Hydrology Model for Determination on the Flood Index Based Analysis of Flood Discharge for Asahan River Management

Rumilla Harahap[1,2], Zulkifli Nasution[3], Abdul Rauf[3] , Herman Mawengkang[4]

[1]*Study Program of Natural Resources and the Environment Management*
University of Sumatera Utara, Medan, Indonesia
[2] *Faculty of Engineering , University of Negeri Medan, Indonesia*
[3,]*Department of Agroecotechnology, Faculty of Agriculture,*
University of Sumatera Utara, Medan, Indonesia
[4] *Faculty of Mathematics and Natural Sciences*
University of Sumatera Utara, Medan, Indonesia

Abstract
Asahan river is a river whose headwaters of Lake Toba and flow into the waterway whose length is approximately 147 km. The existence of Asahan river as part of the hydrologic system becomes a very important thing to be kept. Frequent flooding in Asahan river is one hydrological events. This paper proposes a form of hydrology model for determination on the flood index based analysis of flood discharge. Secondary data include data from relevant agencies such as rainfall data, flow data, land use data, and then analyzed with Gumbel and log Pearson method . Furthermore, the calculation of flood discharge using Rational method, Nakayasu, and flooding in the downstream surface calculation also uses a combination of methods HEC-RAS. The main purpose of this paper is to produce a model of hydrology flood index determination that can be used as a benchmark would be flooding and manage sustainable Asahan river. Inundation in the downstream area index average of 0.32 and an index obtained in downstream flooding average obtained at 0.52. With hydrological modeling based index flood discharge in Asahan river against rainfall and land can be mapped if there was a flood in the region.

Keywords: Asahan river, Hydrology, Flood Index.

1. INTRODUCTION

The study of flood discharge in Asahan river is so needs to be studied through hydrology. Hydrological data must meet the standards, reliability, accuracy, and can be used, flood discharge study is needed around the basin. To get flood discharge firststep is to analyzing rain, because rain is an important component in the process of hydrology [1]. Rainfall characteristics is including the intensity, duration, depth and frequency . From hydrological data obtained 106.6 m^3/sec avarege discharge. Asahan river entering the Piasa river and Silau river. Asahan population continues to change and grow from year to year with a fluctuates growth rate. According [2] Flood is a state of the river where the situation is no longer accommodated by the riverbed, while the riverbed is a major part of the river flow that serves to drain some water from upstream to downstream. The method is a basic method used in the concept of river flow contributions from direct runoff and groundwater base flow [3].

Study on the Asahan discharge was reported [4], however, study on river flood index of this river has not been reported. Hence, the objective of the present study was to assess of flood index of Asahan River in North Sumatra, Indonesia.

2. Data and Method

Flood discharge analysis performed in this study includes the processing of raw data to obtain discharge rates. Rainfall data used for this analysis from 5 (five) stations are scattered in several areas, namely: rainfall data used in the work is the result of data recording stations scattered rain graduated WS Asahan. The amount of rainfall stations used are five stations, which exist in Fig-1.

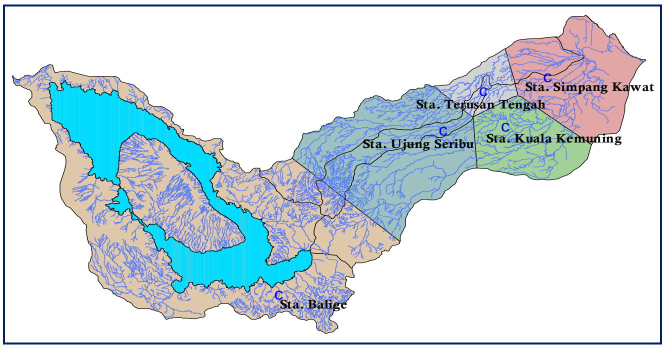


Fig-1.Station spread rain in the watershed Asahan

The research was done in Asahan River North Sumatra Province, located in the East Coast region of North Sumatra. Geographically located between 02⁰03'-03⁰26' 'North latitude and 99⁰01'-100⁰00' East longitude, The location wet sectional area of Asahan river existing condition on Fig-2.

