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Drainage Network Performance Mapping in the Tukad Ngenjung Sub-System Based on Geographic Information Systems (GIS)

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Abstract

The aim of this research is to determine the condition and performance of the drainage network. The method used in this research is a quantitative descriptive method based on field observations. The results of this research based on hydrological and hydraulic calculations show that in the Tukad Ngenjung Sub System drainage network, out of a total of 52 channels, 42 channels are unable to accommodate the design flood discharge with a return period of 2 years and there are 45 channels that are unable to accommodate the design flood discharge with a 5 year return period. For channels that are unable to accommodate flood discharge, the design should be given more attention or repairs should be carried out by the relevant parties, so that the runoff that occurs in the channel can be resolved.

Keywords: flood, gis, drainage network, discharge, ngurah rai university denpasar.

INTRODUCTION

Flooding is defined as a condition where water cannot be accommodated in the drain channel or the flow of water in the drain channel is obstructed, so that it overflows and inundates the surrounding residential areas (Suripin 2003).

Designed as a basic facility to meet community needs, the drainage system plays a crucial role in city planning, particularly in infrastructure planning. According to Suripin (2004), drainage is defined as draining, disposing of, or channeling water. Generally, drainage refers to a set of water structures that serve to minimize or eliminate surplus water from a region, enabling optimal land use and fostering life. The goal is to create a city that is safe, comfortable, clean, and healthy.

The city of Denpasar divides its drainage system into four systems: the North Denpasar system, the West Denpasar system, the East Denpasar system, and the South Denpasar system. One of the drainage systems in the South Denpasar system is the Tukad Ngenjung Sub System, which covers service areas in Sidakarya Village, Sumerta Kelod Village, and Renon Village. Tukad Ngenjung is one of the longest rivers in Denpasar's southern region.

The river spans 5,573 km, with a watershed area of 4,878 km2 (BWS Bali Penida PUPR Service, 2016).

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In recent years, the use of technology in drainage network performance mapping research has grown significantly. A Geographic Information System (GIS) is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently acquire, store, update, manipulate, analyze, and display all forms of geographically referenced information (ESRI, 1990).

Based on the problems described above, researchers need to assess the drainage network's performance in the Tukad Ngenjung Sub-System using Geographic Information Systems (GIS). Researchers will produce a map of the Tukad Ngenjung Sub System area, a runoff coefficient map, and a discharge map. These maps will serve as a foundation for relevant agencies to make decisions about drainage network maintenance, aiming to decrease flooding in the Tukad Ngenjung Sub System.

METHOD

This research employs a quantitative descriptive method, grounded in field observations, to gain a comprehensive understanding of the current situation. Ardani et al. (2020) define a descriptive research method as one that systematically and accurately provides symptoms, facts, or events related to the characteristics of a specific population or area.

Sugiyono (2013) asserts that we refer to quantitative methods as traditional methods due to their long-standing use as a research method. The philosophy of positivism forms the basis for this method's positivistic label. This method is scientific because it adheres to scientific principles, namely concrete/empirical, objective, measurable, rational, and systematic. We also refer to this method as the discovery method, as it facilitates the discovery and development of various new sciences and technologies. We call this method a quantitative method because it uses numerical research data and statistical analysis.

Data Collection Technique

1. Primary Data

Field inspections or surveys gather primary data. We obtained the primary data for this research using the following methods:

a. Conduct a survey at the research site.

b. Determine the condition of the channel under study by identifying existing measurements.

c. Ascertain the coordinates of the drainage channel under investigation.

2. Secondary Data

Secondary data is obtained from the Bali Penida BWS PUPR Service agency, BMKG Region III Bali. The following is the secondary data obtained:

a. Rainfall data.

The research used maximum rainfall data from a minimum of 10 years of observation.

b. Topographic and landscape maps

This research uses topographic maps to provide information about the location and height of contours.

c. Drainage network scheme

This research's drainage network scheme provides information on where the drainage routes are.

