

# Flood Modelling due to dam failure using HEC-RAS 2D with GIS overlay: case study of Karalloe dam in South Sulawesi Province Indonesia

*By Zubair Saing*

1 **Flood Modelling due to dam failure using HEC-RAS 2D with GIS overlay:**  
2 **case study of Karalloe dam in South Sulawesi Province Indonesia**

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4 Riswal Karamma<sup>1)</sup>, Sugiarto Badaruddin<sup>2)</sup>, Rifaldi Mustamin<sup>1)</sup>, Zubair Saing<sup>3)</sup>

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6 <sup>1</sup>Civil Engineering Department, Hasanuddin University, P.O. Box 90245, South Sulawesi,  
7 Indonesia

8 <sup>2</sup>Civil Engineering Department, Politeknik Negeri Ujung Pandang, P.O. Box 90245, South  
9 Sulawesi, Indonesia

10 <sup>3</sup>Department of Civil Engineering, Universitas Muhammadiyah Maluku Utara, Ternate City,  
11 Indonesia

12

13 Email addresses:

14 Riswal Karamma: [riswalchiwal@gmail.com](mailto:riswalchiwal@gmail.com) (Corresponding Author)

15 13 Sugiarto Badaruddin: [sugibadaruddin@poliupg.ac.id](mailto:sugibadaruddin@poliupg.ac.id)

16 Rifaldi Mustamin: [aldirifal09@gmail.com](mailto:aldirifal09@gmail.com)

17 Zubair Saing: [zubairsaing@ummu.ac.id](mailto:zubairsaing@ummu.ac.id)

18

19 \*Corresponding author at: Civil Engineering Department, Hasanuddin University, P.O. Box  
20 90245, South Sulawesi, Indonesia. Email address: [riswalchiwal@gmail.com](mailto:riswalchiwal@gmail.com) (Riswal  
21 Karamma)

22

23 Highlights:

- 24 • Flood impact due to dam failure is investigated in this study
- 25 • The flood impact was modelled using HEC-RAS 2D with GIS overlay for mapping
- 26 • The simulation results showed that 22 villages will be affected by flash flood due to  
27 dam failure

28

29 **Abstract**

30

31 The impact of flooding caused by the failure of the Karalloe dam in Bone Regency,  
32 Indonesia, was explicitly examined in this study. The Creager graph validated the selected  
33 flood discharge by comparing the calculated discharge from several synthetic unit  
34 hydrograph methods (HSS) with the flood discharge measured on the automatic water level  
35 recorder (AWLR). Flooding was simulated using HEC-RAS 2D overlaid with ArcGIS. <sup>7</sup>The  
36 results showed that the HSS SCS method was the design flood discharge value closest to the  
37 measured discharge value and Q1000 Creager. The flood discharge values obtained using the  
38 HSS SCS method were 322.70, 464.10, 560.40, 658.40, 682.70, 787.00, 885.70, and 1202.60  
39 m<sup>3</sup>/s for Tr 2, 5, 10, 20, 25, 50, 100, and 1000 years, respectively. According to the results,  
40 flooding will affect 22 villages, and the flood's fastest standby time is 12 minutes.

41

42 **Keywords:** Flood Modelling, Dam break, Synthetic Unit Hydrograph, HEC-RAS 2D.

43

44

45 **1. Introduction**

46

47 The dam is a piece of infrastructure beneficial to human life by promoting social and  
48 economic development. Dams serve <sup>6</sup> many purposes, including irrigation, power generation,  
49 <sup>12</sup> water supply, flood control, fishing, and recreation (de Paiva et al., 2020; Aureli et al., 2021).

50 The Karalloe Dam is a rock-fill type with a concrete membrane and side spillway without a  
51 door with a maximum storage volume of 40.53 million m<sup>3</sup>, which is used to meet water needs  
52 for irrigation of Kelara-Karalloe, covering an area of 7004 ha and is expected to be developed  
53 for hydropower potential of 4.5 MW, flood control (64.17 m<sup>3</sup>/second), conservation of water  
54 resources, and tourism development (Hasbi et al., 2020; Rakhim and Sirajuddin, 2020; Sandi  
55 et al., 2020).

56

57 In addition to their numerous advantages, dams pose a significant risk of disaster in the event  
58 of a failure or collapse, <sup>5</sup> which can result in loss of life and property as well as the destruction  
59 of existing infrastructure <sup>2</sup> in the downstream area (Evangelista et al., 2013; Kyaw et al., 2020).

60 The construction of a dam is frequently followed by the development of communities in the  
61 downstream area, which increases the risk of dam failure (Urzică et al., 2020). Dams can  
62 break or collapse due to overtopping, the overflow of water through the dam's top, causing  
63 erosion and landslides in the dam's body, particularly in embankment dams. The dam's failure  
64 will result in flash floods, in which the water stored in the dam will flow downstream with a  
65 giant flood discharge and at high speed (Perera et al., 2021).

66

67 Because of the conditions affecting dam stability and retention efficiency, a greater spread of  
68 awareness about risk factors affecting dam safety is required (Perera et al., 2021). Some  
69 negative factors include damaging spillway capacity that cannot drain flood discharge due to

70 changes in weather patterns effectively and exacerbated extreme climates (Bocchiola and  
71 Rosso, 2014; Krzto et al., 2022). These factors can increase the risk of flooding in  
72 downstream areas due to dam failure, which is exacerbated by increased exposure to human  
73 settlements and the potential for high flood susceptibility (Li et al., 2018). Given the  
74 possibility of disasters caused by a dam collapse in response to conditions downstream of the  
75 dam, flood simulations are required to predict areas that will be affected downstream of the  
76 dam, particularly in a dam collapse (Ahmadi and Yamamoto, 2021).