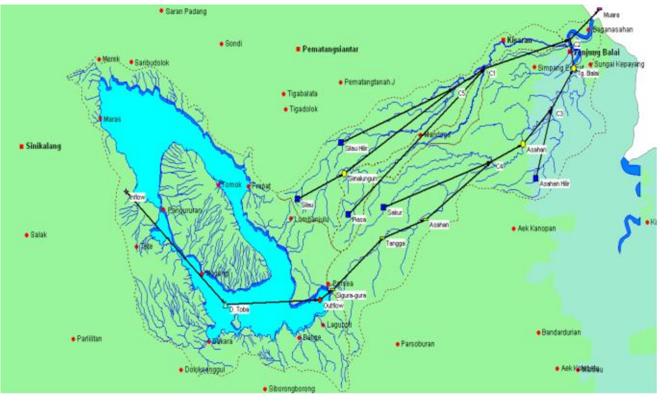


Fig-2.Wet sectional area of Asahan river existing condition

Distribution hydrological model as an expression of pragmatic realism. Some issues consideration include modeling of the problem of flood discharge in river areas. the channel evaluation, land use and river management. On the simulation system is a system or process stage of experimental approach using a model to study the behavior of the system. In such systems widely analyzed the influence (km^2) watershed, [5].

The hydrologic and hydraulic simulations were conducted using hydro-climatology and water discharge data of headwater of Asahan River. In addition, the topography, land use and river networks maps were also utilized in the study. The maximum of rainfall frequency was analyzed using two models; a). Log Pearson distribution model, and b). Gumbell distribution model. The Chi quire and Smirnov-Kolmogrov tests were employed to determine the suitable model of distribution. In addition, the flood discharges was examined using Nakayasu method.

The equation used to calculate rainfall plans using the Gumbel method is:

$$x = \overline{x} + K.Sd$$

The formula for computing the average ($\overline{x}$):

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{N}$$

Standard deviation calculation formula (Sd) :

$$Sd = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{(N-1)}}$$

Frequency factor calculation formula (K) :

$$K = \frac{Yt - Yn}{Sn}$$

$$Yt = -\left(0.834 + 2.303.\log.\log {}^{T}\!/_{T-1}\right)$$

$\overline{x}$ = The average rainfall, K= Factor Frequency, Sd = Standard deviation , x_i= rainfall data, N = Number of data, Y_t = reduction of the return period , Y_n = reduction of the mean value, S_n = standard deviation reduction value, T= Return period.

Log Pearson Type III distribution into account the three statistical parameters, namely:

a. Data average annual maximum daily rainfall total of n changed in the form (log X)

b. Calculated mean logarithm of average

$$\overline{LogXi} = \frac{1}{n}\sum_{1}^{n} LogX_i$$

c. Calculated on the standard deviation .

$$Sd = \frac{\sqrt{(X - \overline{X})^2}}{n-1}$$

d. Calculate the coefficient skewness :

$$Cs = \frac{n \times \sum_{i=1}^{n} \left(Xi - \overline{X}\right)^3}{(n-1) \times (n-2) \times S^3}$$

e. Calculate the logarithm of the design rainfall return period specified:

$$\text{Log } X_T = \overline{\log X} + G.Sd$$

The development of rational methods for watershed was the method of time-area is done by dividing the watershed into sub watershed with the watershed line of the river stretching isochrone [6]. For large watersheds can use Rational method with Grid System [7]. Daily rainfall plans (R_{24}) for the 5 year .

The calculation of the design flood discharge using methods Nakayasu Fig-3 . According to [8] the general equation Synthetic unit Hydrograph Nakayasu are as follows:

$$Qp = \frac{C.A.R_0}{3.6(0.3Tp + T_{0.3})}$$

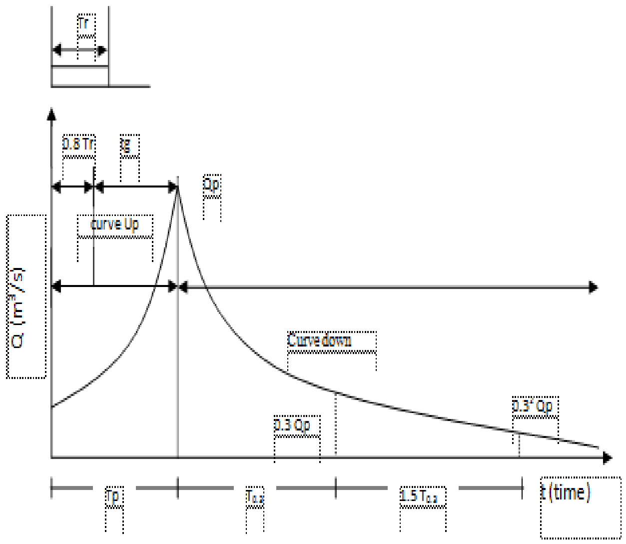


Fig-3. Nakayasu hydrograph method

Where, Qp= flood peak discharge (m^3/s), C= coefficient of drainage, R_o= rain unit (mm), A= watershed area (km^2), Tp= interval period from the beginning of the rain until the flood peak (hour), $T_{0.3}$= the times required to decrease flood discharge up to 30% of the peak discharge (hour), tg= concentration time (hour), tr= time rain unit (1 hour), α= parameter of hydrograph, the value ranged between 1.5 to 3.5 and L= river length (m).

The Nakayasu hydrograph formula as follow:

Curved up, $0 \le t \le Tp$, where $Qt = \left(\frac{t}{Tp}\right)^{2.4} x\ Qp$

Curved down, $Tp < t \le (Tp + T_{0.3})$, where

$$Qt = Qp\ x\ 0.3^{\left[\frac{t - Tp}{T_{0.3}}\right]},$$

$(Tp + T_{0.3}) \le t \le (Tp + T_{0.3} + 1.5T_{0.3})$,

for $Qt = Qp\ x\ 0.3^{\left[\frac{t - Tp + 0.5T_{0.3}}{1.5T_{0.3}}\right]}$,

and

$t > (Tp + T_{0.3} + 1.5T_{0.3})$,

where

$$Qt = Qp\ x\ 0.3^{\left[\frac{t - Tp + 1,5T_{0,3}}{2T_{0,3}}\right]}$$

The time series data of runoff discharge from 2001 to 2014 will be used to estimate the water stock for watershed of Asahan River. According to [9]. Inflow discharge index is defined as the ratio between the flood discharge that occurs reduced with minimum discharge at interval period between the maximum with the minimum discharges as the formula:

$$IQ = \frac{Qt - Qmin}{Qmax - Qmin}$$

Where. I_Q = inflow discharge index, Q_t = flood discharge, Q_{min} = minimum discharge causes flooding, and Q_{maks} = maximum discharge causes flooding.

The same as on flood discharge to equation flooding of area index is extensive inundation is occurring on the flood plains along the river due to flood water being modeled. flooding of area that occurs is a function of the size of the inflow discharge. The larger of flood discharge that occurs will be more extensive, so extensive flooding of area caused by the maximum discharge called Amaks, and extensive flooding of area caused by the minimum discharge called Amin.

The research was done in Asahan river Sumatera Utara Province, located in the East Coast region of Sumatera Utara. Geographically located between 02⁰03'-03⁰26' 'North latitude and 99⁰01'-100⁰00' East longitude, With the existing condition analysis using HEC-RAS and combined with topographic maps from DEM generated, it can be predicted areas was inundated by flooding various time again [10]. The data required in analisis cross the river with the help of HEC-RAS software are:

- Longitudinal cross section of the river
- Cross-section of the river
- Through river discharge data
- Manning figures cross the river.

This paper I did not review in detail hec-ras only on Nakayasu analysis for flood discharge.

3. Results and Discussion

Flood discharge analysis conducted in this study includes the processing the raw data to be obtained discharge rates. Rainfall data that is used for this analysis come from 5th. [11] the station are scattered in a few areas, ie: The rainfall data that are used in jobs is the result of data recording stations are scattered in a graduated of rain in Asahan river area. Number of of rain the station used were 5 stations, ie: Balige , Terusan Tengah, Ujung Seribu , Simpang Kawat and Kuala Kemuning . Discussion of these data through a computation step by step. Average of Monthly Rainfall in fifth The location can be seen in Table - 1.