Geographic Information Systems

We conducted data analysis by assessing the physical condition of the drainage network in each segment using secondary and tertiary data. Each channel in the section between road intersections undergoes a drainage network assessment. After completing the hydrological

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and hydraulic analysis calculations, we conduct a GIS analysis and input the results into the ArcMap application. This process yields a database, an administrative map of the drainage network conditions in the Tukad Ngenjung Sub-System, a river flow map, and a river network performance map over a 2-year period. This process continues until the individual reaches the age of 5.

The physical assessment of the drainage network will appear according to the condition values for each network segment depicted in the symbols and/or legends on the thematic map.

RESULT AND DISCUSSION

The Meteorology, Climatology, and Geophysics Agency (BMKG) Region III Denpasar provided the rainfall data for this research, which covered the Tukad Ngenjung Sub-System over a period of 5 (five) and 10 (ten) years, from 2013 to 2022. These were taken at four (4) observation stations: Sumerta Rain Station, Ngurah Rai Station, Suwung Station, and Sanglah Station.

Table 1. Maximum Rainfall

Year	Maximum Rainfall (mm)			
	Sumerta Post	Sanglah Post	Suwung Post	Ngurah Rai Post
2013	140,00	128,00	80,00	103,20
2014	119,00	68,00	85,00	107,40
2015	110,00	98,60	83,00	88,70
2016	164,00	180,00	95,00	145,60
2017	98,00	106,00	106,00	117,70
2018	194,00	138,70	122,00	85,20
2019	115,00	72,50	92,00	76,90
2020	71,50	123,40	84,00	80,70
2021	155,00	183,50	98,00	173,90
2022	180,00	120,00	63,00	107,80

Source: Calculation Results (2023)

Design Rainfall

A design rainfall (DAS) is an estimate of the rain that will occur in a river basin. You can use the Log Pearson Type III method to calculate the annual rainfall plan. Log Pearson Type III produces R24 rainfall as follows:

At the 2-year anniversary, R24 = 83,332

At the 5-year anniversary R24 = 108,091

Runoff Coefficient C

We calculate the runoff coefficient by taking the average runoff coefficient figure from each land use and calculating the weight of each part according to the area it represents. One can tabulate the runoff coefficient as follows:

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Table 2. Calculation of Runoff Coefficient

No	Street Name	C
1	Jl. Hayam Wuruk I	0,47
2	Jl. Hayam Wuruk II	0,36
3	Jl. Narakusuma I	0,47
4	Jl. Narakusuma I	0,48
5	Jl. narakusuma II	0,47
6	Jl. narakusuma II	0,38
7	Jl. Pandu	0,51
8	Jl. Merdeka II	0,48
9	Jl. Merdeka II	0,39
10	Jl. Laksamana I	0,34
11	Jl. Laksamana I	0,36
12	Jl. laksamana II	0,52
13	Jl. laksamana III	0,51
14	Jl. laksamana IV	0,34
15	Jl. laksamana IV	0,43
16	Jl. laksamana V	0,44
17	Jl. laksamana V	0,43
18	Jl. laksamana VI	0,34
19	Jl. laksamana VI	0,43
20	Jl. Moh Yamin IX	0,44
21	Jl. Moh Yamin IX	0,43
22	Jl. laksamana VIII	0,34
23	Jl. laksamana VIII	0,43