77

78 This significant potential danger necessitates the creation of a detailed and effective  
79 emergency action plan (EAP). In general, dam break analysis is the primary input of EAP  
80 (Said et al., 2019). The source of data for compiling this EAP is the result of dam break  
81 analysis in the form of dam collapse simulation results (Said et al., 2019). In most  
82 downstream flood simulations caused by a dam failure, it is assumed that the dam collapses  
83 completely and unexpectedly (Azeez et al., 2020). Kheirkhah et al., 2021), SMPDBK (Nazif,  
84 2019), FLDWAV (Kheirkhah et al., 2021), and HEC-RAS can be used to model water flow  
85 due to dam collapse (Kilania and Chahar, 2019). Among the many applications available, the  
86 2D numerical model HEC-RAS is ideal for determining water depth, inundation area, flow  
87 velocity, and water level profile in two dimensions (Bharath et al., 2021).

88

89 Flood simulations due to the collapse of the Karalloe dam were performed in this study using  
90 HEC-RAS 2D and combined with ArcGIS for mapping. A flood flow pattern will be obtained  
91 from the simulation results, which will then be followed by flood tracing in flood-prone  
92 locations to <sup>3</sup>serve as a guide for dam managers and governments in the affected areas to  
93 prepare anticipatory steps in the event of an emergency condition at the dam.

94

## 95 2. Materials and Method

96

### 97 2.1. Materials

98 Several data sets are required to carry out this research, including (1) TRMM rainfall data  
99 (Tropical Rainfall Measuring Mission). The National Institute of Aeronautics and Space  
100 obtained rain data from 1998 to 2020 (23 years) (LAPAN). (2) Karalloe Dam technical data  
101 in general, primary dam body, and spillway building data to determine dam characteristics.  
102 (3) The reservoir capacity curvature describes the reservoir in the reservoir that is used in the  
103 flood track. (4) For flood tracking, topographic and bathymetric data were combined with  
104 DEMNAS (National Bathymetry and Digital Elevation Model) with an 8.3 m spatial  
105 resolution. (5) Pompengan-Jeneberang river basin authority (BBWSPJ) soil type map from  
106 2018. (6) The Geospatial Information Agency provided a map of the 2019 Land Use Pattern.

107

### 108 2.2. Flood discharge design

109 Flood discharge analysis is used to determine flood discharge design based on data from  
110 current conditions. The availability of flow data determines the method for designing flood  
111 discharge analysis. Because flow data is not available, the flood discharge in this study is  
112 calculated by converting rain into the flow (Karamma and Pallu, 2018). The design flood  
113 analysis was carried out using a synthetic unit hydrograph based on previous research that  
114 revealed that the HSS SCS method (HEC-HMS Application) was the closest to the  
115 Likupadde AWLR discharge and Crager Graph (Mustamin et al., 2021).

116

117 Data on land use, soil type, river topography, and TRMM rainfall were used in the  
118 hydrological analysis using the HEC-HMS application. TRMM is used in this study because

119 it performs well for Indonesian territory and correlates with average daily rainfall observation  
120 data of 0.90 derived from various satellite rainfall data sources (Vernimmen et al., 2012).

121

### 122 **2.3. Dam break analysis**

123 The HEC-RAS 2D application <sup>2</sup> was used to simulate the failure of the Karalloe Dam. In this  
124 case, an evaluation is also performed to determine whether flooding from the most recent  
125 rainfall can cause overtopping at the dam's top. Table 1 shows technical information about  
126 the Karalloe Dam.

127

128

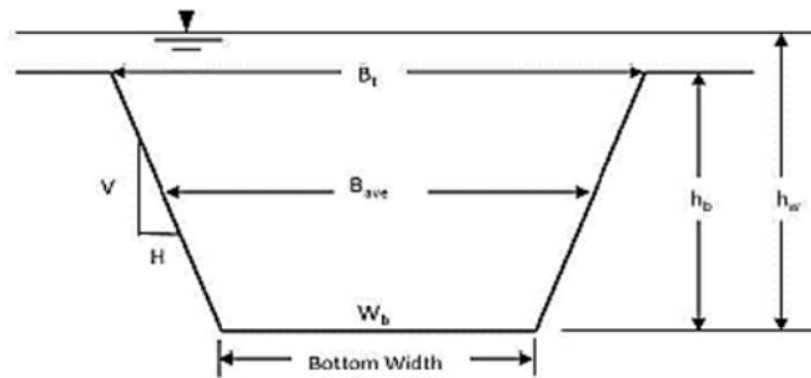
Table 1. Technical data of Karalloe Dam

River's name	: Karalloe
Watershed area	: 195 km <sup>2</sup>
Inundation area	: 145 Ha
Maximum storage volume	: 40.53 million m <sup>3</sup>
Effective storage volume	: 29.50 million m <sup>3</sup>
Off storage volume	: 11.03 million m <sup>3</sup>
Flood water level	: + 252.40 m
Normal water level	: + 248.50 m
Low water level	: + 220.50 m
Type of dam	: Concrete membrane Stone backfill
Height of the dam from the foundation's base	: 82 m
Top elevation of dam	: + 253.00 m
Dam crest height	: 396 m

