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To cite this article: Sunaryo *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **602** 012107

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Analysis of water balance on Lake Maninjau, West Sumatera

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Abstract. Lake Maninjau is located in Tanjung Raya sub-district, Agam Regency, West Sumatra Province. Geographically, it's located at $100^{\circ} 32'46.33''$ and $0^{\circ} 50'84.2''$. The research was to analyze the water balance of Lake Maninjau in accordance with the rainfall data. The data used in this study was a land use map in order to determine the progress of its land cover, rainfall data, and outlet data of Lake Maninjau. The rainfall value was the value of the debit calculation input using FJ Mock, and ETo from the calculation of annual air temperature climatology data. Outflow data was obtained from a summary of the measurements of Lake Maninjau hydropower from the year of 2007 to 2017. From the analysis of water availability of Lake Maninjau, an analysis of water needs and its availability was considered sufficient to meet the water needs around the lake. It was occurred when the average lake water inflow was $174,935 \text{ m}^3 / \text{sec}$ per year with $5,593 \text{ m}^3 / \text{sec}$ per year on the need for (outflow) lake water, and the difference between the two was $169,342 \text{ m}^3 / \text{sec}$ per year according to data from 2007 to 2017. Therefore, the capacity of Lake Maninjau's water is still requisite in number.

1. Introduction

A lake that has an important role in West Sumatera Province is Lake Maninjau due to its function as a power plant, and tourism site for this province. Lake Maninjau is located in Tanjung Raya Sub-district, Agam Regency, West Sumatera Province with a distance of 105 kms from the city of Padang. Geographically, this lake is located at $100^{\circ} 32'46.33''$ and $0^{\circ} 50'84.2''$ [3].

As a matter of the fact, this lake has several functions for its surrounding life, such as the source for the clean water for the surrounding community, a source of fish cultivation, tourism attraction, hydroelectric power resource, and maintaining the balance of the surrounding natural ecosystem.

To some extent, this leads to the lake arrangement and management so it is maximally utilized, and to control water pollution in order to maintain the water quality of the lake well. Taking this into consideration, the analysis of water balance on Lake Maninjau is discussed.

The purpose of this study is to analyze the availability of water (water balance) of Lake Maninjau. To add, it is set to analyze the water balance of this lake also according to the obtained rainfall data. This study takes place in Lake Maninjau shown in figure 1.1 Map and the Situation Picture of Lake Maninjau.



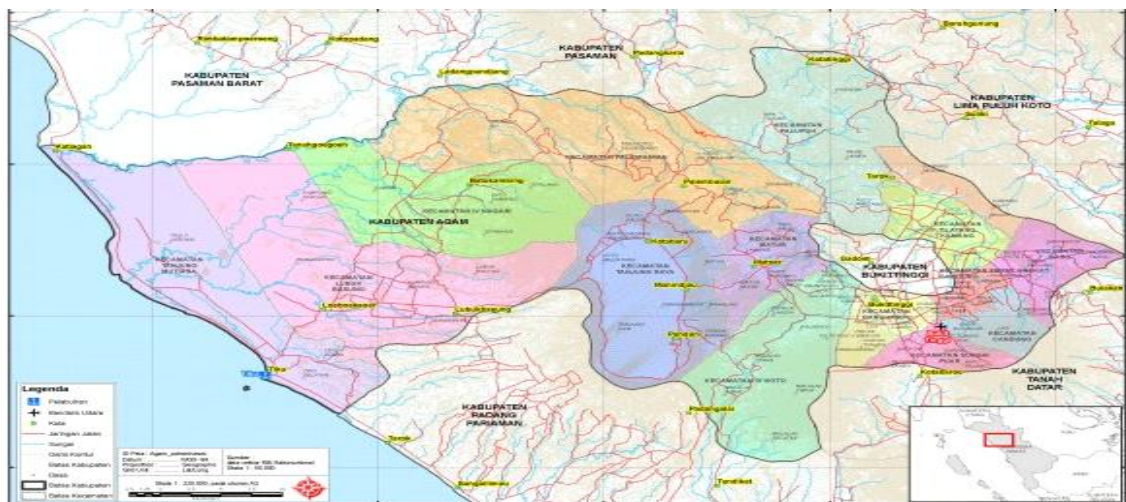


Figure 1.1 Map of Lake Maninjau Area, source: BWSSV 2014

2. Literature Review

2.1. Literature review

In 2014, Dewi R [5] et al. conducted a research on the participation of Lake Beratan communities in the water resources conservation aiming to identify and analyze community participation around this lake in the conservation of water resources.