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No	Street Name	C
24	Jl. laksamana X	0,44
25	Jl. laksamana X	0,43
26	Jl. Moh Yamin V	0,34
27	Jl. Moh Yamin V	0,43
28	Jl. laksamana XII	0,44
29	Jl. laksamana XII	0,43
30	Jl. Moh Yamin IV	0,34
31	Jl. Moh Yamin III	0,43
32	Jl. Moh Yamin III	0,44
33	Jl. Laksamana XV	0,43
34	Jl. Laksamana XIV	0,34
35	Jl. Laksamana XIV	0,43
36	Jl. Raya Puputan I	0,44
37	Jl. Raya Puputan II	0,43
38	Jl. Raya Puputan II	0,34
39	Gg. Trikora	0,43
40	Gg. Trikora	0,44
41	Jl. Tukad Badung XI	0,43
42	Jl. Tukad Badung XI	0,34
43	Jl. Tukad Balian	0,43
44	Jl. Tukad Balian	0,44
45	Jl. Merta Sari I	0,51
46	Jl. Merta Sari I	0,38
47	Jl. Merta Sari II	0,43

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No	Street Name	C
48	Jl. Merta Sari II	0,45
49	Jl. Kerta Petasikan III	0,43
50	Jl. Kerta Petasikan III	0,34
52	Jl. By Pass Ngurah Rai I	0,43
53	JL. By Pass Ngurah Rai II	0,44

Source: Calculation Results (2023)

Planned Flood Discharge

The design flood discharge consists of three components, namely runoff coefficient (C), rainfall intensity (I), and area (A). The following is a calculation of the magnitude of the flood discharge for the 5-year return period using the rational method, taken as an example from Jalan Hayam Wuruk I:

Q = 0.278. C x I x A
= 0.278 x 0.4650 x 7.900 x 0.125
= 1.2610 m3/sec

Table 3. Calculation of Flood Discharge for 5 Year and 2 Year Return Period Plans

No	A (km^2)	I2 (mm/hour)	I5 (mm/hour)	Q Flood Design	
		2 yrs	5 years	2yrs (m^3/sec)	5 yrs (m^3/sec)
1	0,125	56,1030	72,7714	0,9095	1,1797
2	0,065	124,1479	161,0329	0,8051	1,0443
3	0,089	97,2854	126,1893	1,1168	1,4485
4	0,089	73,2781	95,0493	0,8623	1,1185
5	0,086	89,5020	116,0935	0,9996	1,2966
6	0,037	149,8224	194,3353	0,5887	0,7636

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No	A (km²)	I2 (mm/hour)	I5 (mm/hour)	Q Flood Design	
		2 yrs	5 years	2yrs (m^3/sec)	5 yrs (m^3/sec)
7	0,023	260,5808	338,0006	0,8390	1,0883
8	0,082	93,5498	121,3438	1,0116	1,3121
9	0,097	76,9235	99,7778	0,8026	1,0410
10	0,088	147,1920	190,9234	1,2327	1,5989
11	0,088	110,8691	143,8089	0,9747	1,2643
12	0,036	169,1787	219,4425	0,8887	1,1528
13	0,031	207,5176	269,1720	0,8968	1,1632
14	0,076	197,0896	255,6458	1,4261	1,8498
15	0,076	191,1916	247,9955	1,7451	2,2635
16	0,076	220,8821	286,5072	2,0625	2,6753
17	0,076	218,8197	283,8320	1,9972	2,5906
18	0,090	177,5691	230,3256	1,5228	1,9752
19	0,090	181,9888	236,0584	1,9687	2,5536
20	0,095	158,2140	205,2202	1,8466	2,3953
21	0,095	119,1713	154,5776	1,3596	1,7636
22	0,119	99,7005	129,3220	1,1356	1,4729
23	0,119	87,3920	113,3565	1,2556	1,6286
24	0,098	101,5601	131,7341	1,2293	1,5945
25	0,098	76,4980	99,2259	0,9051	1,1740
26	0,101	113,3657	147,0471	1,0937	1,4187
27	0,101	107,0246	138,8221	1,3025	1,6894

