

Scenario-Based Design-Storm Runoff Attenuation by Infiltration Wells in the Tanralili Sub-Watershed

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ABSTRACT

This study evaluates design-storm surface runoff and an infiltration-well scenario for the Tanralili Sub-Watershed, South Sulawesi, Indonesia. Annual rainfall records for 1997–2018 from Tanralili, Tompobulu, and Batubassi stations were used to derive regional rainfall, design rainfall with Gumbel and Log-Pearson type III distributions, and short-duration intensity using the Mononobe equation. Peak runoff was estimated with the Rational method for eight land-cover classes. The no-well scenario used an 85.35% runoff factor and the infiltration-well scenario used 27.63%; these factors were treated as scenario assumptions rather than measured field efficiencies. Summed Rational-method discharge increased from $56.90 \text{ m}^3 \text{ s}^{-1}$ for the 2-year event to $95.65 \text{ m}^3 \text{ s}^{-1}$ for the 25-year event. At the 25-year return period, scenario discharge decreased from 82.49 to $26.71 \text{ m}^3 \text{ s}^{-1}$, with the largest absolute reduction assigned to mixed dryland agriculture ($23.95 \text{ m}^3 \text{ s}^{-1}$). The results identify high-leverage locations for runoff control, but engineering deployment requires reconciliation of mapped areas, land-cover-specific runoff coefficients, field infiltration measurements, and event-based hydraulic validation before the scenario can be interpreted as operational performance.

ARTICLE HISTORY

Received June 15, 2026
Received in revised form
July 25, 2026
Accepted August 20, 2026
Available online August 27,
2026.

KEYWORDS

*infiltration well; surface runoff;
design rainfall; Rational
method; tropical watershed*

1. Introduction

Intense rainfall does not become flood-producing runoff by rainfall magnitude alone. The response depends on how quickly water can be intercepted, stored, infiltrated, and routed across a catchment. In tropical and monsoon settings, short periods of intense rainfall can dominate annual runoff, while antecedent wetness, slope, soil properties, vegetation, and drainage connectivity alter both runoff coefficients and peak timing [1-3]. Land-use change can amplify this response by replacing permeable or rough surfaces with compacted, cultivated, or built land. Recent watershed studies show that the hydrological effect of land conversion is especially visible in peak flow and runoff volume during design storms [4-6]. In Makassar, a local spatial analysis reported expansion of built land together with a shift toward higher flood susceptibility between 2014 and 2024, reinforcing the relevance of land management to runoff control in South Sulawesi [7].

The Tanralili Sub-Watershed forms part of the Maros River system and is reported to cover about 278.39 km^2 . The catchment supports agriculture, water supply, and downstream economic activity, but its hydrological function is increasingly sensitive to land-cover change. Recent analysis of the wider Maros watershed found contraction of secondary dryland forest and expansion of shrub and agricultural land together with increasing runoff, erosion, and peak-flood response [8]. Event-scale evidence from other tropical and subtropical catchments likewise shows that rainfall intensity interacts with seasonal land cover, so the same rainfall can generate markedly different runoff when protective cover is reduced or soil storage is already limited [9,10]. These observations make distributed runoff

control attractive because intervention can be placed near source areas instead of depending solely on downstream conveyance.

Design-storm methods remain useful in data-scarce basins because they expose the assumptions that connect rainfall, catchment area, and runoff. Their simplicity, however, places more weight on parameter quality. Studies of drainage systems and urban catchments show that land-use change and rainfall forcing can alter peak discharge simultaneously, and the relative importance of each driver changes with storm magnitude [11,12]. Catchment size and rainfall intensity also influence the magnitude and timing of storm runoff, particularly as storage becomes less important during larger events [13]. These findings are relevant to Tanralili because a single runoff coefficient and a single design duration cannot represent all hydrological mechanisms. The value of the present approach is therefore transparency: it gives a reproducible first estimate while making clear which assumptions should be replaced by observations in a subsequent model.

Infiltration wells are small subsurface structures that receive runoff, provide temporary storage, and allow water to seep through the base and sidewalls where soil conditions permit. Comparable decentralized systems include recharge wells, soakaways, infiltration trenches, and curbside infiltration devices. Reported performance varies widely. Modeling in rapidly urbanizing catchments has produced substantial peak-flow reductions, while monitored systems often show smaller benefits because storage fills, infiltration declines with wetting, or overflow activates during larger storms [14,15]. In a recent Tanralili study, infiltration wells and biopore holes improved hydrological response on critical land, but the results also emphasized the importance

of soil permeability and local hydraulic conditions [16]. A 2026 study in Panakkukang paired infiltration-rate assessment with surface-runoff analysis, illustrating the type of local field evidence needed to connect soil intake capacity with runoff response [17].

The practical question is therefore not whether infiltration can reduce runoff in principle, but where an infiltration-well program would produce the greatest absolute benefit and how strongly a screening calculation can support that conclusion. Spatial planning studies in Indonesia increasingly combine hydrological information with geographic screening. A flood-management study in Bulukumba used GIS to integrate hazard, vulnerability, and capacity information for decision support [18], while a village-scale study combined flood-vulnerability mapping with the placement and design of mitigation infrastructure [19]. These approaches are pertinent to Tanralili because infiltration wells cannot be deployed uniformly: slope, groundwater depth, soil permeability, land ownership, sediment loading, and drainage connectivity determine whether a theoretically favorable location is technically feasible.

Experience with infiltration-based stormwater control also shows that structural capacity and site feasibility must be considered together. A shallow artificial infiltration device in an Indonesian residential setting increased local infiltration capacity and delayed the onset of surface runoff [20]. A GIS-based assessment in Bali found that the number of infiltration wells that could actually be placed was lower than the theoretical requirement because buildings, roads, drainage paths, open space, topography, and setbacks constrained feasible locations [21]. Climate-sensitive soakaway analysis further shows that a design adequate for one rainfall regime may be conservative or undersized under another [22]. These studies support treating LSR as infrastructure whose performance depends on both hydraulic capacity and the spatial context in which it is installed.