In 2015, Ahmad R [1] carried out an analysis of water quality and pollution load in Pondok Lapan Lake in Langkat District. The goal is to find out whether the polluted or uncontaminated lake water must be analyzed for the water quality including biological, physical, and chemical parameters. All these parameters must be balanced so that they can continuously support the survival of organisms which live in these waters. The unbalance on each of these parameters value can cause disruption in the life cycle in the aquatic ecosystem.

Bambang I [2] in 2014 set up a water balance estimation for PLTA Maninjau using TRMM and debit data. The study concerned on the flow of Lake Maninjau, which used to produce 68 megawatts of hydropower, and irrigate 4200 ha of rice fields. There are 19 rivers flowing into the lake, where the main rivers are Sundai Batang Limau, Maransi Batang, Bandar Ligin, Ampang Bridge, Batang Kalarian, and Dinding Asam. The exit from the station's hydroelectric power plant flows to the Batang Antokan which, and ends in the Indian Ocean in the West. The balanced water for inflows and outflows from 2009 to 2012 showed an increase from an average of 5.8 m³ / second to 23.53 m³ / second. This condition raised concerns that rainfall input could not maintain a sustainable water level. In addition, the measurement of instant debit on March 25 and 26, 2013 showed that the input to the lake was smaller than the output. The study found that the rainfall flow was dominant during the rainy season which contributed to the outflow of the dam.

Daru S R [3] in 2015 also performed a study on the implementation of eco-hydrolic engineering for strengthening riverbanks, and restoring the habitat of the Surabaya fish reserve area. Recovery for the damage on the littoral habitat due to riverbank erosion in the Surabaya River Fish Reserved Area was carried out by applying the eco-hydrolytic engineering model utilizing local natural materials namely river stone, logs, and bamboo, as well as planting natural vegetation along the riverbanks. This model was an effort to reduce riverbank erosion at a lower cost and is more environmentally friendly than erosion control using a conventional technique for building slope and concrete slabs.

Jaya A [6] also presented the current conditions, problems and management of Lake Maninjau. Here, the study examined the condition of Maninjau Lake where it mainly comes from the rivers along the

watershed, and leads to the lake, rainwater, and from inside the lake itself. In the lake area, there are 88 large and small rivers with a maximum width of 8 meters and flow into the lake. The rivers on the north which lead to Lake Maninjau have a linear pattern (straight or unbranched), while the river on the west part is generally dendritic (branched) pattern. Most of these rivers (61.4%) are dry during the dry season, while the rivers of water throughout the year are only 34 rivers. The rivers flow with a relatively small discharge. According to the West Sumatera Bapedalda in 2001, most of Lake Maninjau water circulations derive from the river, and also the water at the lake's bottom. Here, the analysis of the water balance is the one from Lake Maninjau, West Sumatra.

2.2. FJ Mock [7]

The Mock (1973) method pointed out a water balance analysis in order to calculate the monthly discharge price based on the transformation of monthly rainfall data, evapotranspiration, soil moisture, and groundwater reservoirs. This method principle stated that rain falls on the water catchment area, some would be lost due to evapotranspiration. Some immediately became direct runoff and some others diffused into the ground or infiltrate. At first, this infiltration would saturate the soil, then percolation occurred, and the water came out through the base flow.

To explain the process of water flow in soil and river systems, therefore the approach developed by Mock was applied. This calculation requires bulk data rain, ETo, soil moisture, and groundwater reservoir to estimate the magnitude runoff. This method is able to predict infiltration (I), base flow (Bf), and runoff (Ro) which value corresponds to the following equation:

$$\begin{aligned} I &= S \times i && \dots\dots\dots (1) \\ DRo &= S - I && \dots\dots\dots (2) \\ Vn &= [0.5 \times (1 + k) \times I] + (k + Vn-1) && \dots\dots\dots (3) \\ Bf &= I \times (Vn - Vn-1) && \dots\dots\dots (4) \\ Ro &= Bf + DRo && \dots\dots\dots (5) \end{aligned}$$

Where I is infiltration, S is the surplus obtained from equation (2), i is the infiltration coefficient, Vn is groundwater storage, Bf is the base flow, and Ro is the runoff. The Surplus Water Equation (SS) is as follow:

$$WS = (P - Ea) + SS \quad \dots\dots\dots (6)$$

In the Mock method, the soil moisture reservoir is calculated as follow:

$$SMS = ISMS + (P - Ea) \quad \dots\dots\dots (7)$$

Where:

ISMS = Initial Soil Moisture Storage is a soil moisture capacity (SMC) of the previous month.