Table-1. Average of monthly rainfall in fifth the location study

Year	Terusan Tengah (mm)	K. Kemuning (mm)	Ujung Seribu (mm)	Simpang Kawat (mm)	Balige (mm)	rainfall The areal (mm)
2001	147	105	138	190	119	140
2002	111	127	136	174	35	117
2003	64	141	82	124	83	99
2004	89	118	104	157	55	105
2005	76	151	90	155	20	98
2006	173	97	101	160	50	116
2007	141	96	184	168	92	136
2008	205	176	188	163	81	163
2009	127	212	164	127	123	151
2010	97	101	139	101	55	98
2011	162	158	160	145	193	164
2012	153	153	151	196	147	160
2013	128	159	157	102	149	139
2014	98	154	133	152	150	137
TOTAL	1768	1949	1927	2114	1352	1822
Average	126	139	138	151	97	130

The results of the analysis of rainfall and return period is calculated based on the Gumbel method. Rainfall tends to increase in 25-year return period frequency factor K for the Gumbel distribution method greatly affect the greater the frequency factor, the greater rainfall. Significant difference from the results of rainfall. This difference can be clearly seen in Fig-3 where the Gumbel method based rainfall tends to be greater in the long period of re-precipitation compared with those obtained by other methods. Precipitation results of Normal method and method of Log Pearson tend to be almost equal to the return period is short <10 years.

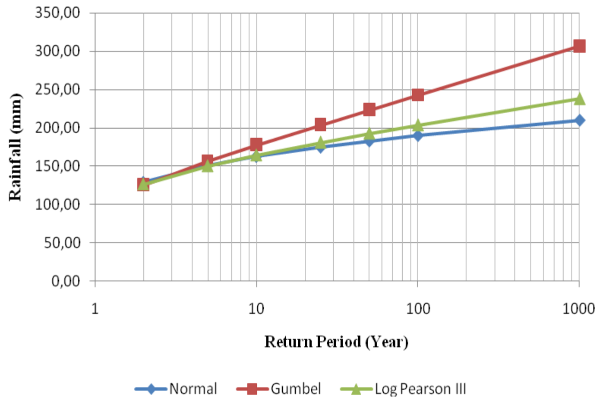


Fig-3. The relationship between the design rainfall and return period

The results of the calculation of the Asahan river region flood discharge design in Table-2 with Synthetic unit Hydrograph calculations Nakayasu.

Table-2. Design of flood discharge 2 year period

Hour	UH	Rain in Hours (mm/Hour)					flood discharge
	U (t,1)	R1	R2	R3	R4	R5	Q
(Hour)	NAKAYASU	15,39	17,76	20,06	11,99	2,74	m³/s
0	0,000	0,000					0,000
1	0.279	4.300	0.000				4.300
2	1.474	22.697	4.962	0.000			27.658
3	3.290	50.647	26.188	5.603	0.000		82.438
4	2.993	46.079	58.439	29.571	3.349	0.000	137.439
5	1.890	29.101	53.169	65.988	17.677	0.765	166.700
6	1.194	18.379	33.578	60.036	39.446	4.037	155.477
7	0.825	12.697	21.206	37.916	35.889	9.009	116.717
8	0.607	9.346	14.651	23.945	22.665	5.177	75.784

From Table-2, Results of the calculation of 5th annual flood discharge obtained maximum flood discharge on the 4th Hour by 137.439 m^3/s.

The dominant factor that cause flooding is the rain characteristics. High intensity rainfall which can cause watershed runoff hydrograph that would cause flooding of the river in its path. Analysis of the results of the maximum flood discharge results in frequent damage to buildings in the surrounding area. Predicted flood discharge plan is based on rainfall data from rainfall recording stations around the catchment area in river

Asahan. Distribution Asahan river flood discharge can be seen in Fig-4.

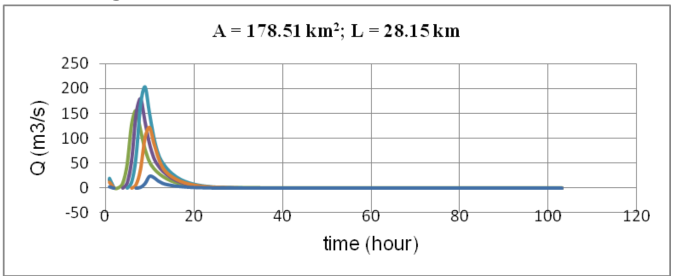


Fig-4. Distribution Asahan river flood discharge

To get the index flood predetermined classification of extensive inundation adjusted to the classification of the flood discharge that caused widespread inundation is to obtain two classifications, namely: widespread inundation between average and maximum, middle watershed inflow discharge index can be seen in Table-3.