This study develops a design-storm screening analysis from a 22-year rainfall record, eight reported land-cover classes, and paired runoff scenarios representing conditions without and with Lubang Sumur Resapan (LSR). The objectives are to: (1) characterize the design rainfall and short-duration intensity used in the runoff calculation; (2) quantify how modeled runoff is distributed among the reported land-cover classes; (3) compare absolute and relative changes between the two LSR scenarios; and (4) identify the data checks and field measurements required before the scenario is used for engineering design. The central hypothesis is that the imposed LSR scenario will reduce modeled runoff across return periods, but the greatest management value will occur where baseline discharge is largest. The study deliberately distinguishes a scenario multiplier from measured hydraulic efficiency so that the result can inform prioritization without overstating certainty.

Figure 1 provides the conceptual hydrological context for the study by illustrating the partitioning of rainfall into surface runoff, evapotranspiration, infiltration, and percolation. This framework highlights the role of infiltration-based interventions in modifying the rainfall-runoff partitioning process.

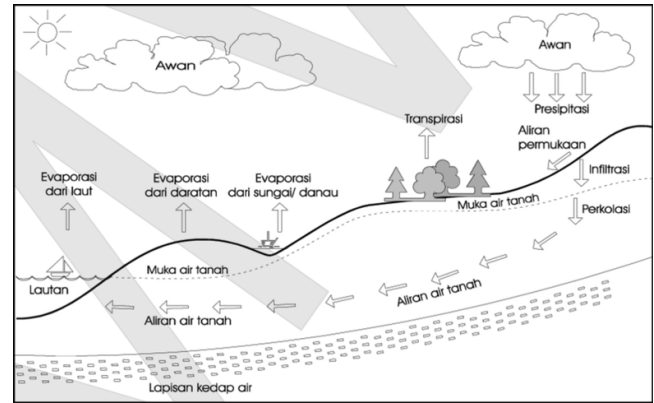


Figure 1. Hydrological-cycle context used to frame rainfall partitioning and surface runoff.

2. Methods

2.1 Study area, rainfall record, and analytical sequence

The analysis covers the Tanralili Sub-Watershed in South Sulawesi, Indonesia. The working dataset contains annual rainfall values from three gauges—Tanralili, Tompobulu, and Batubassi—for 1997–2018. The location of the Tanralili Sub-Watershed and its surrounding spatial context are shown in Figure 2. The hydrological sequence begins with regional rainfall, continues through frequency analysis and design-rainfall intensity, and ends with peak-runoff estimation and two LSR scenarios. The study is deterministic rather than a continuous rainfall-runoff simulation. No new streamflow series was introduced, and no parameter was calibrated against observed hydrographs. This distinction is important because a design-storm calculation can compare scenarios but cannot by itself reproduce flood timing, inundation extent, or event water balance. The analytical sequence used in this study, from problem identification and site survey to LSR installation, evaluation, hydrological data analysis, and reporting, is summarized in Figure 3. Figure 4 illustrates the infiltration-well (LSR) configuration adopted in this study, including the subsurface well arrangement and the intended infiltration pathway.

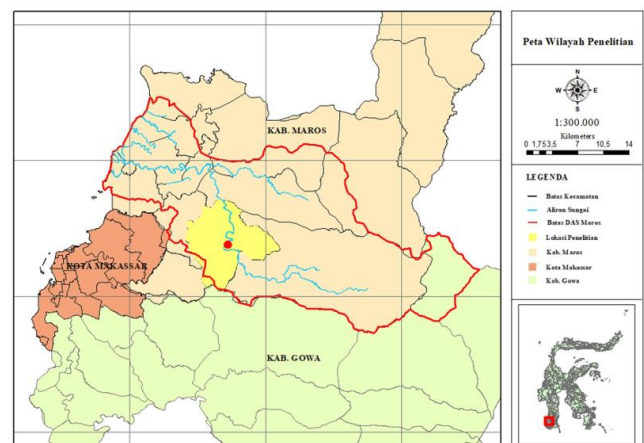


Figure 2. Location of the Tanralili Sub-Watershed study area.

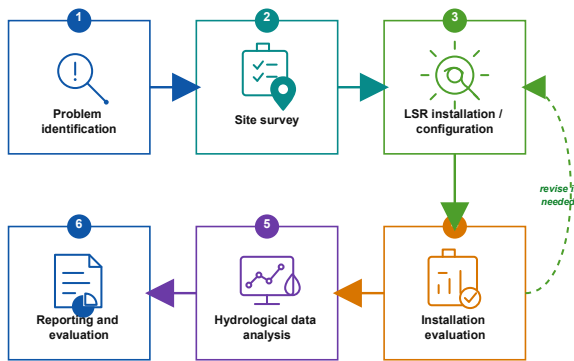


Figure 3. Analytical workflow for rainfall, runoff, and LSR scenario assessment.

2.2 Regional rainfall and frequency analysis

The annual rainfall observations from the Tanralili, Tompobulu, and Batubassi stations are summarized in Table 1, while the corresponding arithmetic-mean regional rainfall series is presented in Table 2. Regional rainfall was represented by the arithmetic mean of the three station values for each year. Design rainfall was evaluated with Gumbel and Log-Pearson type III distributions for return periods from 2 to 200 years. For the Gumbel calculation, a return-period quantile was expressed as $X_T = \bar{X} + K_T S$, where $\bar{X}$ is the sample mean, S is the standard deviation, and K_T is the frequency factor. Log-Pearson type III analysis used logarithmically transformed rainfall, its mean, standard deviation, and skewness coefficient. The use of two distributions provides a sensitivity check because long-return-period estimates from short records are sensitive to distribution choice and the presence of unusual events [23]. The numerical worksheets are retained in Tables 3–7 so that the calculation chain remains auditable.

Table 1. Annual rainfall observations at Tanralili, Tompobulu, and Batubassi stations (1997–2018).