P - Ea = Precipitation that has experienced evapotranspiration.

There are two conditions to determine the SMC, namely:

1. SMC = 200 mm / month, if P - Ea = 0
2. SMC = SMC the previous month + (P - Ea), if P - Ea < 0

For Base Flow calculation, Direct Off and Storm Runoff according to Mock, the amount of infiltration is the water surplus (WS) multiplied by the infiltration coefficient (if), or infiltration (i) = WS x if.

The zone (groundwater storage abbreviated GS) is formulated as follow: $\{0.5 \times (1 + K) \times i\} + \{K \times GS_{\text{previous}}\}$.

Perubahan dalam penyimpanan air tanah (GSA) adalah perbedaan antara bulan penyimpanan air tanah yang ditinjau dengan penyimpanan air tanah bulan sebelumnya. Arus basis perhitungan dihitung dalam bentuk persamaan:

The change in groundwater storage (ΔGS) is the difference between the month of storing the groundwater reviewed by the groundwater storage in the previous month. The calculation Base Flow is measured in the form of the equation:

$$BF = i - \Delta GS \quad \dots\dots\dots (8)$$

Direct run off is calculated by the equation:

$$DRO = WS - i \quad \dots\dots\dots (9)$$

After the base flow and direct runoff, the other components of the discharge are storm runoff where Mock determined them as listed below:

If Precipitation (P) > maximum soil moisture capacity, then the value of storm runoff = 0

If $P <$ maximum soil moisture capacity then storm runoff is the amount of rainfall in the relevant month multiplied by percentage factor, or: $SRO = P \times PF$.

Total Run Off (TRO) is the component forming the river discharge (stream flow). It is the amount between base flow, direct runoff and storm runoff, or: $TRO = BF + DRO + SRO$

If this TRO is multiplied by the water catchment area in km with a certain conversion number, the amount of discharge in m^3 / dt will be obtained.

2.3. Availability Water (water balance)

Water balance is a way of analyzing the balance (water) equation based on the law of mass conservation stating that a substance cannot be created or destroyed, how ever, a substance can change its shape. This water balance equation shows the amount of input (inflow / gain), and output (outflow / losses), and storage.

In the process of water circulation, the relationship between the flow of water into inflow and outflow in a particular area for a certain period is called the water balance see in figure 2.1.

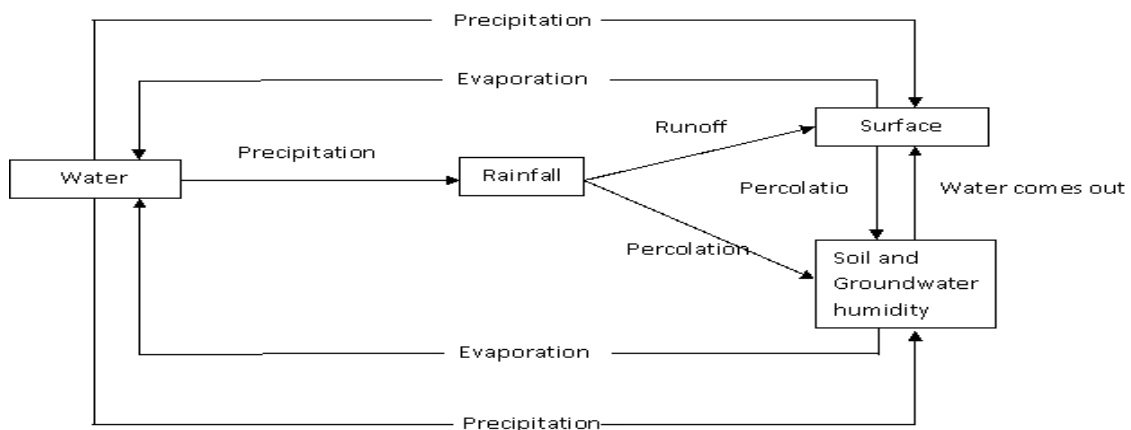


Figure 2.1 Water Circulation, source: hydrology, Suyono S 2003 [8]

The balance relationship is as follow:

$$P = (D2 - D1) + E + (G2 - G1) + M \quad \dots\dots\dots (10)$$

Where:

