The design of an artificial lake as a reservoir for potential rainwater from rainfall for daily usage: a case study of Pangandaran in West Java, Indonesia

Ida Widyaningsih¹², Bakhtiar Abu Bakar¹, Didin Kusdian¹

¹ Department of Water Resources Management and Infrastructure, Sangga Buana University, Bandung, 40124, Indonesia
² Post Graduate School of Civil Engineering, Langlangbuana University, Bandung, 40126, Indonesia

E-mail: widya.rissa@gmail.com

Abstract. Pangandaran Regency is located in the Province of West Java and consists of the sub-districts of Parigi, Cijulang, Cimerak, Cigugur, Langkaplancar, Mangunjaya, Padaherang, Kalipucang, Pangandaran, and Sidamulih. The capital of Pangandaran Regency is located in Parigi Sub-District. The rapid growth in the area has resulted in increased water demands, which in turn has resulted in an imbalance between water availability and water needs. To restore the function of recharge areas, Pangandaran Reservoir was built in order to conserve water. In addition to its function to recharge, the reservoir can be used as a source of raw water supply for Pangandaran Regency. In its operation, the water collected in the reservoir must be used optimally to meet the needs of various sectors. To achieve this goal, a study of reservoir operations is needed. This study of reservoir operations includes analysis of rainfall, analysis of water availability using the F.J. Mock method and NRECA, analysis of reliable discharge, and analysis of needs for various needs such as irrigation and drinking water for the people. By using water equilibrium as well as minimum and maximum storage limits (effective storage), the fulfilment of water needs for domestic, municipal, and irrigation or industrial use can be known.

Keywords: Pangandaran, Operation, Reliable, Recharge.

1. Introduction
Regional development in an area will cause water demands to continue to increase along with the population growth rate. Considering water demands, meeting the demands and activities of the people is always a difficult issue. These demands are unavoidable, but must be predicted and planned for the best possible fulfilment.

The construction of a reservoir in Pangandaran Regency has the main objective of providing a location that can be used for fishery by the surrounding people, in addition to other environmental functions such as water storage, flood prevention, and other functions.
The purpose of this article is to analyse the water availability and demands of the Pangandaran Reservoir and to analyse the allocation of water in the fulfilment of raw water needs in Pangandaran Regency, West Java Province.

The objective of this paper is to determine the allocation of water, including water for agriculture and irrigation, and raw water for domestic, municipal, and industrial/irrigation use. Pangandaran Reservoir has an area of 4.1 hectares with depths ranging from 3 to 7 meters. The total capacity is approximately 287,000 m$^3$.

2. Materials and Methods
The data collected to support this study are in the form of primary and secondary data. Primary data were obtained from the results of review in the form of photographs and information obtained directly from the study location, while secondary data involved the results of collection and processing of data obtained from relevant agencies. Secondary data includes regional maps, topographic maps, land use maps, Pangandaran Regency Spatial Planning data, climate, rainfall, population data, and study reports on the Pangandaran Reservoir, as well as information that is assumed to be quite relevant to the materials in this study.

3. Results and Discussion
Hydrological analysis requires observational data for all aspects of precipitation such as runoff, river discharge, infiltration, percolation, evaporation, and so on. More specifically, the data are related to hydrology and include:

![Figure 1. Study of flowchart](image-url)
1. Rainfall Data
2. Climate Data
3. River Discharge Data
4. Topography Map of Reservoir Pangandaran Watershed

3.1 Rainfall Data
One of the uses of rainfall data is to calculate the availability of water in a river or on land. The aim of this analysis is to obtain the average rainfall of an area and the planned rainfall that represents a watershed, taking into account the amount of daily and monthly rainfall recorded at rain observation stations. Available data were obtained from three rain observation stations, which are the Rainamidih, Kalipucang, and Cigugur rain stations. The obtained data consist of daily rainfall data for the ten years from 2009 to 2018.

3.2 Climate Data
Recorded climate data for the area closest to the location of Pangandaran Reservoir were taken from the Sidamulih climate recording post. The recorded climate data used in this analysis consist of data from 2009 to 2018. The complete data can be seen in the appendix.