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No	A (km²)	I2 (mm/hour)	I5 (mm/hour)	Q Flood Design	
		2 yrs	5 years	2yrs (m^3/sec)	5 yrs (m^3/sec)
28	0,101	74,8484	97,0861	0,9319	1,2087
29	0,099	140,4462	182,1734	1,6855	2,1862
30	0,108	71,0588	92,1708	0,7332	0,9510
31	0,102	98,8393	128,2050	1,2112	1,5711
32	0,102	74,4486	96,5676	0,9333	1,2106
33	0,109	84,5461	109,6651	1,1075	1,4365
34	0,092	106,2915	137,8711	0,9400	1,2193
35	0,092	80,0617	103,8484	0,8931	1,1585
36	0,148	88,0887	114,2602	1,6146	2,0943
37	0,094	146,8920	190,5343	1,6635	2,1577
38	0,089	117,9516	152,9956	1,0036	1,3018
39	0,113	146,0335	189,4207	1,9993	2,5933
40	0,113	146,0335	189,4207	2,0454	2,6531
41	0,104	168,1019	218,0458	2,1026	2,7273
42	0,104	173,0886	224,5140	1,7163	2,2262
43	0,090	158,8943	206,1025	1,7188	2,2295
44	0,090	155,6472	201,8907	1,7225	2,2342
45	0,020	265,7090	344,6524	0,7580	0,9832
46	0,020	200,1395	259,6019	0,4293	0,5569
47	0,123	101,7338	131,9594	1,5132	1,9628
48	0,117	97,0600	125,8970	1,4371	1,8641

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No	A (km²)	I2 (mm/hour)	I5 (mm/hour)	Q Flood Design	
		2 yrs	5 years	2yrs (m^3/sec)	5 yrs (m^3/sec)
49	0,077	171,1302	221,9737	1,5909	2,0635
50	0,077	122,3976	158,7624	0,9020	1,1700
52	0,211	42,1966	54,7334	1,0770	1,3969
53	0,242	37,9811	49,2654	1,1362	1,4737

Source: Calculation Results (2023)

By comparing the design flood discharge with the existing channel discharge, we can determine the capacity of existing drainage channels and identify which ones can accommodate the design flood discharge. The following is an example of calculating the capacity of an existing channel, taken from Jalan Hayam Wuruk I and Jl. Narakusuma II:

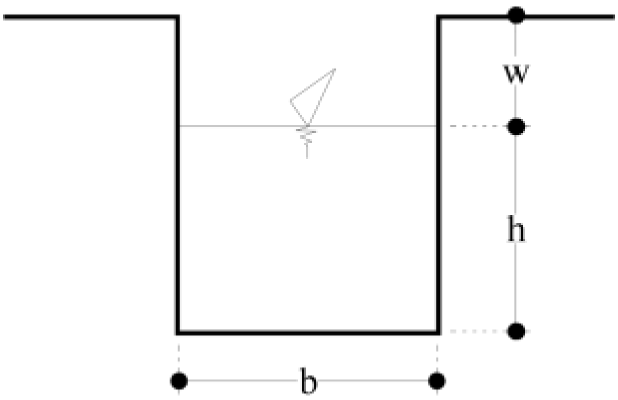

Figure 1. Cross-section of a square channel

b = 0,55 m
h = 0,55 m
n = 0,0,17 (Manning Coefficient for Masonry Channels)
S = 0,00048
A = b x h
= 0,55 x 0,55
= 0,303 m2
P = b + 2h
= 0,55 + (2 x 0,55)
= 1,650 m
R = A / P
= 0,303 m2 / 1,650 m
= 0,183 m
Vsal = 1/n x R2/3 x S1/2

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= 1/0,017 x (0,1832/3 x 0,000481/2)
= 0,4150 m/dt
Qsal = Vsal x A
= 0,41505 x 0,303
= 0,1255 m3/dt