D1 : Surface water from the upstream that flows into the reviewed area

D2 : Surface water flowing out of the downstream reviewed area

G1 : Groundwater flowing from upstream to the reviewed area

G2 : Groundwater flowing out of the downstream reviewed area

M : Addition onto soil moisture

P : Precipitation

E : Evapotranspiration

3. Research Methodology

Principally, the research implementation process is divided into three parts; data collection, data processing, and output in the form of conclusions and recommendations taken from the results. The study procedures are illustrated in the flowchart below in figure 3.1:

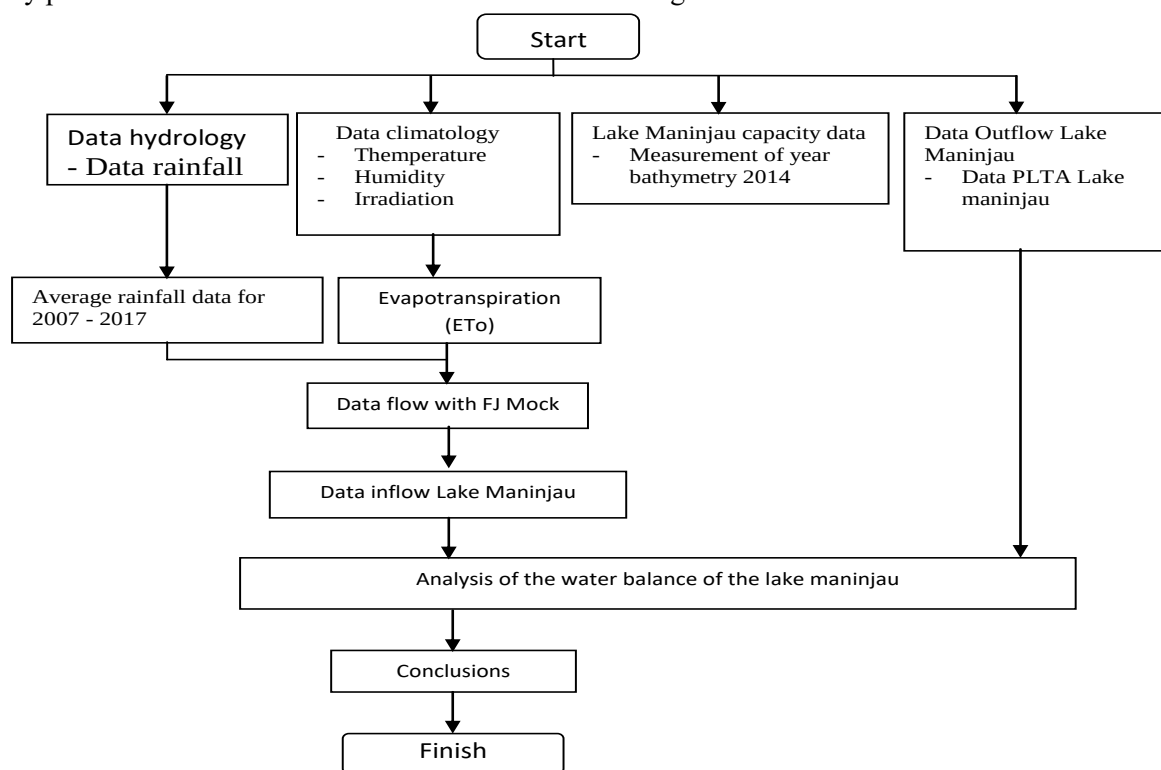


Figure 3.1 Research Flowchart

4. Discussion

Rainfall data of Lake Maninjau, and Gumarang Hydropower Station are taken to analyze the water balance on the years of 2007-2017 at Table 4.1.