Dam crest width	: 10 m (Hot mix)
Spillway type	: Ogee
Overflow type	: Side overflow without door
Threshold elevation	: + 248.50 m
Overflow width	: 100 m

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130



131

132

Figure 1. Fracture parameter overview

133

134 Fractures usually occur prior to the dam's total collapse (Figure 1). The following is

135 Froehlich's (2022) regression equation for average fracture width and failure time:

136 
$$B_{ave} = 0.27 K_o \cdot Vw^{0.32} \cdot hb^{0.04} \quad (1)$$

137 
$$tf = 63.2 \sqrt{\frac{Vw}{ghb^2}} \quad (2)$$

138 Where,  $B_{ave}$  = The average width of the fracture (m)

139  $K_o$  = Constant (1.3 for overtopping collapse)

140  $Vw$  = Storage volume at collapse ( $m^3$ )

141  $Hb$  = Final height of fracture (m)

142  $g$  = Gravity constant ( $9,80665 \text{ m/s}^2$ )

143  $tf$  = Collapse time (detik)



144 According to Froechlich (2022), the mean side slope for overtopping failure should be  
145 horizontal to vertical (1:1).

146

## 147 **2.4. Flood Mapping and Tracking**

148 The flood simulation results from dam failure will be mapped using ArcGIS 10.8 software to  
149 identify flood-prone areas, which will then be classified based on a specific depth. Following  
150 the flood mapping, flood identification was performed to determine the affected location's  
151 distance from the dam, the depth of the flood, and the time of flood concentration from the  
152 dam to flood-prone locations.

153

## 154 **3. Results and Discussion**

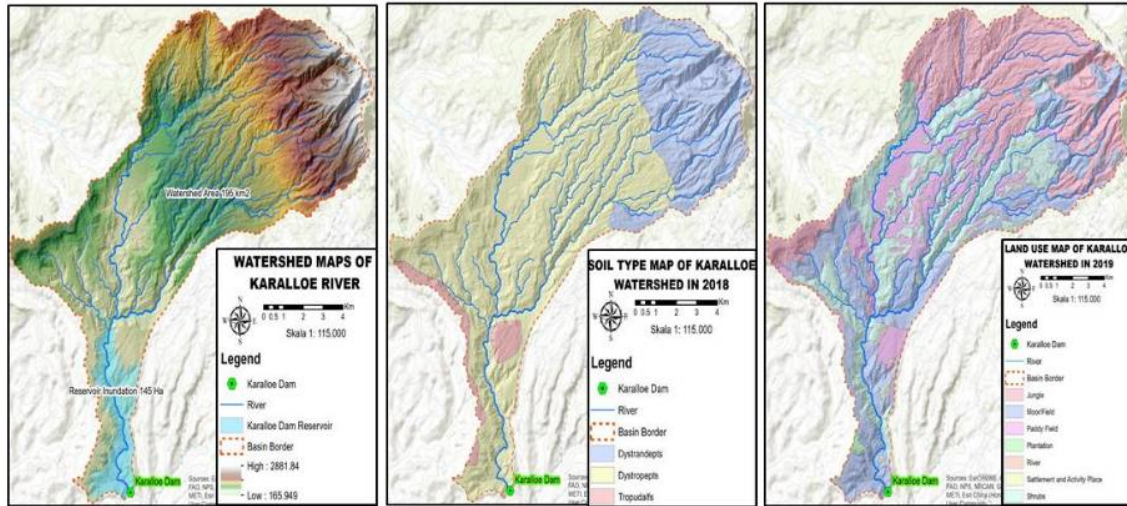
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### 156 **3.1. Karalloe Dam Design Flood Discharge**

157 Based on the Karalloe Dam's design data, a QPMF (i.e., flow discharge for the Probable  
158 Maximum Flood) of 2,020 m<sup>3</sup>/s was obtained in 2012, while the results of other researchers'  
159 analyses of the Karalloe Dam obtained a QPMF of 3307 m<sup>3</sup>/s in 2017. (Rakhim and  
160 Sirajuddin, 2020). Recognizing an increase in flood discharge necessary to analyze flood  
161 discharge using the most recent rainfall data to determine the increase in flood discharge,  
162 with the most significant discharge used as input for simulation to determine the impact of  
163 the Karalloe Dam failure.

164

165 Data on watershed characteristics such as topography, land use, and soil type are derived  
166 from the hydrological analysis using the SCS method (i.e., HEC-HMS) because they  
167 significantly impact rainwater that will become surface runoff. The map in Figure 2 can  
168 describe the characteristics of the Kelara watershed.



170

171 **Figure 2.** Map of Topographic, soil type and land use of the Karalloe Watershed

172

173 The characteristics of the Karalloe watershed <sup>10</sup> can be seen in Figure 2, which shows that the  
 174 watershed area is 195.23 km<sup>2</sup>, the length of the main river is 27.27 km, the highest elevation  
 175 is +848 masl, the lowest elevation is +165 masl, the average river slope is 0.026 percent,  
 176 dystropepts dominate the soil type, and the land is dominated by forest. The input parameters  
 177 for the HEC-HMS are derived from the results of the watershed characteristics analysis.  
 178 Table 2 displays these parameters. Three TRMM posts collect rainfall data, which affects the  
 179 Karalloe watershed. Figure 3 and Table 3 show the TRMM location and data.