Year	Tanralili	Tompobulu	Batubassi
1997	130.00	90.00	123.00
1998	126.00	89.00	151.00
1999	250.00	200.00	210.00
2000	200.00	178.00	129.00
2001	260.00	208.00	273.00
2002	200.00	150.00	154.00
2003	150.00	165.00	136.00
2004	130.00	94.00	164.00
2005	200.00	119.00	184.00
2006	250.00	210.00	165.00
2007	160.00	135.00	158.00
2008	172.00	190.00	126.00
2009	122.00	198.00	123.00
2010	89.00	151.00	94.00
2011	125.00	98.00	302.00
2012	80.00	154.00	208.00
2013	164.00	150.00	277.00
2014	154.00	68.00	289.00
2015	144.00	250.00	167.00

Year	Tanralili	Tompobulu	Batubassi
2016	86.00	150.00	192.00
2017	184.00	150.00	138.00
2018	132.50	130.00	135.00

Table 2. Reported regional rainfall series calculated by arithmetic averaging.

Year	Tanralili	Tompobulu	Batubassi	Arithmetic mean
1997	130.00	90.00	123.00	114.33
1998	126.00	89.00	151.00	122.00
1999	250.00	200.00	210.00	220.00
2000	200.00	178.00	129.00	169.00
2001	260.00	208.00	273.00	247.00
2002	200.00	150.00	154.00	168.00
2003	150.00	165.00	136.00	150.33
2004	130.00	94.00	164.00	129.33
2005	200.00	119.00	184.00	167.67
2006	250.00	210.00	165.00	208.33
2007	160.00	135.00	158.00	151.00
2008	172.00	190.00	126.00	162.67
2009	122.00	198.00	123.00	147.67
2010	89.00	151.00	94.00	111.33
2011	125.00	98.00	302.00	175.00
2012	80.00	154.00	208.00	147.33
2013	164.00	150.00	277.00	197.00
2014	154.00	68.00	289.00	170.33
2015	144.00	250.00	167.00	187.00
2016	86.00	150.00	192.00	142.67
2017	184.00	150.00	138.00	157.33
2018	132.50	130.00	135.00	132.50

Table 3. Reported Gumbel calculation worksheet for the regional rainfall series.

No.	x_i	x_r	$x_i - x_r$	$(x_i - x_r)^2$	$(x_i - x_r)^3$	$(x_i - x_r)^4$
1	247	163	84	7056	592704	49787136
2	220	163	57	3249	185193	10556001
3	208	163	45	2025	91125	4100625
4	197	163	34	1156	39304	1336336
5	187	163	24	576	13824	331776
6	175	163	12	144	1728	20736
7	170	163	7	49	343	2401
8	169	163	6	36	216	1296
9	168	163	5	25	125	625
10	168	163	5	25	125	625
11	163	163	0	0	0	0
12	157	163	-6	36	-216	1296
13	151	163	-12	144	-1728	20736
14	150	163	-13	169	-2197	28561
15	148	163	-15	225	-3375	50625
16	147	163	-16	256	-4096	65536
17	143	163	-20	400	-8000	160000
18	133	163	-30	900	-27000	810000
19	129	163	-34	1156	-39304	1336336
20	122	163	-41	1681	-68921	2825761

No.	x_i	x_r	$x_i - x_r$	$(x_i - x_r)^2$	$(x_i - x_r)^3$	$(x_i - x_r)^4$
21	114	163	-49	2401	-117649	5764801
22	111	163	-52	2704	-140608	7311616
Σ	3577			24413	511593	84512825

Table 4. Gumbel return-period calculation

Return period (years)	$\bar{X}$	S	K	$K \times S$	$XT = \bar{X} + K \times S$
2	162.591	34.093	-0.147	-4.981	157.610
5	162.591	34.093	0.919	31.364	193.955
10	162.591	34.093	1.625	55.425	218.016
25	162.591	34.093	2.518	85.834	248.425
50	162.591	34.093	3.180	108.390	270.981
100	162.591	34.093	3.837	130.780	293.371
200	162.591	34.093	4.492	153.095	315.686

Table 5. Reported Log-Pearson type III calculation worksheet.

x_i	$\log x_i$	$\log x_r$	$\log x_i - \log x_r$	$(\Delta \log x)^2$	$(\Delta \log x)^3$	$(\Delta \log x)^4$
247	2.392697	2.202299	0.19039774	0.036251	0.006902	0.001314
220	2.342422	2.202299	0.14012347	0.019634	0.002751	0.000385
208	2.318063	2.202299	0.11576412	0.013401	0.001551	0.000179
197	2.294466	2.202299	0.09216701	0.008494	0.000782	7.216E-05
187	2.271841	2.202299	0.06954239	0.004836	0.000336	2.339E-05
175	2.243038	2.202299	0.04073883	0.001659	6.761E-05	2.754E-06
170	2.230448	2.202299	0.02814971	0.000792	2.231E-05	6.279E-07
169	2.227886	2.202299	0.02558749	0.000654	1.675E-05	4.287E-07
168	2.225309	2.202299	0.02301007	0.000529	1.218E-05	2.803E-07
168	2.225309	2.202299	0.02301007	0.000529	1.218E-05	2.803E-07
163	2.212187	2.202299	0.00988839	9.778E-05	9.669E-07	9.561E-09
157	2.195899	2.202299	-0.00639955	4.095E-05	-2.62E-07	1.677E-09
151	2.178976	2.202299	-0.02332226	0.000543	-1.27E-05	2.959E-07
150	2.176091	2.202299	-0.02620795	0.000686	-1.8E-05	4.718E-07
148	2.170261	2.202299	-0.03203749	0.001026	-3.29E-05	1.053E-06
147	2.167317	2.202299	-0.03498187	0.001223	-4.28E-05	1.498E-06
143	2.155336	2.202299	-0.04696317	0.002205	-0.000104	4.864E-06
133	2.123851	2.202299	-0.07844756	0.006154	-0.000483	3.787E-05
129	2.110589	2.202299	-0.09170949	0.008410	-0.000771	7.074E-05

x_i	$\log x_i$	$\log x_r$	$\log x_i - \log x_r$	$(\Delta \log x)^2$	$(\Delta \log x)^3$	$(\Delta \log x)^4$
122	2.086359	2.202299	-0.11593937	0.013441	-	0.000180
114	2.056904	2.202299	-0.14539435	0.021139	-	0.000446
111	2.045323	2.202299	-0.15697623	0.024641	-	0.000607
357	48.45058			0.166396	0.002491	0.003330

Table 6. Reported Log-Pearson type III return-period calculation.