Table-3. Middle Index watershed inflow discharge Area 34.22 km²

Return Period	Q_{max}(m³/s)	Q_{min}(m³/s)	Q_t(m³/s)	inflow discharge index
2	123.59	14.30	71.24	0.52
5	169.01	20.23	86.86	0.45
10	199.46	23.87	97.86	0.42
25	238.25	28.52	111.76	0.40
50	267.22	31.99	122.07	0.38
100	296.11	35.44	132.31	0.37
1000	392.33	46.96	166.13	0.35

The calculations show that the peak discharge rate from Nakayasu method ranged from 10% to 20% of the discharge Rational. Based on the above results. it turns out that the flood peak discharge can be calculated from the Nakayasu method by simply multiplying the peak flood discharge of the Rational method with constant 0.1 to 0.2. The results of the previous description shows the relationship between the design rainfall Hour R1.R2 Hours. R3. R4 and R5. thus increasing flood discharge varies depending on the length of the rainy obtained. Maybe there is a link between the watershed area. Length of the river. and magnitude of peak flows. Significant in the calculation of the discharge by any method because of the length of the rain is one of the parameters in the calculation of the discharge process. The next step is the calculation of inflow discharge index, the index decreased inflow discharge a minimum flow with the boundary between the maximum with a minimum flow that has been in the can as shown in table 3.

In Table 3. Middle river basin Flood Index to 34.22 km² wide and 49 miles long return period of 2 years at the maximum flood discharge of 123.59 m³/s, indeks input flood of 0.52, While the 100-year return period the maximum flood discharge of 296.11 m³/s, index flood input of 0.37 Calculation results show that the value of the index flood discharge the higher the index the smaller.

Downstream Asahan river flood events always happen several times in 1 year flood one of the reasons is because of its inability to hold the Asahan river with the rain water discharge, as shown in Table 4.

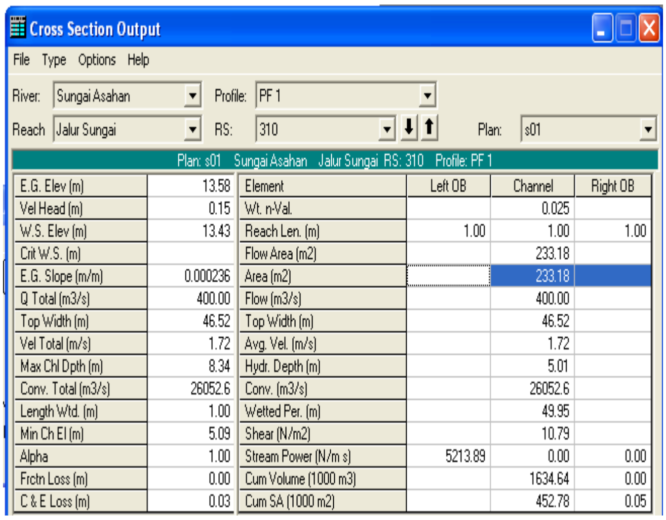
Table 4. Maximum discharge downstream watershed

Return Period	Q_{maks} A (m³/s)	Q_{maks} B (m³/s)	Q_{maks} C (m³/s)	Q_{maks} D (m³/s)	Q_{maks} average
2	469.06	469.68	827.59	532.54	575
5	642.52	643.37	1120.38	729.49	784
10	758.79	759.80	1323.12	861.50	926
25	906.93	908.14	1581.44	1029.69	1107
50	1017.56	1018.91	1774.35	1155.29	1242
100	1127,89	1129,38	1966,73	1280,55	1376

A=141.37 km². B=141.67 km². C=470.66 km².D=178.51 km²

From Table-4. Asahan river downstream watershed has an area of 141.37 km². 2-year retrun period in the flood discharge downstream of the discharge obtained by 469.06 m³/s. The area of 141.67 km² calculations flood return period of 2 years in the downstream area. in may flood at 469.68 m³/s. Area of 470.66 km² for flood discharge obtained at 827.59m³/s. for 178.51 km² large flood discharge 532.54 m³/s. so that the average flood discharge 575 m³/s. The results of the calculation of flood discharge indicates that the average value of the maximum discharge downstream in the watershed there are wide. the more extensive the higher flood discharge. Based on the results obtained in 100 year return period flood peak discharge is 1376 m³/s.