Table 1. Monthly Average Climatology Data (2009-2018)

| Month    | Temp °C | Humidity % | Wind km/day | Sun hours | Rad MJ/m²/day |
|----------|---------|------------|-------------|-----------|--------------|
| January  | 23.28   | 79.4       | 4           | 50.4      | 29.77        |
| February | 23.37   | 81.1       | 4.1         | 45.3      | 32.95        |
| March    | 23.58   | 80.8       | 3.6         | 52.7      | 29.77        |
| April    | 23.83   | 81.4       | 3.2         | 53.5      | 30.76        |
| May      | 23.77   | 80.1       | 3.1         | 59.2      | 29.77        |
| June     | 23.55   | 78.1       | 3           | 64.7      | 30.78        |
| July     | 23.2    | 75.3       | 3.2         | 72.8      | 29.78        |
| August   | 23.43   | 71.2       | 3.2         | 76.6      | 29.79        |
| September| 23.86   | 71.2       | 3.2         | 72.2      | 30.79        |
| October  | 23.95   | 75.1       | 3.2         | 60.8      | 29.79        |
| November | 23.55   | 81.2       | 3.4         | 45.5      | 30.75        |
| December | 23.79   | 79.9       | 3.5         | 46.2      | 29.74        |
| Average  | 23.60   | 77.90      | 3.39        | 58.33     | 30.37        |

3.3 Evapotranspiration Analysis
In this study, the calculation of evapotranspiration utilised the Penman-Monteith method. To perform the evapotranspiration analysis, daily evapotranspiration values were generated.
Evaporation data for the reservoir site was utilized to calculate the reduction in the volume of water in the reservoir due to solar radiation. The results of the evaporation calculation can be seen in Table 4.

### 3.4 Rainfall Analysis

Regional rainfall calculation was performed to create time-series of rainfall values in each rainfall area, which can be in the form of river basins based on point rainfall data from existing stations. The purpose of finding regional rainfall is to convert point rainfall into regional rainfall, or to find a value that can represent a watershed, which is called the average value.

Table 2. Monthly potential transpiration value in the Pangandaran Reservoir watershed by the Penman-Monteith method

| Month   | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | Average mm/day |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------------|
| January | 54.02 | 45.59 | 40.25 | 38.15 | 37.97 | 42.60 | 36.84 | 45.93 | 42.99 | 49.94 | 43.43         |
| February| 24.21 | 34.54 | 35.78 | 50.60 | 49.34 | 44.70 | 41.42 | 46.76 | 38.07 | 36.58 | 40.20         |
| March   | 36.85 | 48.75 | 35.66 | 41.53 | 47.05 | 46.24 | 41.00 | 47.63 | 34.07 | 42.60 | 42.14         |
| April   | 26.71 | 34.57 | 46.97 | 34.82 | 36.99 | 34.45 | 41.19 | 33.42 | 33.38 | 33.42 | 35.59         |
| May     | 34.42 | 27.64 | 29.01 | 31.62 | 35.70 | 28.01 | 30.40 | 35.63 | 27.08 | 33.25 | 31.28         |
| June    | 29.68 | 31.56 | 25.07 | 35.00 | 36.45 | 28.67 | 28.48 | 38.87 | 26.16 | 26.58 | 30.23         |
| July    | 44.05 | 44.88 | 21.48 | 39.93 | 41.31 | 29.87 | 32.96 | 45.08 | 32.50 | 35.47 | 36.95         |
| August  | 39.30 | 55.55 | 33.49 | 50.95 | 58.39 | 50.85 | 48.53 | 59.13 | 45.92 | 49.63 | 49.17         |
| September| 57.18 | 59.85 | 34.54 | 61.57 | 61.42 | 60.82 | 72.44 | 72.09 | 39.00 | 54.44 | 57.38         |
| October | 62.49 | 48.55 | 36.68 | 54.43 | 53.13 | 59.00 | 58.83 | 74.95 | 31.51 | 45.76 | 52.53         |
| November| 38.41 | 40.72 | 35.30 | 35.58 | 34.42 | 55.40 | 42.29 | 44.87 | 33.86 | 32.54 | 39.34         |
| December| 38.02 | 41.07 | 33.92 | 41.84 | 36.97 | 35.91 | 37.70 | 39.81 | 45.84 | 46.64 | 39.77         |
| Average | 40.44 | 42.77 | 34.01 | 43.00 | 44.10 | 43.04 | 42.55 | 48.67 | 35.86 | 40.57 | 41.50         |