Return period (years)	$\log x_r$	G	Sd	$\log XT$	XT
2	2.203	-0.032	0.089	2.1994512	158.622
5	2.203	0.830	0.089	2.2761692	189.557
10	2.203	1.301	0.089	2.3180882	207.535
25	2.203	1.818	0.089	2.3641012	228.637
50	2.203	2.157	0.089	2.3942722	243.427
100	2.203	2.472	0.089	2.4223072	257.554
200	2.203	2.763	0.089	2.4482062	271.267

Table 7. Consolidated comparison of Gumbel and Log-Pearson type III design rainfall.

No.	Return period (years)	Gumbel	Log-Pearson type III
1	2	157.610	158.622
2	5	193.955	189.557
3	10	218.016	207.535
4	25	248.425	228.637
5	50	270.981	243.427
6	100	293.371	257.554
7	200	315.686	271.267

2.3 Rainfall intensity and Rational-method runoff

Short-duration rainfall intensity was estimated with the Mononobe relationship, $I = (R_{24}/24)(24/t)^{(2/3)}$, where I is rainfall intensity in mm h^{-1} , R_{24} is 24-hour design rainfall in mm, and t is duration in hours. The reported intensities span 5–60 min and return periods of 2–100 years. Peak runoff was then estimated using the Rational method, $Q = 0.28CIA$, where Q is discharge in $\text{m}^3 \text{s}^{-1}$, C is the runoff coefficient, I is rainfall intensity in mm h^{-1} , and A is drainage area in km^2 after conversion from the tabulated hectare values. Similar combinations of Mononobe intensity and Rational-method runoff remain common in data-limited Indonesian applications [24,25]. However, recent research also shows that C varies with rainfall, land cover, soil, slope, and antecedent conditions, so a common coefficient should be interpreted cautiously [1,26]. The resulting Mononobe rainfall intensities for the evaluated durations and return periods are summarized in Table 8.

Table 8. Mononobe rainfall intensities by duration and return period.

No.	Duration (min)	I2 (mm h ⁻¹)	I5	I10	I25	I50	I100
1	5	288.24	343.204	377.905	420.142	450.460	480.300
2	10	181.196	216.205	238.065	264.673	283.772	302.570
3	15	138.278	164.996	181.678	201.983	216.558	230.904
4	20	114.146	136.201	149.972	166.733	178.765	190.607
5	25	98.368	117.374	129.242	143.686	154.055	164.260
6	30	87.110	103.941	114.450	127.241	136.423	145.461
7	35	78.602	93.790	103.272	114.815	123.100	131.255
8	40	71.908	85.801	94.476	105.035	112.615	120.075
9	45	66.477	79.322	87.342	97.103	104.110	111.007
10	50	61.968	73.941	81.417	90.517	97.049	103.478
11	55	58.153	69.389	76.405	84.944	91.074	97.107
12	60	54.876	65.479	72.099	80.157	85.941	91.634

2.4 Infiltration-well configuration

The LSR configuration is a shallow infiltration well approximately 0.8–1.0 m in diameter and about 1.5 m deep. The structure includes a stabilized wall, inflow connection, overflow path, gravel layer at the base, and a covered top. Suitable sites should be stable and relatively flat, remain above the wet-season groundwater table, and possess adequate soil permeability. These constraints are not secondary design details: low hydraulic loading can leave infiltration storage underused, while sediment accumulation can progressively reduce infiltration capacity [27,28]. The infiltration-well configuration adopted in this study is illustrated in Figure 4, showing the principal structural components and intended subsurface infiltration pathway.

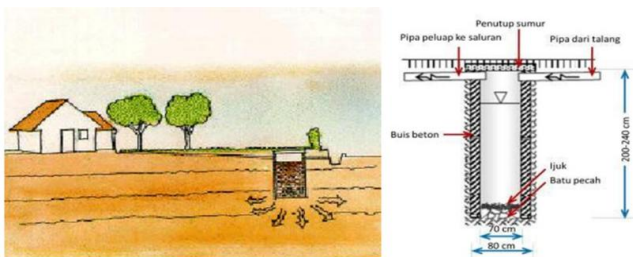


Figure 4. Infiltration-well (LSR) configuration used in the study.

2.5 Land-cover classes and aggregation

Eight land-cover classes are represented in the runoff tables: secondary dryland forest, industrial forest, shrubland, grass-and-tree vegetation, mixed dryland agriculture, paddy fields, open land, and water bodies. The tabulated area values are expressed in hectares and were converted to square kilometres before application of the Rational method. Because the summed tabulated area does not represent the stated total watershed extent, the spatial coverage of these classes should be interpreted as part of the screening dataset and verified before engineering implementation. For interpretation, class discharges were summed at each return period to obtain a screening total, and each class contribution was compared with that total. This aggregation is descriptive rather than a routed watershed hydrograph because flows from different spatial units may peak at different times. Similar caution is needed

in data-scarce catchments, where land-cover information can be more detailed than the available hydrological observations and model calibration remains limited [29]. The resulting Rational-method peak discharge for each reported land-cover class and return period is summarized in Table 9.

Table 9. Rational-method runoff by reported land-cover class and return period.