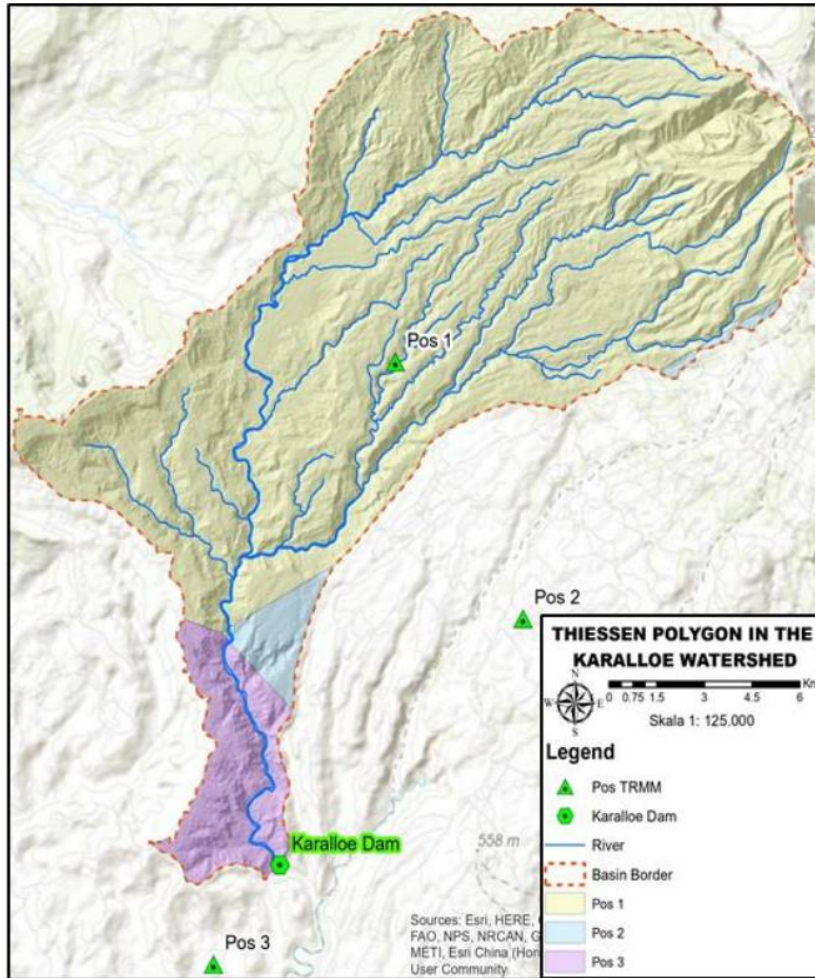
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**Table 2.** HEC - HMS Input Parameters

Physical Parameters	Value
Watershed Area (km <sup>2</sup> )	195,23
Initial Abstraction (mm)	23,40
Impervious (%)	0,58
Curve Number (CN)	68
Lag Time (min)	124,17

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**Figure 3.** Thiessen polygon of the Karalloe watershed

**Table 3.** Maximum Daily Rainfall from TRMM posts

Year	Maximum Daily Rainfall (mm)		
	Pos 1	Pos 2	Pos 3
1998	87	64	80
1999	128	137	173
2000	108	112	96
2001	95	99	98
2002	75	75	83
2003	96	87	88
2004	102	103	96
2005	85	71	77
2006	129	123	97

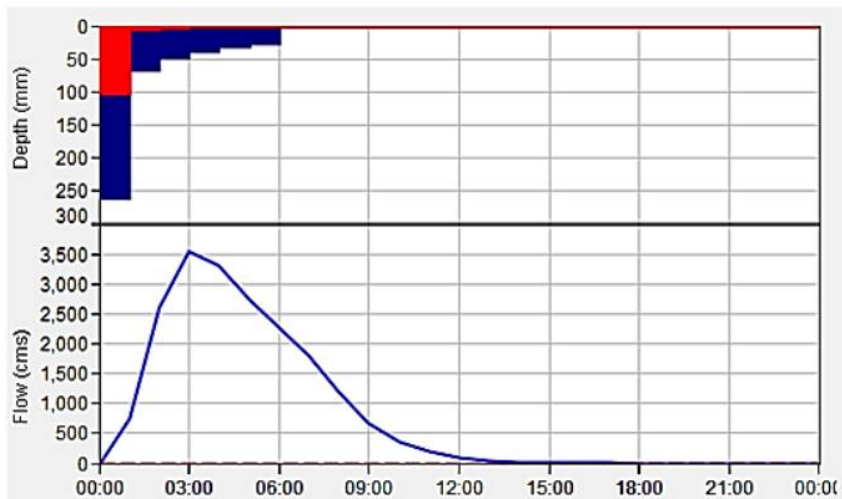
Year	Maximum Daily Rainfall (mm)		
	Pos 1	Pos 2	Pos 3
2007	73	79	72
2008	72	72	96
2009	84	89	80
2010	111	134	101
2011	84	87	94
2012	70	73	81
2013	108	118	155
2014	74	79	96
2015	116	113	138
2016	80	82	101
2017	95	100	102
2018	80	76	78
2019	109	127	138
2020	89	100	74

187

188

189 The Probable Maximum Precipitation (PMP) analysis performed at the Karalloe Dam  
 190 location yielded a value of 478.77 mm/day. In addition, a QPMF discharge analysis was  
 191 performed using the HEC-HMS application, yielding a value of 3534.8 m<sup>3</sup>/sec. Figure 4  
 192 depicts the outcome of the QPMF discharge analysis.