Table 3. Average monthly evapotranspiration value in the Pangandaran Reservoir watershed by the Penman-Monteith method

| Month   | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | Average mm/day |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------------|
| January | 4.12  | 3.73  | 3.46  | 3.46  | 3.47  | 3.66  | 3.34  | 3.78  | 3.74  | 3.95  | 3.67         |
| February| 2.75  | 3.24  | 3.24  | 3.97  | 3.91  | 3.72  | 3.57  | 3.79  | 3.54  | 3.37  | 3.51         |
| March   | 3.35  | 3.82  | 3.25  | 3.65  | 3.90  | 3.81  | 3.54  | 3.85  | 3.27  | 3.64  | 3.61         |
| April   | 2.87  | 3.26  | 3.89  | 3.34  | 3.40  | 3.28  | 3.58  | 3.25  | 3.28  | 3.25  | 3.34         |
| May     | 3.34  | 2.95  | 3.08  | 3.19  | 3.40  | 2.98  | 3.11  | 3.41  | 3.00  | 3.31  | 3.17         |
| June    | 3.10  | 3.18  | 2.70  | 3.42  | 3.49  | 3.09  | 2.94  | 3.57  | 3.01  | 2.96  | 3.15         |
| July    | 3.78  | 3.83  | 2.69  | 3.63  | 3.71  | 3.12  | 3.28  | 3.89  | 3.31  | 3.45  | 3.47         |
| August  | 3.55  | 4.27  | 3.24  | 3.97  | 4.41  | 4.09  | 3.97  | 4.44  | 4.11  | 4.05  | 4.01         |
| September| 4.34 | 4.47  | 3.21  | 4.49  | 4.51  | 4.47  | 4.95  | 4.93  | 3.58  | 4.24  | 4.32         |
| October | 4.42  | 3.93  | 3.36  | 4.22  | 4.15  | 4.36  | 4.48  | 5.07  | 3.13  | 3.76  | 4.09         |
| November| 3.43  | 3.55  | 3.26  | 3.29  | 3.25  | 4.22  | 3.65  | 3.76  | 3.27  | 3.18  | 3.49         |
| December| 3.42  | 3.55  | 3.24  | 3.65  | 3.56  | 3.36  | 3.45  | 3.51  | 4.00  | 3.88  | 3.54         |
| Average | 3.54  | 3.65  | 3.21  | 3.69  | 3.75  | 3.68  | 3.65  | 3.94  | 3.44  | 3.59  | 3.61         |
Table 4. Results of Evaporation Calculation at Pangandaran Reservoir

| Month  | $E_o$ (mm/day) |
|--------|----------------|
| January| 1.86           |
| February| 1.71           |
| March  | 1.78           |
| April  | 1.76           |
| May    | 1.88           |
| June   | 2.05           |
| July   | 2.25           |
| August | 2.66           |
| September | 2.73       |
| October| 2.37           |
| November| 1.74          |
| December| 1.89          |

Table 5. Calculation Results of Monthly Rainfall with the Thiessen Method

| No. | Month  | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Year | Equals | Average |
|-----|--------|------|------|------|------|------|------|------|------|------|------|-------|--------|---------|
| 1   | January| 122  | 155  | 251  | 198  | 213  | 203  | 283  | 209  | 266  | 102  | 2000  | 1598   | 160     |
| 2   | February| 203  | 175  | 293  | 231  | 299  | 192  | 261  | 199  | 170  | 192  | 2216  | 222    | 222     |
| 3   | March  | 189  | 213  | 346  | 236  | 160  | 181  | 111  | 184  | 304  | 298  | 2277  | 223    | 223     |
| 4   | April  | 201  | 224  | 137  | 190  | 315  | 160  | 170  | 108  | 326  | 174  | 2005  | 201    | 201     |
| 5   | May    | 66   | 157  | 272  | 304  | 238  | 157  | 153  | 122  | 298  | 170  | 1596  | 194    | 194     |
| 6   | June   | 16   | 279  | 217  | 104  | 44   | 42   | 172  | 126  | 258  | 140  | 1598  | 160    | 160     |
| 7   | July   | 1    | 44   | 263  | 143  | 6    | 500  | 484  | 11   | 129  | 61   | 1643  | 164    | 164     |
| 8   | August | 15   | 21   | 205  | 0    | 2    | 77   | 75   | 14   | 94   | 37   | 540   | 54     | 54      |
| 9   | September| 36   | 42   | 253  | 6    | 16   | 33   | 3    | 1    | 238  | 64   | 693   | 69     | 69      |
| 10  | October| 188  | 235  | 173  | 60   | 99   | 141  | 129  | 6    | 274  | 397  | 1703  | 170    | 170     |
| 11  | November| 369  | 255  | 257  | 363  | 498  | 282  | 378  | 296  | 367  | 279  | 3343  | 334    | 334     |
| 12  | December| 229  | 286  | 130  | 338  | 484  | 335  | 427  | 326  | 235  | 179  | 3010  | 301    | 301     |
|     | Equal   | 1634 | 2088 | 2861 | 2175 | 2374 | 2504 | 2649 | 1502 | 296  | 2092 |        |        |         |
|     | Average | 136  | 174  | 238  | 181  | 198  | 209  | 221  | 133  | 25   | 174  |        |        |         |