Land-cover class	Return-period intensity	A (ha)	C	I (mm h ⁻¹)	Q (m ³ s ⁻¹)
Secondary dryland forest	I2	39.92	0.460	98.368	5.06
Secondary dryland forest	I5	39.92	0.496	117.374	6.51
Secondary dryland forest	I10	39.92	0.513	129.242	7.41
Secondary dryland forest	I25	39.92	0.529	143.686	8.50
Industrial forest	I2	17.29	0.460	98.368	2.19
Industrial forest	I5	17.29	0.496	117.374	2.82
Industrial forest	I10	17.29	0.513	129.242	3.21
Industrial forest	I25	17.29	0.529	143.686	3.68
Shrubland	I2	8.27	0.460	98.368	1.05
Shrubland	I5	8.27	0.496	117.374	1.35
Shrubland	I10	8.27	0.513	129.242	1.54
Shrubland	I25	8.27	0.529	143.686	1.76
Grass/tree vegetation	I2	1.19	0.460	98.368	0.15
Grass/tree vegetation	I5	1.19	0.496	117.374	0.19
Grass/tree vegetation	I10	1.19	0.513	129.242	0.22
Grass/tree vegetation	I25	1.19	0.529	143.686	0.25
Mixed dryland agriculture	I2	190.21	0.460	98.368	24.09
Mixed dryland agriculture	I5	190.21	0.496	117.374	31.02
Mixed dryland agriculture	I10	190.21	0.513	129.242	35.31
Mixed dryland agriculture	I25	190.21	0.529	143.686	40.51
Paddy fields	I2	19.78	0.460	98.368	2.51
Paddy fields	I5	19.78	0.496	117.374	3.23
Paddy fields	I10	19.78	0.513	129.242	3.67
Paddy fields	I25	19.78	0.529	143.686	4.21
Open land	I2	23.18	0.460	98.368	2.94
Open land	I5	23.18	0.496	117.374	3.78
Open land	I10	23.18	0.513	129.242	4.30
Open land	I25	23.18	0.529	143.686	4.94
Water bodies	I2	149.31	0.460	98.368	18.91
Water bodies	I5	149.31	0.496	117.374	24.35
Water bodies	I10	149.31	0.513	129.242	27.71
Water bodies	I25	149.31	0.529	143.686	31.80

2.6 TLSR and DLSR scenarios

For each reported land-cover class and return period, the base Rational-method discharge was multiplied by 85.35% to represent the condition without LSR (TLSR) and by 27.63% to represent the condition with LSR (DLSR). The corresponding absolute change is $\Delta Q = Q_{\text{TLSR}} - Q_{\text{DLSR}}$, and the relative change is $100\Delta Q/Q_{\text{TLSR}}$. The two percentages are treated strictly as scenario factors because no calibration record is available that would establish them as measured catchment efficiencies. Since the same factors are applied to all classes and return periods, the relative reduction is mathematically constrained to remain nearly constant. Management interpretation therefore focuses on absolute reduction and spatial contribution rather than on variation in percentage performance. The paired TLSR and DLSR discharge estimates for each land-cover class and return period are summarized in Table 10.

Table 10. Paired TLSR and DLSR scenario discharge.

Land-cover class	Return period	TLSR Q ($\text{m}^3 \text{s}^{-1}$)	TLSR multiplier	DLSR Q ($\text{m}^3 \text{s}^{-1}$)	DLSR multiplier
Secondary dryland forest	Q2	4.32	85.35%	1.40	27.63%
Secondary dryland forest	Q5	5.56	85.35%	1.80	27.63%
Secondary dryland forest	Q10	6.32	85.35%	2.05	27.63%
Secondary dryland forest	Q25	7.26	85.35%	2.35	27.63%
Industrial forest	Q2	1.87	85.35%	0.61	27.63%
Industrial forest	Q5	2.41	85.35%	0.78	27.63%
Industrial forest	Q10	2.74	85.35%	0.89	27.63%
Industrial forest	Q25	3.14	85.35%	1.02	27.63%
Shrubland	Q2	0.89	85.35%	0.29	27.63%
Shrubland	Q5	1.15	85.35%	0.37	27.63%
Shrubland	Q10	1.31	85.35%	0.42	27.63%
Shrubland	Q25	1.50	85.35%	0.49	27.63%
Grass/tree vegetation	Q2	0.13	85.35%	0.04	27.63%
Grass/tree vegetation	Q5	0.17	85.35%	0.05	27.63%
Grass/tree vegetation	Q10	0.19	85.35%	0.06	27.63%
Grass/tree vegetation	Q25	0.22	85.35%	0.07	27.63%
Mixed dryland agriculture	Q2	21.07	85.35%	6.82	27.63%
Mixed dryland agriculture	Q5	27.12	85.35%	8.78	27.63%
Mixed dryland agriculture	Q10	30.87	85.35%	9.99	27.63%
Mixed dryland agriculture	Q25	35.42	85.35%	11.47	27.63%
Paddy fields	Q2	2.14	85.35%	0.69	27.63%
Paddy fields	Q5	2.75	85.35%	0.89	27.63%
Paddy fields	Q10	3.13	85.35%	1.01	27.63%
Paddy fields	Q25	3.60	85.35%	1.16	27.63%
Open land	Q2	2.51	85.35%	0.81	27.63%
Open land	Q5	3.23	85.35%	1.04	27.63%
Open land	Q10	3.67	85.35%	1.19	27.63%

Land-cover class	Return period	TLSR Q ($\text{m}^3 \text{s}^{-1}$)	TLSR multiplier	DLSR Q ($\text{m}^3 \text{s}^{-1}$)	DLSR multiplier
Open land	Q25	4.21	85.35%	1.36	27.63%
Water bodies	Q2	16.14	85.35%	5.23	27.63%
Water bodies	Q5	20.78	85.35%	6.73	27.63%
Water bodies	Q10	23.65	85.35%	7.66	27.63%
Water bodies	Q25	27.14	85.35%	8.79	27.63%

2.7 Data-quality safeguards

The rainfall records and derived hydrological calculations were cross-checked for internal consistency before interpretation. The 1998 Tompobulu rainfall entry was reconciled with the regional rainfall series used in the subsequent frequency analysis, and the Gumbel return-period calculations were harmonized with the consolidated design-rainfall results. The Mononobe intensity series was also checked for consistency with the expected intensity-duration relationship. The remaining limitations concern the spatial representativeness and mapped extent of the tabulated land-cover areas and the use of common runoff coefficients across land-cover classes; these are therefore treated explicitly as constraints on engineering interpretation rather than as unresolved calculation errors.