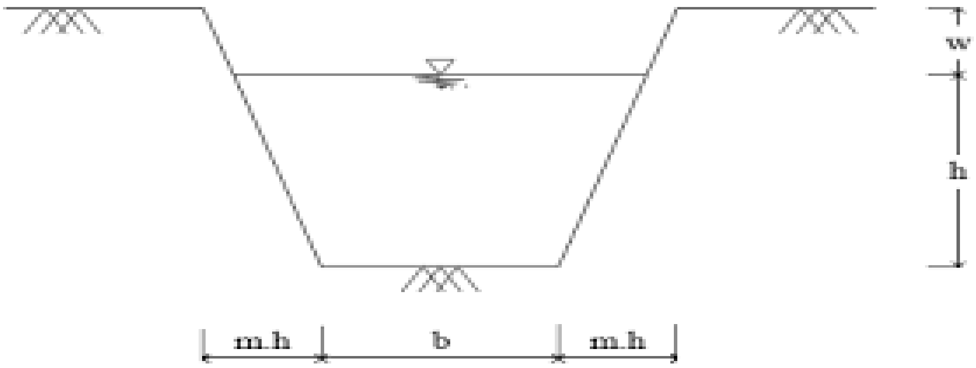

Figure 2. Cross-section of a Trapezoidal Channel

b = 0,65 m
h = 0,35 m
m= 0,58 m
n = 0,17 (Manning Coefficient for Masonry Channels)
s = ,00139
A = (b + mh).h
= (0,65 + 0,58 x 0,35) x 0,35
= 0,246m2
P = b + 2h(m2+1)0,5
= 0,65 + (2 x 0,35) x ((0,582)+ 1)0,5
= 1,396 m
R = A/P
= 0,246 / 1,396
= 0,396 m
vsal = (\frac{1}{n}) xR^{2\ /3\ }x\ I^{1/2}\ m/dtk
= (\frac{1}{0,17}) x{0,396}^{2/3\ }x\ {0,00068}^{1/2}
= 0,6886 m/dtk
QSal = vsal x A
= 60,6886 x 0,00139
S = 1,0894 m3/ dtk

Comparison of Q Flood and Q Channel

We compared Qflood and Qchannel to ascertain the existing drainage channel's capacity for the calculated design flood discharge. If Qflood < Qchannel, then the channel is safe from runoff, and conversely, if Qflood > Qchannel, then the channel will not fill or runoff will occur in the channel.

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Table 4. Calculation Of Comparison of Channel Discharge (Qsal) With Design Flood Discharge (Q Flood) At 2-Year Return Period

No	Street Name	Q Difference in Runoff	Condition
1	Jl. Hayam Wuruk I	0,7839	Overflow
2	Jl. Hayam Wuruk II	0,5026	Overflow
3	Jl. Narakusuma I	-0,6999	Accommodate
4	Jl. Narakusuma I	-0,2272	Accommodate
5	Jl. narakusuma II	0,8302	Overflow
6	Jl. narakusuma II	0,0711	Overflow
7	Jl. Pandu	-0,2051	Accommodate
8	Jl. Merdeka II	0,8952	Overflow
9	Jl. Merdeka II	0,7483	Overflow
10	Jl. Laksamana I	1,0192	Overflow
11	Jl. Laksamana I	0,7483	Overflow
12	Jl. laksamana II	0,8093	Overflow
13	Jl. laksamana III	0,8764	Overflow

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No	Street Name	Q Difference in Runoff	Condition
14	Jl. laksamana IV	1,3791	Overflow
15	Jl. laksamana IV	1,7007	Overflow
16	Jl. laksamana V	2,0070	Overflow
17	Jl. laksamana V	1,9361	Overflow
18	Jl. laksamana VI	0,8297	Overflow
19	Jl. laksamana VI	1,4465	Overflow
20	Jl. Moh Yamin IX	1,3775	Overflow
21	Jl. Moh Yamin IX	1,1542	Overflow
22	Jl. laksamana VIII	0,6460	Overflow
23	Jl. laksamana VIII	1,0145	Overflow
24	Jl. laksamana X	0,8918	Overflow
25	Jl. laksamana X	0,7133	Overflow
26	Jl. Moh Yamin V	0,7668	Overflow
27	Jl. Moh Yamin V	1,0391	Overflow