Table 4.1 Rainfall Stations of Lake Maninjau, and Gumarang Hydropower Stations

YEARS	MONTH												TOTAL
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DES	
2007	7.347	6.043	5.085	8.573	4.219	4.172	3.789	2.006	3.317	5.157	6.011	2.883	58.603
2008	4.893	4.586	9.554	13.001	8.540	7.968	9.816	8.816	15.258	10.484	10.538	5.383	108.837
2009	7.293	10.608	5.843	6.213	3.686	2.720	1.344	11.060	12.720	16.378	15.090	23.695	116.649
2010	30.279	16.194	23.859	24.241	13.843	10.807	7.504	8.415	12.896	13.441	14.713	10.099	186.290
2011	6.976	10.694	8.056	10.470	7.336	7.549	7.331	4.051	8.629	7.643	18.349	13.168	110.251
2012	7.834	14.707	10.133	9.619	9.602	7.938	6.521	6.942	13.498	13.302	17.787	17.257	135.142
2013	11.744	11.679	8.817	10.555	6.691	5.504	6.310	6.216	6.953	6.275	13.865	16.180	110.789
2014	11.649	6.469	5.699	6.485	6.039	4.965	4.270	5.370	4.128	3.351	10.384	8.125	76.933
2015	5.597	0.415	0.482	0.347	0.273	0.224	0.137	0.291	0.331	0.223	0.407	0.378	9.105
2016	4.584	4.828	3.663	4.412	5.137	3.904	3.378	5.362	4.915	5.438	7.723	11.556	64.901
2017	9.727	5.439	4.579	4.557	4.357	2.778	1.402	2.350	6.175	8.776	19.522	14.219	83.881
Average	9.811	8.333	7.797	8.952	6.338	5.321	4.709	5.535	8.074	8.224	12.217	11.177	
TOTAL	107.923	91.663	85.771	98.472	69.722	58.528	51.802	60.880	88.819	90.467	134.389	122.945	

Based on the results of the performed analysis, the results of the water demand analysis / water balance are obtained as follow at table 4.2, table 4.3 and figure 4.1.

Table 4.2 Inflow from the lake referred to the rainfall and inflow data from the year 2007 to 2017

Years	lake Inflow from rainfall		Lake Inflow	
	m3/s	m3	m3/s	m3
2007	58.60	1,822,784,227	4929.71	153,333,658,420
2008	108.84	3,385,278,148	5343.64	166,208,646,597
2009	116.65	3,628,255,332	5223.55	162,473,408,445
2010	186.29	5,794,348,836	6694.31	208,219,946,110
2011	110.25	3,429,247,848	4486.55	139,549,497,073
2012	135.14	4,203,445,355	4251.24	132,230,706,238
2013	110.79	3,445,984,966	5690.00	176,981,681,242
2014	76.93	2,392,938,191	4928.47	153,295,052,908
2015	9.11	283,210,569	4128.71	128,419,417,579
2016	64.90	2,018,691,730	5824.48	181,164,614,313
2017	83.88	2,609,025,545	5973.99	185,814,889,631

Table 4.3 Analysis of water availability in Lake Maninjau

YEARS	DAY	INFLOW	REQUIREMENT OUTFLOW		INITIAL POOL	DIFFERENCE (3-5)	ACCOMMODATING CAPACITY	RUNOFF
	N	m ³	m ³ /s	m ³	m ³	m ³	m ³	m ³
1	2	3	4	5	6	7	8	9
							Kapasitas Danau	
2007	360	155,156,442,646.81	173.950	5,410,540,800.00	10,265,000,000.00	149,745,901,846.81	-	149,745,901,846.81
2008	360	169,593,924,745.41	184.700	5,744,908,800.00	10,265,000,000.00	163,849,015,945.41	-	163,849,015,945.41
2009	360	166,101,663,776.39	156.620	4,871,508,480.00	10,265,000,000.00	161,230,155,296.39	-	161,230,155,296.39
2010	360	214,014,294,945.88	202.450	6,297,004,800.00	10,265,000,000.00	207,717,290,145.88	-	207,717,290,145.88
2011	360	142,978,744,921.25	154.920	4,818,631,680.00	10,265,000,000.00	138,160,113,241.25	-	138,160,113,241.25
2012	360	136,434,151,593.29	139.840	4,349,583,360.00	10,265,000,000.00	132,084,568,233.29	-	132,084,568,233.29
2013	360	180,427,666,208.00	177.820	5,530,913,280.00	10,265,000,000.00	174,896,752,928.00	-	174,896,752,928.00
2014	360	155,687,991,098.90	157.560	4,900,746,240.00	10,265,000,000.00	150,787,244,858.90	-	150,787,244,858.90
2015	360	128,702,628,147.85	140.370	4,366,068,480.00	10,265,000,000.00	124,336,559,667.85	-	124,336,559,667.85
2016	360	183,183,306,042.74	185.240	5,761,704,960.00	10,265,000,000.00	177,421,601,082.74	-	177,421,601,082.74
2017	360	188,423,915,175.72	197.730	6,150,193,920.00	10,265,000,000.00	182,273,721,255.72	-	182,273,721,255.72
TOTAL		1,820,704,729,302.23		58,201,804,800.00		1,762,502,924,502.23		1,762,502,924,502.23
The amount of runoff (m ³ /s)								55,888.681
AVERAGE m ³		165,518,611,754.75		5,291,073,163.64		160,227,538,591.11		160,227,538,591.11
AVERAGE m ³ /s		5,248.561		167.779		5,088.782		5,088.782