Figure 2. Histogram of Monthly Rainfall in the Pangandaran Watershed
Natural conditions greatly affect the existence of reservoirs, especially climate, which also influences the availability of water in rivers that originate from rainwater that falls in river basins. Calculation of rainfall can be performed based on annual rainfall or reliable rainfall (80% for irrigation, 90% for domestic/municipal/industrial, or 95% for hydropower, and others).

### Table 6. Reliable Monthly Rainfall Calculation Results

|     | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|
| R80 | 122 | 175 | 160 | 137 | 122 | 44  | 6   | 2   | 3    | 60  | 257 | 190 |
| R50 | 203 | 199 | 189 | 174 | 157 | 61  | 21  | 33  | 141  | 296 | 286 |
| R80 eff | 67 | 83  | 78  | 71  | 66  | 34  | 0   | 0   | 0    | 43  | 107 | 87  |
| R50 eff | 91 | 90  | 87  | 82  | 77  | 72  | 43  | 14  | 26   | 72  | 119 | 116 |

### 3.5 Water Supply Analysis

The calculation of water availability is intended to determine the dependable flow at the study location. The mainstay discharge is the minimum discharge from a watershed (DAS) which is determined at a certain level of opportunity (P). The mainstay discharge was obtained from the analysis of the daily flow duration curve based on coherent discharge data.

#### 3.5.1 Calculation of Water Availability by the F. J. Mock Method

Discharge calculation using the F. J. Mock method was performed with the aid of Microsoft Excel. The calculation was performed by creating a water balance calculation table.

In the calculation of discharge using the F. J. Mock method, there are several parameters that need to be determined using certain restrictions.

![Figure 3. Chart of the Discharge Calibration Results for the F. J. Mock Method](image)

#### 3.5.2 Calculation of Water Availability with the NRECA Method

The NRECA (National Rural Electrical Cooperation Agency) model can be used to calculate monthly discharge from rainfall based on the water balance in the watershed.
3.6 Mainstay Discharge Analysis

Mainstay discharge is the availability of water in a river that exceeds or equals a value that is related to the percentage of time or the likelihood of it occurring. For example, for irrigation purposes, a reliable mainstay with 80% reliability is used, meaning that 80% of the discharges that occur are greater or equal to those discharges, or the irrigation system may fail once in five years. For the needs of drinking water and industry, the reliability is demanded to be higher, at 90-95%.
4. Conclusion
The main conclusions of the study on the water potential of the reservoir for supplying water resources in Pangandaran are presented below:

a. Calculation of rainfall in the watershed of the Pangandaran Reservoir resulted in a maximum average rainfall of 334 mm in November and a minimum average rainfall of 54 mm in August.

b. The calculation of discharge was carried out with the two methods of F. J. Mock and NRECA (National Rural Electrical Cooperation Agency). From both methods, the level of accuracy (correlation) of the F. J. Mock and NRECA methods is found to be 1, which indicates closeness to the observed or measured discharge. From the level of error, the F.J. Mock method is better because it has an RMS (Root-Mean-Square Error) value of 0.054 and an Average Absolute Error of 0.032, which are smaller than for the NRECA method (0.429 and 0.112, respectively). Because the F. J. Mock method is better than the NRECA Method, further calculations utilized the monthly average discharge value from the F. J. Mock method.

c. From the results of water balance analysis, for existing conditions in 2018, the mainstay discharge (Q80%) for the months of January - December is not sufficient to meet demands.

d. Based on the simulation, it was found that the potential of the water reservoir can be utilized for irrigation purposes (irrigation in the Sidamulih area extending to 100 Ha) with the reservoir floor completely covered by water.

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