3. Findings and Discussion

3.1 Rainfall variability and design rainfall

The three gauges show marked interannual variability. Tanralili ranges from 80 mm in 2012 to 260 mm in 2001, Tompobulu from 68 mm in 2014 to 250 mm in 2015, and Batubassi from 94 mm in 2010 to 302 mm in 2011. The arithmetic regional series in Table 2 ranges from 111.33 to 247.00 mm. High annual values do not occur at the same station every year, indicating spatial variability that is partly lost when the three gauges are reduced to a single average. That simplification is acceptable for a screening analysis but limits inference about storm movement and sub-catchment rainfall gradients.

3.2 Distribution choice and rainfall intensity

The Log-Pearson type III series rises from 158.622 mm at the 2-year return period to 271.267 mm at 200 years. The consolidated Gumbel series in Table 7 rises from 157.610 to 315.686 mm over the same return periods. The two estimates are close at short return periods and diverge progressively at longer ones; at 200 years the difference reaches 44.419 mm. The divergence is expected when a 22-year sample is extrapolated far beyond the observation length, and it argues against treating 100- or 200-year values as equally certain as more frequent events. The intensity calculations in Table 8 show the expected increase with return period and decrease with rainfall duration. The 25-min intensities used for runoff calculations are 98.368, 117.374, 129.242, and 143.686 mm h^{-1} for the 2-, 5-, 10-, and 25-year events, respectively.

3.3 Baseline runoff and the importance of area weighting

The summed Rational-method discharge across the reported classes increases from 56.90 $\text{m}^3 \text{s}^{-1}$ at Q2 to 73.25 $\text{m}^3 \text{s}^{-1}$ at Q5, 83.37 $\text{m}^3 \text{s}^{-1}$ at Q10, and 95.65 $\text{m}^3 \text{s}^{-1}$ at Q25. Mixed dryland agriculture contributes the largest modeled discharge at every return period, rising from 24.09 to 40.51 $\text{m}^3 \text{s}^{-1}$. Water

bodies are second, increasing from 18.91 to 31.80 $\text{m}^3 \text{s}^{-1}$. Secondary dryland forest contributes 5.06–8.50 $\text{m}^3 \text{s}^{-1}$, whereas grass-and-tree vegetation contributes only 0.15–0.25 $\text{m}^3 \text{s}^{-1}$. Figure 5 visualizes this distribution.

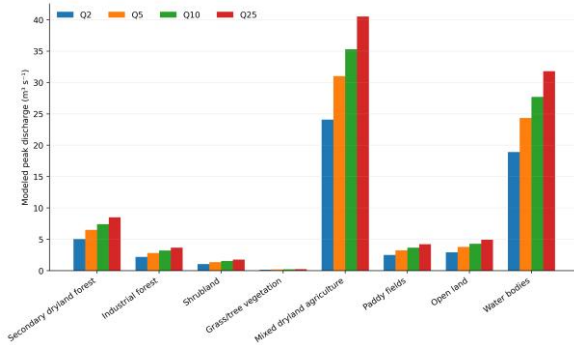


Figure 5. Rational-method peak discharge by reported land-cover class and return period.

3.4 Interpreting land-cover differences

The ranking in Table 9 is useful for locating the largest modeled runoff burden, but it is not a direct measurement of hydrological behavior by land-cover type. At each return period, the same C value is assigned to forest, agriculture, open land, paddy fields, and water bodies. Consequently, most of the inter-class contrast is generated by the reported area term rather than by class-specific infiltration or roughness. Field and modeling studies consistently show that land cover changes runoff partly by changing infiltration, interception, storage, and flow connectivity [2,10,30]. Evidence from Makassar likewise associates expanding built land with increased flood susceptibility [7]. For Tanralili, class-specific C values or event-calibrated parameters are therefore necessary before statements such as “agriculture produces more runoff than forest per unit area” can be supported.

3.5 Runoff attenuation under the LSR scenario

Table 10 summarizes the paired TLSR and DLSR discharge estimates, while Figures 6 and 7 visualize the corresponding class-level discharge patterns under the two scenarios. Across all return periods, mixed dryland agriculture and water bodies contribute the largest absolute discharges, whereas grass-and-tree vegetation contributes the smallest values. Application of the DLSR scenario shifts the modeled discharge downward for every land-cover class because the same scenario multiplier is applied consistently across the calculations. Figure 8 further illustrates the paired relationship between TLSR and DLSR discharge and demonstrates the near-linear proportional reduction imposed by the fixed scenario factors. These results should therefore be interpreted as scenario-based attenuation rather than as independently measured infiltration-well efficiency.

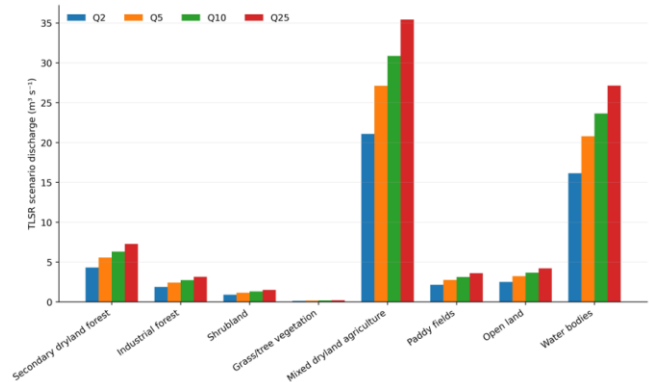


Figure 6. TLSR scenario discharge without infiltration wells.