193



194

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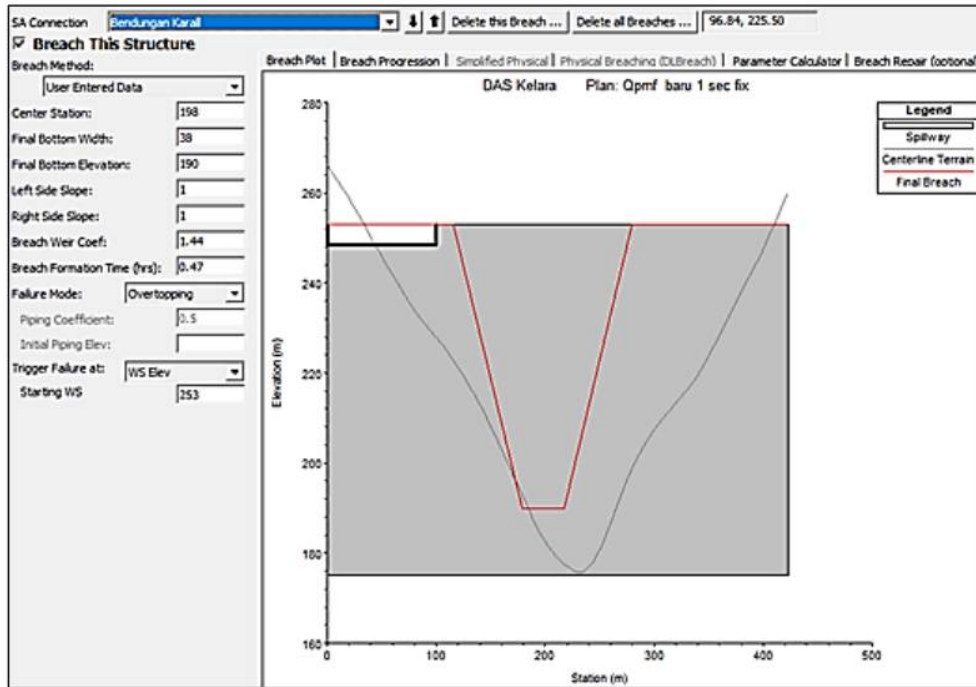
**Figure 4.** QPMF flood hydrograph of the Karalloe Watershed

196

197 **3.2. Simulation of dam failure**

198 In this study, data are required to support the simulation to run HEC-RAS 6.0.1 and obtain  
199 the results of the dam collapse analysis. Figures 5 and 6 show the primary data and scenarios  
200 used in general.

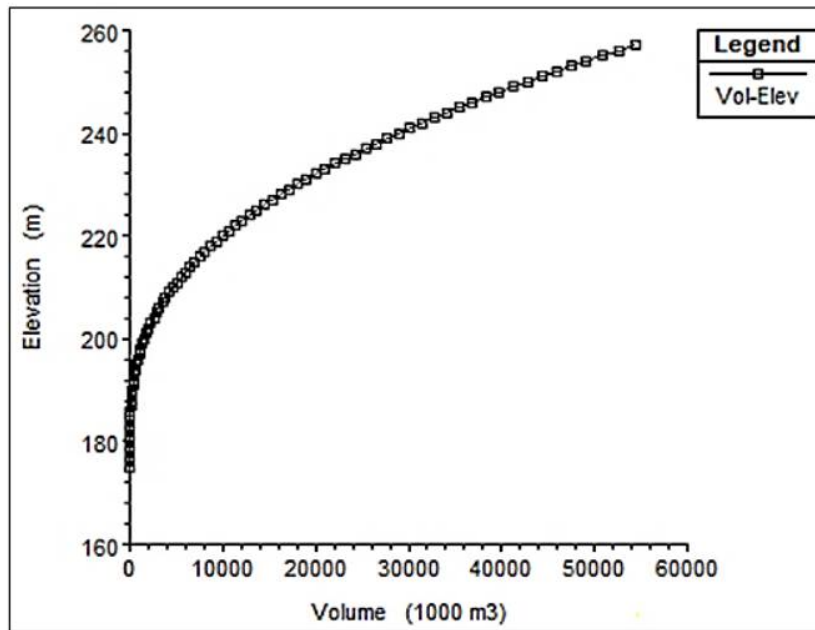
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202

203 **Figure 5.** Dam breach parameter plan option is considered a steady Flow

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**Figure 6.** Curve capacity of the Karalloe dam's reservoir

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208 The simulation results of a dam collapse carried out not only produce the distribution of flood