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No	Street Name	Q Difference in Runoff	Condition
28	Jl. laksamana XII	0,8429	Overflow
29	Jl. laksamana XII	1,0484	Overflow
30	Jl. Moh Yamin IV	0,5262	Overflow
31	Jl. Moh Yamin III	1,1408	Overflow
32	Jl. Moh Yamin III	0,8883	Overflow
33	Jl. Laksamana XV	1,0632	Overflow
34	Jl. Laksamana XIV	0,7728	Overflow
35	Jl. Laksamana XIV	0,7676	Overflow
36	Jl. Raya Puputan I	0,3564	Overflow
37	Jl. Raya Puputan II	-1,9923	Accommodate
38	Jl. Raya Puputan II	-0,0864	Accommodate
39	Gg. Trikora	1,6600	Overflow
40	Gg. Trikora	1,7395	Overflow
41	Jl. Tukad Badung XI	1,5944	Overflow

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No	Street Name	Q Difference in Runoff	Condition
42	Jl. Tukad Badung XI	1,2348	Overflow
43	Jl. Tukad Balian	0,9621	Overflow
44	Jl. Tukad Balian	0,9581	Overflow
45	Jl. Merta Sari I	-4,9261	Accommodate
46	Jl. Merta Sari I	-2,4266	Accommodate
47	Jl. Merta Sari II	-2,3381	Accommodate
48	Jl. Merta Sari II	0,7421	Overflow
49	Jl. Kerta Petasikan III	1,4298	Overflow
50	Jl. Kerta Petasikan III	0,8378	Overflow
52	Jl. By Pass Ngurah Rai I	-27,7629	Accommodate
53	JL. By Pass Ngurah Rai II	-28,0616	Accommodate

Source: Calculation Results (2023)

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Table 5. Calculation Of Comparison of Channel Discharge (Qsal) With Design Flood Discharge (Q Flood) For Return Period 5

No	Street Name	Q Spleen Difference (m3/sec)	Condition
1	Jl. Hayam Wuruk I	-1,0541	Overflow
2	Jl. Hayam Wuruk II	-0,7418	Overflow
3	Jl. Narakusuma I	0,3681	Accommodate
4	Jl. Narakusuma I	-0,0290	Overflow
5	Jl. narakusuma II	-1,1272	Overflow
6	Jl. narakusuma II	-0,2461	Overflow
7	Jl. Pandu	-0,0442	Overflow
8	Jl. Merdeka II	-1,1957	Overflow
9	Jl. Merdeka II	-0,9868	Overflow
10	Jl. Laksamana I	-1,3855	Overflow
11	Jl. Laksamana I	-1,0379	Overflow
12	Jl. laksamana II	-1,0734	Overflow
13	Jl. laksamana III	-1,1429	Overflow
14	Jl. laksamana IV	-1,8028	Overflow
15	Jl. laksamana IV	-2,2192	Overflow
16	Jl. laksamana V	-2,6197	Overflow
17	Jl. laksamana V	-2,5295	Overflow
18	Jl. laksamana VI	-1,2822	Overflow

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No	Street Name	Q Spleen Difference (m3/sec)	Condition
19	Jl. laksamana VI	-2,0314	Overflow
20	Jl. Moh Yamin IX	-1,9261	Overflow
21	Jl. Moh Yamin IX	-1,5582	Overflow
22	Jl. laksamana VIII	-0,9833	Overflow
23	Jl. laksamana VIII	-1,3875	Overflow
24	Jl. laksamana X	-1,2570	Overflow
25	Jl. laksamana X	-0,9823	Overflow
26	Jl. Moh Yamin V	-1,0917	Overflow
27	Jl. Moh Yamin V	-1,4260	Overflow
28	Jl. laksamana XII	-1,1198	Overflow
29	Jl. laksamana XII	-1,5491	Overflow
30	Jl. Moh Yamin IV	-0,7440	Overflow
31	Jl. Moh Yamin III	-1,5007	Overflow
32	Jl. Moh Yamin III	-1,1655	Overflow
33	Jl. Laksamana XV	-1,3922	Overflow
34	Jl. Laksamana XIV	-1,0521	Overflow

