34	1.13	4.16
Oct	2.78	1.85	3.75	2.61	1.34	4.08	2.33	1.48	3.61
Nov	2.30	1.28	3.55	2.15	1.52	3.18	1.93	1.19	2.79
Dec	1.52	0.93	3.33	1.67	0.64	4.31	1.36	0.71	2.28

	B (21.8 km^2)								
Month	BASELINE			2006 - 2035 RCP 8.5			2036 - 2065 RCP 8.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	0.20	0.08	0.46	0.19	0.06	0.41	0.19	0.09	0.35
Feb	0.11	0.06	0.22	0.14	0.06	0.28	0.14	0.06	0.26
Mar	0.16	0.04	0.42	0.14	0.03	0.37	0.15	0.03	0.38
Apr	0.23	0.11	0.48	0.19	0.06	0.34	0.18	0.06	0.35
May	0.38	0.24	0.51	0.35	0.21	0.59	0.29	0.16	0.47
Jun	0.56	0.38	0.84	0.53	0.39	0.81	0.45	0.28	0.96
Jul	0.59	0.46	0.78	0.48	0.37	0.63	0.49	0.33	0.68
Aug	0.61	0.46	0.90	0.61	0.35	0.97	0.57	0.30	0.84
Sep	0.58	0.30	0.84	0.53	0.30	0.97	0.53	0.26	0.94
Oct	0.63	0.42	0.85	0.59	0.30	0.93	0.53	0.34	0.82
Nov	0.52	0.29	0.81	0.49	0.34	0.72	0.44	0.27	0.63
Dec	0.34	0.21	0.76	0.38	0.15	0.98	0.31	0.16	0.52
	C (14.1 km^2)								
Month	BASELINE			2006 - 2035 RCP 8.5			2036 - 2065 RCP 8.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	0.10	0.04	0.23	0.10	0.03	0.21	0.10	0.04	0.18
Feb	0.06	0.03	0.11	0.07	0.03	0.14	0.07	0.03	0.13
Mar	0.08	0.02	0.21	0.07	0.01	0.19	0.08	0.01	0.19
Apr	0.12	0.06	0.24	0.10	0.03	0.17	0.09	0.03	0.18
May	0.21	0.13	0.29	0.20	0.12	0.33	0.16	0.09	0.27
Jun	0.31	0.21	0.47	0.30	0.22	0.46	0.26	0.16	0.54
Jul	0.33	0.26	0.44	0.27	0.21	0.35	0.28	0.18	0.39
Aug	0.34	0.26	0.51	0.34	0.20	0.55	0.32	0.17	0.48
Sep	0.33	0.17	0.47	0.30	0.17	0.55	0.30	0.15	0.53
Oct	0.36	0.24	0.48	0.33	0.17	0.52	0.30	0.19	0.46
Nov	0.29	0.16	0.46	0.28	0.19	0.41	0.25	0.15	0.36
Dec	0.19	0.12	0.43	0.21	0.08	0.55	0.17	0.09	0.29
	D (7.8 km^2)								
Month	BASELINE			2006 - 2035 RCP 8.5			2036 - 2065 RCP 8.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**

Jan	0.03	0.01	0.06	0.02	0.01	0.05	0.02	0.01	0.04
Feb	0.01	0.01	0.03	0.02	0.01	0.04	0.02	0.01	0.03
Mar	0.02	0.01	0.05	0.02	0.00	0.05	0.02	0.00	0.05
Apr	0.03	0.01	0.06	0.02	0.01	0.04	0.02	0.01	0.04
May	0.03	0.02	0.05	0.03	0.02	0.05	0.03	0.01	0.04
Jun	0.05	0.03	0.07	0.05	0.03	0.07	0.04	0.03	0.09
Jul	0.05	0.04	0.07	0.04	0.03	0.06	0.04	0.03	0.06
Aug	0.05	0.04	0.08	0.05	0.03	0.09	0.05	0.03	0.08
Sep	0.05	0.03	0.08	0.05	0.03	0.09	0.05	0.02	0.08
Oct	0.06	0.04	0.08	0.05	0.03	0.08	0.05	0.03	0.07
Nov	0.05	0.03	0.07	0.04	0.03	0.06	0.04	0.02	0.06
Dec	0.03	0.02	0.07	0.03	0.01	0.09	0.03	0.01	0.05
E (17.6 km^2)									
Month	BASELINE			2006 - 2035 RCP 8.5			2036 - 2065 RCP 8.5		
	Ave	**Min**	**Max**	**Ave**	**Min**	**Max**	**Ave**	**Min**	**Max**
Jan	0.06	0.02	0.13	0.05	0.02	0.12	0.05	0.02	0.10
Feb	0.03	0.02	0.06	0.04	0.02	0.08	0.04	0.02	0.08
Mar	0.05	0.01	0.12	0.04	0.01	0.11	0.04	0.01	0.11
Apr	0.07	0.03	0.14	0.06	0.02	0.10	0.05	0.02	0.10
May	0.08	0.05	0.10	0.07	0.04	0.12	0.06	0.03	0.10
Jun	0.11	0.08	0.17	0.11	0.08	0.16	0.09	0.06	0.19
Jul	0.12	0.09	0.16	0.10	0.07	0.13	0.10	0.07	0.14
Aug	0.12	0.09	0.18	0.12	0.07	0.20	0.12	0.06	0.17
Sep	0.12	0.06	0.17	0.11	0.06	0.20	0.11	0.05	0.19
Oct	0.13	0.08	0.17	0.12	0.06	0.19	0.11	0.07	0.17
Nov	0.11	0.06	0.16	0.10	0.07	0.15	0.09	0.05	0.13
Dec	0.07	0.04	0.15	0.08	0.03	0.20	0.06	0.03	0.10