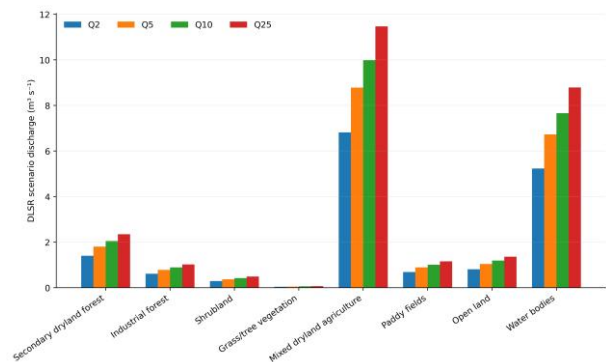


Figure 7. DLSR scenario discharge with infiltration wells.

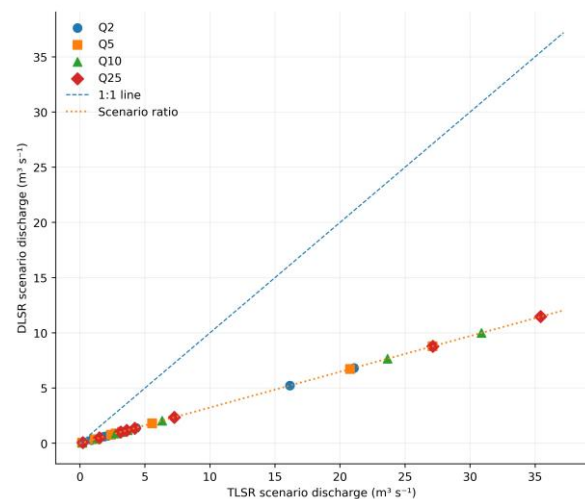


Figure 8. Pairwise TLSR–DLSR comparison across land-cover classes and return periods.

3.6 Why the 67.6% reduction is a scenario result

The relative decrease between TLSR and DLSR is about 67.6% for every return period because 85.35% and 27.63% are fixed multipliers. This constancy is a property of the calculation, not evidence that an infiltration well will retain the same fraction during Q2 and Q25 storms. Actual performance usually changes as available storage is filled and infiltration capacity becomes limiting. Modeling of low-impact development shows declining relative runoff

reduction as storm magnitude increases [31,32], and integrated surface–subsurface modeling similarly finds that infiltration-based measures lose some effectiveness for more severe design events [33]. Monitored curbside infiltration systems also demonstrate that catchment-scale reductions can be much smaller than idealized scenario values [15]. The 67.6% result is therefore best read as a sensitivity case that identifies how a strong runoff-control assumption would redistribute modeled discharge.

3.7 Implications for targeting infiltration wells

The most useful management output is the ranking of absolute leverage rather than the repeated percentage. Mixed dryland agriculture should be the first class investigated because it carries the largest baseline discharge in the present calculation. That does not mean wells should be distributed uniformly across all agricultural land. Candidate sites must be screened for slope, soil permeability, groundwater depth, available space, sediment load, and hydraulic connection to drainage. Recent Indonesian work demonstrates the value of spatial decision support: GIS-based flood management in Bulukumba organizes physical and risk information for local action [18], while a village-scale study shows how flood vulnerability can guide the placement of mitigation infrastructure [19]. The same logic can be applied in Tanralili by overlaying high-runoff source areas with LSR suitability.

3.8 Infiltration measurements as the missing calibration layer

Field infiltration is the key process measurement missing from the current watershed calculation. A well located in highly permeable soil may drain between storms and recover storage, whereas a structure in clay-rich soil may behave primarily as temporary detention. Recent Tanralili research reports that local infiltration interventions can improve hydrological response but that performance depends on site conditions [16]. A study conducted in Panakkukang evaluated infiltration together with surface runoff in a local setting [17], providing a relevant methodological basis for linking field infiltration measurements with runoff response. A Tanralili monitoring program should record well inflow, water level, recession time, overflow, rainfall intensity, antecedent wetness, and nearby surface discharge. These observations would allow the scenario factor to be replaced by an event-dependent storage and infiltration function.

3.9 From screening discharge to flood-risk prediction

The Rational method estimates a peak discharge but does not predict hydrograph shape, travel time, channel capacity, or inundation depth. Those outcomes matter if LSR is expected to reduce downstream flood risk rather than only local runoff. A recent study on the Jeneberang River combined design hydrology with HEC-RAS and GIS to relate increasing return-period discharge to inundation-prone areas [34]. A similar second-stage framework would strengthen Tanralili assessment: first calibrate rainfall–runoff response and LSR storage against observed events, then route the resulting hydrographs through the channel network. Such a model could test whether distributed wells

reduce peak discharge, delay time to peak, reduce total volume, or merely shift runoff in time.

3.10 Engineering uncertainty and implementation priorities

Two remaining uncertainties have the greatest influence on engineering application. First, the spatial extent and representation of the land-cover areas should be confirmed because Q is directly proportional to A . Second, runoff coefficients should represent land-cover and soil conditions rather than vary only by return period. Recent studies treat design runoff coefficients as functions of several catchment attributes and show that event-based C can vary substantially with rainfall and antecedent conditions [26]. These limitations may alter the relative contribution of individual land-cover classes even if mixed dryland agriculture remains the dominant modeled source area. Until these parameters are supported by field and spatial verification, the present results should be used primarily for reconnaissance and monitoring priorities rather than final well sizing.