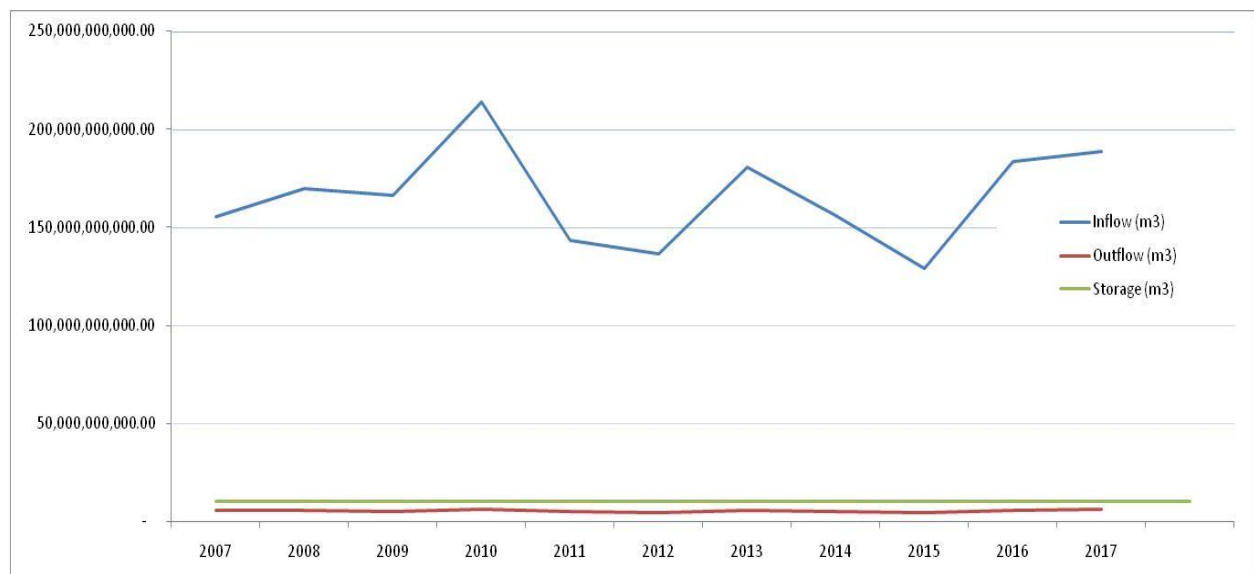


Figure 4.1 Graph of Water Balance Analysis on Lake Maninjau

The Water Analysis Results (Water Balance) of Lake Maninjau based on the rainfall data in the year 2007 to 2017 was in the form of the analysis of water utilization in terms of the outlet water needs of the electricity operation supply at Lake Maninjau hydropower, and maximum lake capacity seen from 2014 bathymetry data.

5. Conclusion

The analysis of lake water availability is reviewed based on an analysis of water needs, and availability. The conclusion that can be drawn from this analysis are; the analysis results of the water availability determines that the water availability in Lake Maninjau is adequate to meet the water needs around the Lake. When the average of lake water inflow $174,952 \text{ m}^3 / \text{sec}$ per year with lake water needs (outflow) $5,593 \text{ m}^3 / \text{sec}$ per year, and the difference between the two is $169,359 \text{ m}^3 / \text{sec}$ per year referred to the data from 2007 to 2017, therefore the capacity of Lake Maninjau's water is still sufficient in number. Lake Maninjau's water capacity to store and keep the water is still satisfactory. This is shown in the amount of water availability that exceeds the needs of the lake water every year.

By all means, the recommended suggestions that can be drawn are; since the rainfall data used in this analysis was from 2007 to 2017, thus for longer periods of calculation by utilizing the rainfall data for more than 20 years is considered much better. The need for water in this study is still derived from assumptions due to the limitations of the data obtained. Significantly, detailed research on water requirements such as groundwater storage capacity, and other variables needed for other water needs can be carried out, and use them as input data.

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