O. WATER RIGHTS IN MONTIBLE CATCHMENT

PROVINCE	MUNICIPALITY	SOURCE	TYPE	LATITUDE	LONGITUDE	GRANTED _LPS	PURPOSE
PALAWAN	PUERTO PRINCESA	MONTIBLE RIVER	**SURFACE WATER**	9.720633	118.640647	725	MUNICIPAL

P. SUMMARY FIELD DATA OF SAMPLING SITES IN MONTIBLE CATCHMENT.

Location (Brgy./Coordinates)	Field Photo	Water Quality	Water Discharge
MIDSTREAM Water District Dam inside Montible Subcolony,Puerto Princesa City Latitude: 9°43'6.8" Longitude: 118°38'21.4"	 Dam (facing upstream) built by the Puerto Princesa City Water District (PPCWD) inside the Montible subcolony. The PPCWD regularly collects discharge data using a flow meter for at least twice a week. Water samples are also sent to the laboratory for water quality assessment twice a month. The water is clear but algae is abundant in the lag deposits upstream of this location. Water sampling was done further upstream of this location (before the water pools into the dam). Photo taken on February 4, 2021	pH: 8.50 Temp: 28.57 C ORP: 152 mV TDS: 141.07 ppm Cond: 220.43 µS Turbidity: 0.85 FNU DO: 9.50 mg/L	9.90 m^3/s At the dam *water has already pooled in the dam 2.74 m^3/s *Further upstream before the pooling of water in the dam:

	 GFI team member demonstrating the use of Ultrameter to the participants from DENR, Water district, CENRO and other LGUs. Photo taken on February 4, 2021		
MIDSTREAM Dam near Montible Bridge II (red bridge) Latitude: 9°41'25.6" Longitude: 118°37'22.2"	 Montible river upstream of the Montible bridge II (in red). The lag deposits are dominated by pebble to cobble rocks. The water flowing in this part of the river comes from a dam immediately upstream of this location. Photo taken on February 4, 2021.	pH: 8.54 Temp: 26.93 C ORP: 139.67 mV TDS: 179.07 ppm Cond: 278.47 µS Turbidity: 1.79 FNU DO: 8.53 mg/L	2.79 m^3/s

UPSTREAM Confluence downstream of Salakot Falls (Montible) Left tributary: Latitude: 9°41'39.8" Longitude: 118°31'8.7" Right tributary: Latitude: 9°41'39.8" Longitude: 118°31'10.2"	 Upstream of the Montibe river (facing upstream) coming from Salakot Falls (right tributary) and another falls (left tributary). The lag and bank deposits in the area are generally dominated by cobble sized rocks. Photo taken on February 4, 2021. 	Left tributary: pH: 8.17 Temp: 24.77 C ORP: 146.33 mV TDS: 88.35 ppm Cond: 139.7 µS Turbidity: 3.28 FNU DO: 8.10 mg/L Right Tributary: (from Salakot falls) pH: 6.51 Temp: 24.75 C ORP: 249 mV TDS: 80.25 ppm Cond: 142.08 µS Turbidity: 4.51 FNU DO: 8.00 mg/L At confluence: pH: 8.08 Temp: 24.47 C ORP: 155.33 mV TDS: 85.21 ppm Cond: 134.9 µS Turbidity: 4.30 FNU DO: 8.27 mg/L	0.19 m^3/s 0.16 m^3/s 0.46 m^3/s