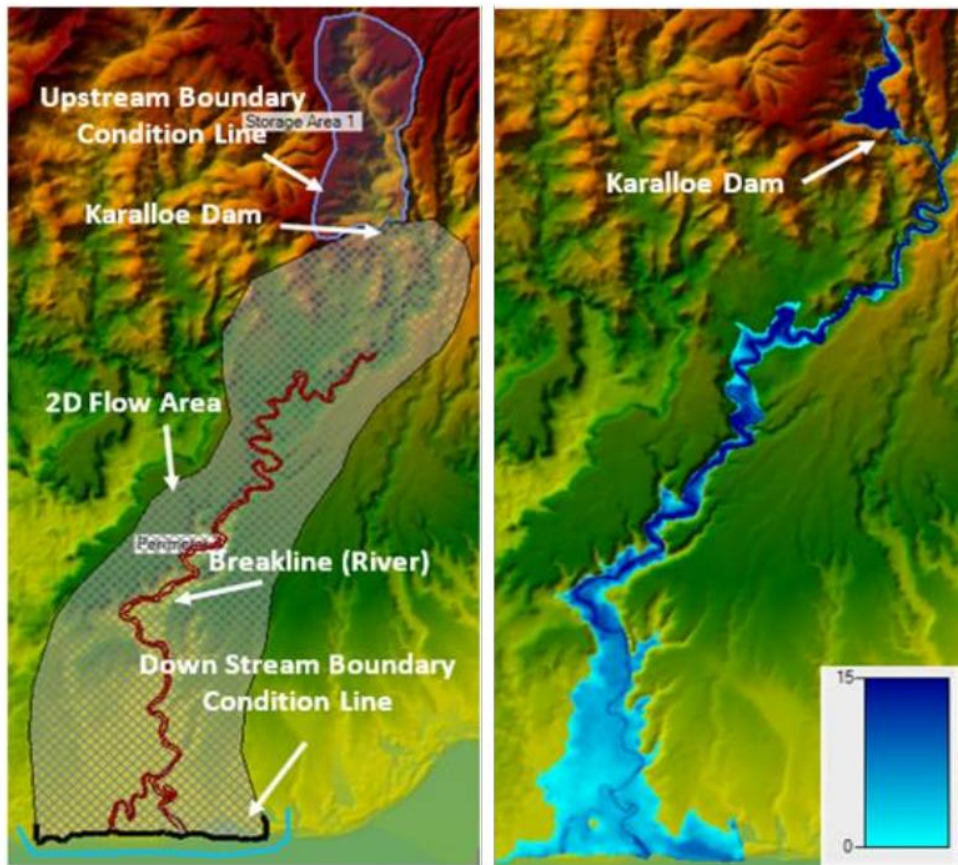
209 inundation but also provide information on the depth at the point to be reviewed, the velocity

210 of the flood flow, and the flood arrival time at a particular location. In general, the flooding

211 visualization due to the collapse of the Karalloe Dam at its top condition <sup>3</sup> can be seen in

212 [Figure 7](#) as follows.

213



214

215 **Figure 7.** Map of DEM/boundary condition and simulation result of the Karalloe dam's

216

failure

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218 The Karalloe dam failure simulation results show that the dam collapsed at 2:28:01 with a

219 QPMF discharge of 3534.8 m<sup>3</sup>/s (simulation time). The floodwater depth level downstream of

220 the Karalloe Dam has decreased as the distance traveled and the time for the flood has

221 increased.

222

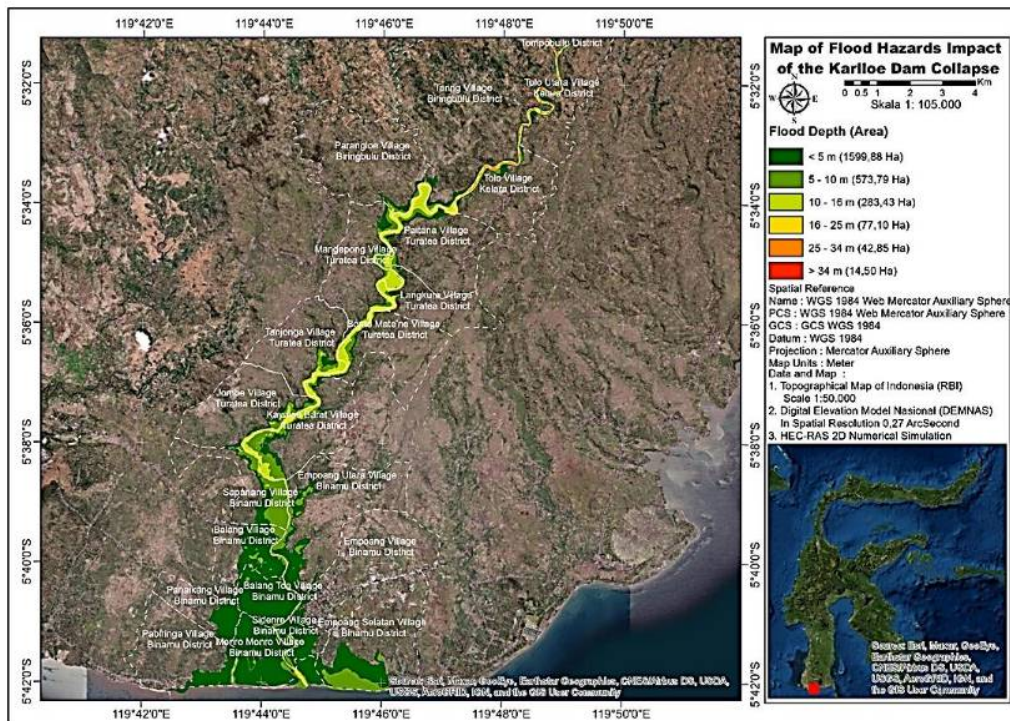
### 223 3.3. Affected area and population

224 A flood hazard map was created as a reference based on the simulation results of the Karalloe

225 dam's failure to determine the extent of the flood impact caused by the dam's collapse. The

226 flood hazard map is intended to provide information on areas that will be flooded due to a  
 227 dam failure. The local government and dam managers can coordinate the notification  
 228 (warning) process for residents and evacuation procedures for residents who are at risk based  
 229 on this flood hazard map. Figure 8 depicts the area affected by the collapse of the Karalloe  
 230 Dam in greater detail.