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No	Street Name	Q Spleen Difference (m3/sec)	Condition
35	Jl. Laksamana XIV	-1,0329	Overflow
36	Jl. Raya Puputan I	-0,8361	Overflow
37	Jl. Raya Puputan II	1,4981	Accommodate
38	Jl. Raya Puputan II	-0,2118	Overflow
39	Gg. Trikora	-2,2540	Overflow
40	Gg. Trikora	-2,3472	Overflow
41	Jl. Tukad Badung XI	-2,2191	Overflow
42	Jl. Tukad Badung XI	-1,7447	Overflow
43	Jl. Tukad Balian	-1,4728	Overflow
44	Jl. Tukad Balian	-1,4698	Overflow
45	Jl. Merta Sari I	4,7009	Accommodate
46	Jl. Merta Sari I	2,2991	Accommodate
47	Jl. Merta Sari II	1,8885	Accommodate
48	Jl. Merta Sari II	-1,1691	Overflow
49	Jl. Kerta Petasikan III	-1,9025	Overflow
50	Jl. Kerta Petasikan III	-1,1058	Overflow
52	Jl. By Pass Ngurah Rai I	27,4429	Accommodate

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No	Street Name	Q Spleen Difference (m3/sec)	Condition
53	JL. By Pass Ngurah Rai II	27,7240	Accommodate

Source: Calculation Results (2023)

Based on the results of calculating the comparison of channel discharge with the 2-year return period design flood discharge from 53 channels, there are 10 channels that can accommodate the design flood discharge, and there are 43 channels that cannot accommodate the design flood discharge. And for the 5-year return period flood discharge, of the 53 channels, there are 7 channels that can accommodate the design flood discharge and 46 channels that cannot accommodate the design flood discharge.

Drainage Channel Mapping

Drainage channel mapping aims to identify locations where flooding frequently occurs, making it easier to anticipate when the rainy season comes. From the evaluation analysis of the calculation results above, maps can then be made from the results of these calculations in the form of a Tukad Ngenjung Drainage Network Map (Figure 3), a 2-year return period channel performance map (Figure 4), and a 5-year return period channel performance map (Figure 5).

Figure 3. Map of the Tukad Ngenjung Sub-System Drainage Network

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Figure 4. Network Performance Map for 2 Year Return Period

CONCLUSION

We can draw the following conclusion from the final assignment research analysis and calculations: From the results of the analysis and calculation of the performance of existing channels in the Tukad Ngenjung Sub System, there are 42 (forty-two) channels that are unable to accommodate the 2-year return period design flood discharge out of a total of 53 (fifty-three) channels reviewed with a maximum runoff discharge of 28.0616 m3/sec on the right side of the Jl Baypas Ngurah Rai II channel (R), and there are 45 (forty-five) channels that are unable to accommodate the 5-year return period flood discharge with a maximum runoff of 0.0711 m3/sec on Jl. Narakusuma II right (R). Based on the calculation results of the existing channel performance analysis and followed by mapping using the Geographic Information System (GIS) for each existing channel in the Tukad Ngenjung Sub System, it was found that there is a channel that overlaps the Overflow channel located on Jl. Hayam Wuruk, Jl. Merdeka, Jl. Laksamana, Jl. Moh Yamin, Jl. Narakusuma II, Jl. Raya Puputan II, Jl. Merdeka, Gang Trikora, Jl. Kerta Petahkan, and Jl. Tukad Badung. Jl Tukad Balian.

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