[12] With the existing condition analysis using HEC-RAS to Downstream reach length = distance of each cross-section of the river with the previous cross-section. Manning's n value = channel Manning roughness coefficient, Main channel Station Bank Station = main river channel point, Cont/Exp coeficients = coefficient of contraction and expansion as in Fig-5. Cross section output ,Elevation and Discharge.



		Element	Left OB	Channel	Right OB
E.G. Elev (m)	13.58	Wt. n-Val.		0.025	
Vel Head (m)	0.15	Reach Len. (m)	1.00	1.00	1.00
W.S. Elev (m)	13.43	Flow Area (m2)		233.18	
Crit W.S. (m)		Area (m2)		233.18	
E.G. Slope (m/m)	0.000236	Flow (m3/s)		400.00	
Q Total (m3/s)	400.00	Top Width (m)		46.52	
Top Width (m)	46.52	Avg. Vel. (m/s)		1.72	
Vel Total (m/s)	1.72	Hydr. Depth (m)		5.01	
Max Chl Dpth (m)	8.34	Conv. (m3/s)		26052.6	
Conv. Total (m3/s)	26052.6	Wetted Per. (m)		49.95	
Length Wtd. (m)	1.00	Shear (N/m2)		10.79	
Min Ch El (m)	5.09	Stream Power (N/m s)	5213.89	0.00	0.00
Alpha	1.00	Cum Volume (1000 m3)		1634.64	0.00
Frctn Loss (m)	0.00	Cum SA (1000 m2)		452.78	0.05
C & E Loss (m)	0.03				

Fig-5. Cross section output ,Elevation and Discharge

Downstream Asahan river has a very important role in the regulation and flood control. In flood control, always required needed information in the form of characters flood flood discharge, length of time up to the top, long inundation and flood flow volume [13]. For the average incidence of flooding in the downstream can be seen in Chart-1.

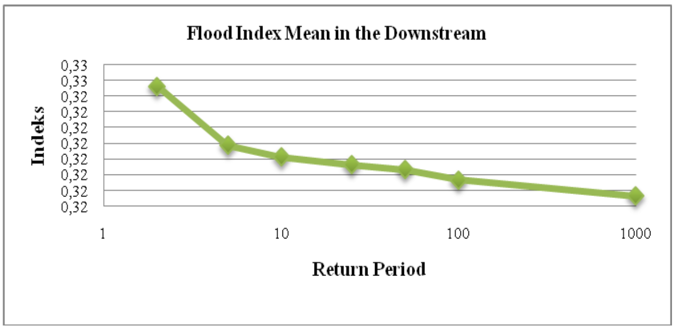


Chart-1. Flood Index Mean in the Downstream

In the Chart-1 Calculation of the average index in the downstream flooding, it is known that the incidence of flooding in downstream not because of high rainfall intensity alone but with lower levels of intensity that can occur due to the effects of flooding in the upstream. For the calculation of the index with the results of calculation of the index flood in downstream averages obtained at 0.3

4. Conclusion

The simulation results show that the model of the flooding that occurred in Asahan Watershed due to rainfall happened after eight hours of every hour of maximum real time and can be control the flooding that occurred about 30%.

Ability Asahan river of middle Asahan river flood index to 34.22 km², wide 49 km long return period 2 years of maximum flood discharge was obtained for 71.24 m³/s, Index input floods at 0.52. Return period of 100 years the maximum flood discharge obtained at 132.31m³/s. Index input floods of 0.37. The results show that the calculation of the index flood the higher the index value the smaller.