231



232

**Figure 8.** Map of flood hazards due to the collapse of the Karalloe dam

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235 Figure 8 shows that the collapse of the Karalloe Dam has affected 22 villages from 5 sub-  
 236 districts. Table 4 shows the affected areas in greater detail. Aside from flood-prone maps,  
 237 simulation results can also provide information on how long it takes floods to reach each area  
 238 based on distance and topographical conditions. Monitoring points in densely populated areas  
 239 must be established to provide information on flood travel times and increase community



240 preparedness in a dam emergency to mitigate the impact of the Karalloe dam's collapse. For

241 more information, see Figure 9 and Table 5. They show flood tracking in the affected areas.

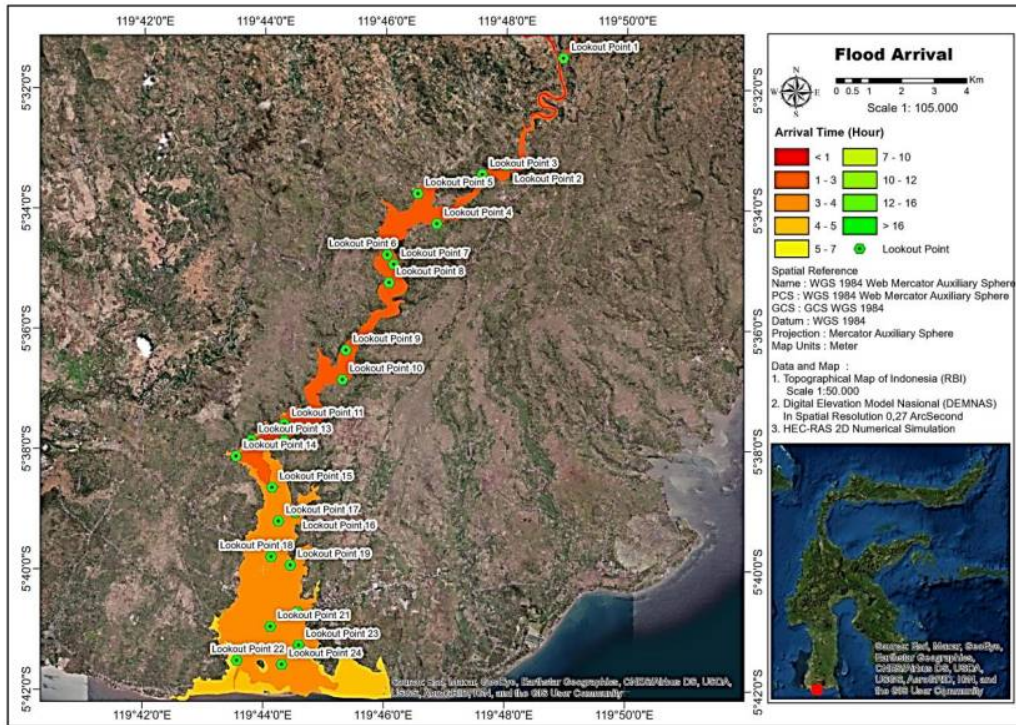
242 **Table 4.** Areas affected by flooding due to Karalloe dam collapse

Affected areas		
Village	Districts	Regency
Taring	Biringbulu	Gowa
Garing	Biringbulu	Gowa
Tolo Utara	Kelara	Jeneponto
Tolo	Kelara	Jeneponto
Paitana	Turatea	Jeneponto
Parangloe	Biringbulu	Gowa
Mangepong	Turatea	Jeneponto
Langkura	Turatea	Jeneponto
Bonto Mate'ne	Turatea	Jeneponto
Tanjonga	Turatea	Jeneponto
Kayuloe Barat	Turatea	Jeneponto
Jombe	Turatea	Jeneponto
Sapanang	Binamu	Jeneponto
Empoang Utara	Binamu	Jeneponto
Balang	Binamu	Jeneponto
Balang Toa	Binamu	Jeneponto
Empoang	Binamu	Jeneponto
Sidenre	Binamu	Jeneponto
Monro - Monro	Binamu	Jeneponto
Empoang Selatan	Binamu	Jeneponto
Panaikang	Binamu	Jeneponto
Pabiringa	Binamu	Jeneponto

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**Figure 9.** Map of Flood arrival time

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249

**Table 5.** Flood travel time due to the collapse of the Karalloe dam

Code	Coordinates	Location	Distance from the dam (Kilometers)	Flood arrival time (minutes)
Lookout Point 1	5°31'28.79"LS & 119°48'56.18"E	Tolo Utara Village, Kelara District , Jeneponto Regency	1.903	17
Lookout Point 2	5°33'15.68"LS & 119°48'0.13"E	Taring Village, Biringbulu District , Gowa Regency	8.026	26
Lookout Point 3	5°33'25.20"LS & 119°47'35.77"E	Taring Village, Biringbulu District , Gowa Regency	8.874	32
Lookout Point 4	5°34'14.46"LS & 119°46'50.66"E	Paitana Village, Turatea District , Jeneponto Regency	11.463	35
Lookout Point 5	5°33'44.42"LS & 119°46'31.80"E	Parangloe Village, Biringbulu District , Gowa Regency	12.855	40
Lookout Point 6	5°34'45.73"LS & 119°46'1.55"E	Mangepong Village, Turatea District , Jeneponto Regency	16.057	32
Lookout Point 7	5°34'55.27"LS & 119°46'8.12"E	Paitana Village, Turatea District , Jeneponto Regency	16.409	12
Lookout Point 8	5°35'13.26"LS &	Mangepong Village,	17.628	32