	A group consisting of participants from PPCWD and barangay officials conducted river profiling and water sampling in the left tributary. The same activity was done by another group in the Salakot falls tributary. Photo taken on February 4, 2021.		
UPSTREAM Iwahig river confluence In Purok Epep Latitude: 9°40'54.2" Longitude: 118°32'35.6"	 Confluence of two upstream tributaries of the Montible river in Purok Epep. The right tributary comes from the Salakot falls tributaries. Sampling was conducted in the left tributary and at the confluence of the rivers. Photo taken on February 4, 2021.	Left tributary: pH: 8.48 Temp: 26.30 C ORP: 221.80 mV TDS: 134.80 ppm Cond: 210.22 µS Turbidity: 1.83 FNU DO: 8.00 mg/L Right tributary: pH: 8.38 Temp: 25.80 C ORP: 164.50 mV TDS: 96.92 ppm Cond: 153.48 µS Turbidity: __ FNU DO: 7.93 mg/L Confluence: pH: 8.30 Temp: 26.00 C ORP: 149.67 mV TDS: 103.40 ppm Cond: 163.37 µS Turbidity: 1.37 FNU DO: 7.93 mg/L	0.58 m^3/s 0.71 m^3/s 0.79 m^3/s

	 Participants conduct water quality parameter measurements (using instruments such as turbidity meter and ultrameter) along the right bank of the Montible river confluence. February 4, 2021.		
DOWNSTREAM Iwahig Bridge Puerto Princesa South Road Latitude: 9°44'0.0" Longitude: 118°41'0.9"	 The Montible River as viewed from the Iwahig Firefly watching area (facing downstream). The water in this area is evidently brackish as reflected in the measured conductivity and TDS as well as the evident back flow in the site. Photo taken on February 4, 2021.	pH: 7.99 Temp: 29.17 C ORP: 255 mV TDS: 27.06 ppt (note change in unit) Cond: 28.05 mS (note change in unit) Turbidity: 1.86 FNU DO: 5.80 mg/L	High tide during time of visit. Back flow is evident. Only the area and back flow rate was measured that is not a representative of the river discharge. Cross-sectional area at the bridge: 386.25 m^2

	 Upstream of the Montible river as viewed from the old Iwahig bridge. Photo taken on February 4, 2021.		
SANTIAGO TRIBUTARY Iwahig Penal Colony Latitude: 9°44'29.81" Longitude: 118°39'12.59"	 River profiling along the Santiago river tributary (facing downstream) inside the Iwahig penal colony. Downstream of this tributary, a damaged dam structure can be found. Photo taken on February 5, 2021.	pH: 8.63 Temp: 25.25 C ORP: 290.50 mV TDS: 384.70 ppm Cond: 577.65 µS Turbidity: 2.99 FNU DO: 7.93 mg/L	0.143 m^3/s

LAPU-LAPU AND MONTIBLE RIVER CONFLUENCE Lapu-lapu: Latitude: 9°43'27.15" Longitude: 118°39'0.99" Montible river: Latitude: 9°43'25.28" Longitude: 118°39'4.05"	 Confluence (facing upstream) of the downstream Montible river (upper middle in photo) and the Lapu-lapu tributary (lower right) that drains from the Thumb Peak. The two rivers are separated by an island in between. Downstream of their confluence, the river pools and the river deepens. Photo taken on February 5, 2021.  River profiling in the Montible river downstream. Photo taken on February 5, 2021.	Lapu-lapu tributary: pH: 8.01 Temp: 27.83 C ORP: 314.67 mV TDS: 81.84 ppm Cond: 129.70 µS Turbidity: 0.62 FNU DO: 7.50 mg/L Montible downstream: pH: 8.53 Temp: 27.87 C ORP: 297.67 mV TDS: 151.03 ppm Cond: 235.33 µS Turbidity: 0.97 FNU DO: 7.93 mg/L	$0.43\ m^3/s$ $2.96\ m^3/s$

	 River profiling in the Lapu-lapu tributary. Photo taken on February 5, 2021.  Participants record the data they collected from the samples in the Lapu-lapu tributary.		

BALSAHAN NATURAL POOL Iwahig Penal Colony Latitude: 9°46'17.47" Longitude: 118°39'46.5"	 Sample collection and dissolved oxygen measurement in the Balsahan natural pool (facing upstream). A man-made (concrete) dam/pool has been built downstream of this location and is used as recreational activities.	pH: 8.64 Temp: 26.37 C ORP: 281.33 mV TDS: 237.97 ppm Cond: 363.67 µS Turbidity: 0.88 FNU DO: 7.77 mg/L	0.38 m^3/s