3.11 Land management, sediment, and maintenance

Runoff control cannot be separated from land management because the same source areas that generate water may also deliver sediment to infiltration structures. In agricultural watersheds, soil and water conservation measures can reduce both runoff and sediment yield, but their performance depends on maintenance and rainfall regime [35]. Rainwater-harvesting interventions in semi-arid agricultural landscapes have likewise been used to capture runoff and support water availability, with effectiveness varying across soils and rainfall conditions [36]. For Tanralili, this means that wells placed below eroding fields could lose capacity if sediment enters without pretreatment. The design program should therefore pair LSR with vegetative cover, erosion control, sediment interception, and maintenance access. Protecting existing permeable land may also be more durable than trying to compensate for continued degradation solely by constructing additional wells.

3.12 Limits on recharge claims

A reduction in surface discharge does not demonstrate an equal increase in groundwater recharge. Water detained in an LSR may infiltrate, remain temporarily stored, overflow, or drain later through shallow pathways. Groundwater recharge in data-scarce basins is typically estimated with an explicit water balance or distributed model because rainfall intensity, soil, vegetation, and subsurface properties control the partitioning of water [37]. The present dataset contains no groundwater-level response, percolation measurement, or well water-balance record. The defensible claim is therefore runoff attenuation under an imposed scenario, not a quantified recharge benefit. Future monitoring should separate storage change, infiltration loss, overflow, and delayed drainage if recharge is to be reported as an outcome.

3.13 Behavior under more extreme storms

The results also imply that a fixed reduction factor becomes increasingly questionable as storm severity rises. During large events, catchment controls can shift because surface storage is exceeded and hydrological connectivity increases. Recent mechanistic work shows that extreme rainfall can reduce the relative influence of spatial heterogeneity as runoff response becomes more uniformly storm-driven [38]. This behavior is consistent with the declining efficiency of several low-impact-development measures under higher design storms. For Tanralili, the Q25 scenario should therefore be interpreted as an upper-level screening case rather than evidence that the same proportional benefit will persist for rarer events. Monitoring across small, moderate, and severe storms is needed to determine when LSR storage begins to saturate and when overflow becomes the dominant pathway.

3.14 Decision criteria for pilot deployment

A pilot program should be designed to test competing explanations rather than merely demonstrate that a well can store water. Candidate sites can be grouped by soil permeability, slope position, land cover, and contributing area, with at least one monitored control location for each dominant setting. For every storm, rainfall depth and intensity should be paired with inflow, maximum stored depth, recession time, overflow volume, and nearby surface discharge. The resulting dataset would show whether the main benefit is rapid infiltration, temporary detention, or delayed drainage. It would also provide a basis for estimating maintenance frequency. Spatial screening should then place higher weight on locations where large contributing areas coincide with acceptable slope and subsurface conditions, rather than on land-cover area alone. The flood-risk literature increasingly uses this combination of hydrological evidence and spatial prioritization: vulnerability mapping can identify where mitigation provides the greatest consequence reduction, while hydraulic models can test whether altered inflows translate into lower inundation downstream [19,34]. For Tanralili, a staged pilot would therefore produce two outputs that the present screening cannot supply: an empirically defensible LSR performance function and a map of feasible, high-leverage intervention zones. Those outputs are more transferable to engineering design than a single catchment-wide reduction percentage.

3.15 A staged management framework

A practical implementation sequence follows from the evidence. Stage 1 is spatial-input verification: confirm the mapped extents, spatial boundaries, and representativeness of the land-cover areas used in the runoff calculations. Stage 2 is field characterization: measure infiltration and groundwater depth across candidate source areas and screen out unstable or poorly drained locations. Stage 3 is pilot deployment: install a limited number of wells and monitor event inflow, storage, recession, and overflow. Stage 4 is calibrated catchment modeling, using observed performance to test alternative numbers and placements of wells under several design storms. Stage 5 combines infiltration wells with land-cover protection, sediment

control, and adequate overflow drainage. This portfolio approach is consistent with evidence that combinations of source-control measures are usually more robust than reliance on one facility type [31]. It also avoids promising groundwater recharge or flood elimination when the available data only demonstrate modeled runoff attenuation.

4. Conclusion

Design-storm runoff in the Tanralili Sub-Watershed increases substantially with return period. Using the reported 25-min rainfall intensities and Rational-method parameters, summed discharge rises from $56.90 \text{ m}^3 \text{ s}^{-1}$ at Q2 to $95.65 \text{ m}^3 \text{ s}^{-1}$ at Q25. The no-LSR scenario yields $49.07\text{--}82.49 \text{ m}^3 \text{ s}^{-1}$ across those return periods, whereas the with-LSR scenario yields $15.89\text{--}26.71 \text{ m}^3 \text{ s}^{-1}$. Because both scenarios are generated with fixed multipliers, the approximately 67.6% relative reduction is an imposed scenario outcome rather than a measured, return-period-independent LSR efficiency.

The strongest planning result is spatial rather than percentage-based. Mixed dryland agriculture provides the largest modeled absolute reduction at Q25 ($23.95 \text{ m}^3 \text{ s}^{-1}$), making it the first class for detailed source-area screening. Before engineering deployment, the land-cover spatial extents and mapped coverage should be confirmed; runoff coefficients should be differentiated by land cover, soil, slope, and event conditions; and LSR performance should be measured during real storms. Coupling these measurements with GIS-based suitability analysis and event-based hydraulic modeling would allow Tanralili to move from a screening scenario toward a defensible flood-mitigation design.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work, OpenAI ChatGPT was used to support manuscript organization, language refinement, and the presentation of calculations derived from the study data. All authors subsequently reviewed and edited the manuscript and independently verified the data, calculations, references, interpretations, and scientific conclusions. The authors take full responsibility for the accuracy, integrity, and content of the published work.

CRedit authorship contribution statement

Ilham Amring: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Amrullah Mansida:** Conceptualization, Methodology, Validation, Supervision, Writing – review & editing. **Farida Gaffar:** Methodology, Validation, Supervision, Project administration, Writing – review & editing. All authors have read and approved the final version of the manuscript.

Funding

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All numerical data supporting the findings of this study are presented within the manuscript, tables, and figures. The underlying rainfall records and calculation worksheets may be made available by the corresponding author upon reasonable request.

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