	119°46'3.36"E	Turatea District , Jenepono Regency		
Lookout Point 9	5°36'20.50"LS & 119°45'20.81"E	Bonto Mate'ne Village, Turatea District , Jenepono Regency	22.620	41
Lookout Point 10	5°36'50.12"LS & 119°45'17.38"E	Bonto Mate'ne Village, Turatea District , Jenepono Regency	23.853	43
Lookout Point 11	5°37'34.48"LS & 119°44'20.07"E	Jombe Village, Turatea District , Jenepono Regency	27.114	52
Lookout Point 12	5°37'50.66"LS & 119°44'19.75"E	Kayuloe Village, Turatea District , Jenepono Regency	27.507	54
Lookout Point 13	5°37'51.00"LS & 119°43'47.13"E	Jombe Village, Turatea District , Jenepono Regency	28.333	55
Lookout Point 14	5°38'7.01"LS & 119°43'32.05"E	Sapanang Village, Binamu District , Jenepono Regency	28.886	61
Lookout Point 15	5°38'37.83"LS & 119°44'8.01"E	Sapanang Village, Binamu District , Jenepono Regency	30.339	63
Lookout Point 16	5°39'2.95"LS & 119°44'31.24"E	Empoang Utara Village, Binamu District , Jenepono Regency	31.564	67
Lookout Point 17	5°39'11.32"LS & 119°44'14.44"E	Sapanang Village, Binamu District , Jenepono Regency	31.802	70
Lookout Point 18	5°39'47.04"LS & 119°44'7.35"E	Balang Toa Village, Binamu District , Jenepono Regency	33.227	76
Lookout Point 19	5°39'55.44"LS & 119°44'26.34"E	Empoang Utara Village, Binamu District , Jenepono Regency	33.831	78
Lookout Point 20	5°40'42.15"LS & 119°44'33.74"E	Balang Toa Village, Binamu District , Jenepono Regency	35.615	83
Lookout Point 21	5°40'56.76"LS & 119°44'6.81"E	Balang Toa Village, Binamu District , Jenepono Regency	36.860	97
Lookout Point 22	5°41'30.63"LS & 119°43'33.45"E	Pabiringa Village, Binamu District , Jenepono Regency	39.743	117
Lookout Point 23	5°41'14.98"LS & 119°44'35.16"E	Sidenre Village, Binamu District , Jenepono Regency	37.704	98
Lookout Point 24	5°41'34.50"LS & 119°44'18.23"E	Monro - Monro Village, Binamu District , Jenepono Regency	38.511	105

250

251 According to Table 5, the arrival time of flooding to residential areas, namely the fastest  
252 standby time, is within 12 minutes at Lookout Point 7 in Paitana Village. Furthermore, the  
253 longest time is 1 hour and 57 minutes at Lookout Point 22 in Paitana Village. This

254 information is critical for the local government in developing a rescue plan for the people  
255 affected by the Karalloe dam failure.

256

#### 257 **4. Conclusions**

258

259 Based on the findings of this study, it is possible to conclude that the analysis of flood  
260 discharge using the HSS SCS method (i.e., HEC-HMS) with a PMF return period (likely  
261 maximum flood) yielded a peak discharge  $Q$  inflow of 3534.8 m<sup>3</sup>/s. This analysis produced a  
262 QPMF value more significant than the designed PMF value of Karalloe Dam, which was  
263 2,020 m<sup>3</sup>/s in 2012, and the results of other researchers, who produced a QPMF of 3307 m<sup>3</sup>/s  
264 in 2017. The map of flood-prone areas obtained in this study shows that 22 villages from 5  
265 sub-districts have been affected by the collapse of the Karalloe Dam, namely: the villages of  
266 Parangloe, Taring, Garing, Monro, Pabiringa, Panaikang, Epoang Selatan, Balang Toa,  
267 Balang, Empoang, Empoang Utara, Sapanang, Kayuloe Barat, Jombe. The collapse occurred  
268 at 2:28:01 according to the flood simulation results using HEC-RAS, which is simulated  
269 using the QPMF value (simulation time). The floodwater depth level downstream of the  
270 Karalloe dam has decreased as the distance traveled and the time for the flood has increased.  
271 There are 24 monitoring points planned in densely populated areas affected by the dam  
272 collapse to provide information on flood travel times and time to improve community  
273 preparedness in an emergency condition at the dam. According to the analysis results, the  
274 quickest standby time is at Lookout Point 7 in Paitana Village within 12 minutes, while the  
275 longest time is at Lookout Point 22 in Paitana Village within 1 hour 57 minutes. Therefore,  
276 the method proposed in this study yields significant results for describing the potential for  
277 flooding caused by dam failure. It assists stakeholders in developing disaster prevention

278 policies and provides new insights into the development of disaster prevention technologies,  
279 particularly flood prevention technologies.

280

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286

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