Asahan river downstream area of 141.37 km², 2 year return period flood discharge of 469.06 m³/s. Return period of 100 years the mean flood discharge is 1127,89 m³/s. Appropriate conditions Asahan river, for a period of 5 years flood index average of 0.33, the maximum flood discharge 642.52 m³/s. Index inflow discharge at 0,33. Hydrology study on the pattern of rainfall as the cause of the flood discharge, an indicator of the index discharge contributes flooding. The immediate benefit of this research is particularly the case Asahan River flood index can be estimated easily by knowing the maximum rainfall areas of the watershed Asahan and then so the flood index based analysis of flood discharge as Asahan river management

5. Acknowledgements

I would like to thank my the authors are grateful to Dr. Delvian, SP , MP as the chairman of the Doctoral Program PSL University of North Sumatra (USU) for the motivation and advice, so that the completion of my dissertation writing, Thanks also to the Prof. Dr. Ir. Erman Munir, as Director of the Graduate School of the University of Sumatera Utara. Prof. Dr. Syawal Gultom M.Pd as a rector University of Negeri Medan in Sumatera Utara. On a more personal note, I am very grateful for the moral support I received from family, friends and colleagues. Without their words of encouragement set backs would have been much more difficult to abide. In particular, I would like to thank.

REFERENCES

[1] Maxwell. O. 2014. Hydrological Data Banking for Sustainable Development in Nigeria: An Overview. Aceh International Journal of Science and Technology. 2 *(2): 59-62.*

[2] Jailani, 2005,Kajian Debit Banjir Sungai Way Laay Kecamatan Karya Penggawas Kabupaten Lampung Barat, Tesis Master, ITB.

[3] Hongbing. S. (2004). Estimating the fate of precipitation from stream discharge: A case study in New Jersey. Bull. New Jersey . Academy of Science . 49(2): 9-15.

[4] Harahap.R. Mawengkang. 2013. Study on Flood Discharge the Asahan river in North Sumatra Trough HEC-RAS. Prosiding International Conference on BIGSTAR; Bandung 27-28 Oktober 2013. Savoy Homan Hotel Bandung ISBN 978-979-3541-26-6 Polban.

[5] Beven, K.J., 2000b. On the future of distributed modelling in hydrology, Hydrol.Process. (HPToday), 14, 3183-3184.

[6] Ponce V.M., 1989. Enginering Hydrology Principals and Practices, Prentice Hall, Englewood Cliffs, New Jersey.

[7] Sobriyah dan Sudjarwadi, 2000, Penggabungan Metode O'Donnel dan Muskingun-Cunge Untuk Penelusuran Banjir Pada Aliran Sungai, Media Teknik, Fakultas Teknik UGM, No.4 th XXII, Edisi November.

[8] Sutapa. 2005 Kajian Hidrograf Satuan Sintetik Nakayasu Untuk Perhitungan Debit Banjir Rancangan Di Daerah Aliran Sungai Kodina . "MEKTEK" Tahun VII NO. 1 Januari 2005 Palu.hlm 35-40.

[9] Suryadi. Y. 2008.Metoda Penentuan Indeks Banjir Berdasarkan Fungsi Debit Puncak Hidrograf Inflow. Luas Genangan. Kedalaman Genangan dan Waktu Genangan. Disertasi Doktor. Pasca sarjana ITB.

[10] Suradi. M.. Fourie A. 2014. The Effect of Rainfall Patterns on the Mechanisms of Shallow Slope Failure. Aceh International Journal of Science and Technology. 3(1): 1-18.

[11] Rees. H.G.. M.G.R Holmes. AR. Young and SR Kansakar. (2004). Recession-based hydrological models for estimating low flows in ungauged catchments in the Himalayas. Journal Hydrology an Earth System Sciences 8(5). 891-902.

[12] Istiarto, 2009. Aplikasi Model Aliran Satu Dimensi HEC-RAS. Modul Universitas Gajah Mada, Yogyakarta.

[13] Spiegel M.R.. 1961 : Theory and Problems of Statistics. McGraw-Hill Internatinonal Book Company. New York.

BIOGRAPHIES

	Rumilla Harahap Study Program of Natural Resources and the Environment Management University of Sumatera Utara, Medan, Indonesia Job Experiences until now as a lecturer at Faculty of Engineering , University of Negeri Medan-Indonesia.
	Prof.Ir.Zulkifli Nasution,MSc.Ph.D. as promotor and lecturer Department of Agroecotechnology, Faculty of Agriculture, University of Sumatera Utara
	Prof.Dr.Ir.Abdul Rauf,MS. as co promotor and lecturer Department of Agroecotechnology, Faculty of Agriculture, University of Sumatera Utara
	Prof.Dr. Herman Mawengkang co promotor and lecturer FMIPA University of Sumatera Utara.