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Comparison of Different Techniques about Reservoir Capacity Calculation at Sami Soydam Sandalcık Dam

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Abstract

Reservoirs are designed to provide the balance between the flow brought by the river which is high variable in time and volume of water. The storage required on a river to meet a specific demand depends basically on three factors; the magnitude and the variability of the river, the size of the demand and the degree of reliability of this demand being met. Several procedures have been proposed to estimate storage requirements. Critical period methods are those in which required reservoir capacity is equated to the difference between the water released from an initially full reservoir and the inflows for periods of low flow. In the presented study reservoir capacity-yield-reliability relationships are investigated for a single reservoir named Sami Soydam Sandalcık Dam. For this purpose, six design techniques (Mass Curve, Residual Mass Curve, Moran Probability Matrix Method, Hardison's method and Minimum flow approach) are used in determining reservoir capacity, monthly and annual mean flow data observed for a period between 1962-2013, of EIE-811 Suçatı Flow Gauging Station on Dalaman River in West Mediterranean Basin in Turkey are used as case study. For 0% probability of failure, the highest reservoir capacity resulted for methods Mass Curve, Residual Mass Curve and Minimum flow approach at the range between 814.22 to 852.74*10^6 m^3 for draft equal 60% and at the range between 2043.4 to 2145.74*10^6 m^3 for draft equal 80% by using the monthly data. On the other hand when high value of probability of failure (5% and 10%) are used for estimation, the reservoir capacity values were resulted at the range between 612.36 to 1154.74*10^6 m^3 for draft equal 60% and at the range between 1443.42 to 2165.13*10^6 m^3 for draft equal 80% for Hardison's method. By using Moran Probability Matrix method, the reservoir capacity resulted 1280*10^6 m^3 and the interval was divided to 140*10^6 m^3 for annual data 52 years.
Keywords — Critical period, Reservoir Capacity, Dalaman River, Sami Soydam Sandalcik Dam, Turkey.

1. Introduction

Freshwater sources like rivers, wells and lakes are 0.3% of the total amount of water in the world. Easily accessible and superficial research points to meet the needs of human beings due to renewable water sources have vital importance. Throughout history, mankind has generally tried to meet the need for freshwater from the rivers, and when the rivers cannot meet the demand with the natural flow quantities, they resorted primarily to the way of building the storage. The flow of a planned stream, such as energy production, storage and transportation, may show an irregular change in time. This may be different from the time needed for the amount of water required for such purposes. To correct this imbalance to some extent, it is being built storage reservoirs on rivers. Also, it is necessary to determine the optimum volume of the storage reservoirs to meet the needs, according to the flow rate which changes continuously over the time. The periods in which the natural flow of the river is greater than the demand are called wettest period, and vice versa is called dry period [1]. Reservoirs are constructed on rivers in order to respond to the water demand during periods where inflow is less than the demand. Determination of the required capacity, i.e. the operation study, for a river reservoir is done using a data set corresponding to a period of time [2]. When the sequence of flow in a month becomes important, which is the case for small reservoirs, the time interval should be reduced to a week or a day. The hydrological design of reservoirs is concerned with determining the storage capacity required to maintain a yield with a given probability of failure [3].

The design of the storage capacity of a reservoir is an old problem in water resources management. The unconstrained form of this problem poses the question: how large must the storage capacity of a reservoir be in order to provide a steady supply of water of a demanded magnitude?" [4].

The critical period, defined as the scarcity according to the demand, is also of great importance in the determination of the volume of the reservoir [5, 6]. If the reservoir is considered full at the beginning of the critical period, it will be completely empty at the end of the critical period. The accumulation volume capacity meets the requirements at the acceptable risk level [7]. As well as using synthetic data in the reservoir capacity design, the relationships between the characteristics of the reservoir, such as capacity-risk-efficiency, can be used directly [6,8]. If the risk-free operation is designed; then the concept of the ideal accumulation reservoir is involved. The ideal accumulation reservoir is neither full of water nor empty [9]. In Turkey, reservior capacity estimation methods are widely used in alot of case studies like the case study of Yenidere dam which Moran probability matrix method were used by Bacanli and Koç in 2006 [10]. Beside of that, reservoir capacity yield reliability relationships are investigated by using McMahon and minimum flow approch in Bacanli and Baran as a case study for Çine Creek in 2005 [11].

In this study, monthly and annual mean flow data observed for a period between 1962-2013, of EIE-Suçatı (811) flow gauging station on Dalaman River are used. Three probabilities of failure (0%, 5% and 10%) are considered for reservoir estimation. The percentage of the draft are taken 60% and 80% for the estimation of reservoir capacity and at the end of the study, a comparison is made between the results.

2. Material and Methods

The volume of the reservoir that can meet the need of water depends on the size and variability of the stream, the amount of need, the level of reliability in meeting the need and the mode of operation [12]. In order to have a water resources assessment, it is crucial to know the capacities of the reservoir in question. To calculate the volume of water contained in the reservoir requires estimating the shape of the reservoir as close as possible [13]. McMahon & Mein (1978) have classified a large number of different design procedures into three broad groups [14,15].

The first group is termed "critical period techniques" which rely on analysing those events when the yield exceeds demand. Examples are provided by the methods proposed by Ripple (1883) [14, 16]. This pattern is a common method used in the preliminary design stage, which is a commonly used method of adding water flows (Ripple diagram) as well as additional differences, minimum flows and successive peaks. However, it is not possible to define the risk that the reservoir volume predicted in these methods carries in the need.

The second group is based on probability matrix methods when the probabilities of the reservoir reaching a given storage condition from a previous condition are analysed [17]. The third group embraces methods which, although using conventional techniques for assessing capacity, make use of sequences of stochastically generated flow data and thus enable an estimate to be made of the error of assessing the required capacity [14].

2.1 Critical Period Techniques

The critical period (CP) is defined as the period during which a reservoir goes from a full to an empty condition without spilling in the interim. The end of CP is when the reservoir first empties; start of CP is a full reservoir [17]. The CP represents a period of extremely low flows in the data record for which storage is required in the reservoir if the shortfall between the low inflow and the water demand placed on the reservoir system is to be met [18].

2.1.1 Mass Curve Method

Ripple (1883) determined the capacity of a reservoir by the mass curve method. This method is based solely on the historical inflow record [16]. The reservoir mass curve has many useful applications in the design of a storage capacity, such as determination of reservoir capacity, operations procedure and flood routing [19]. By using the mass curve method, the reservoir capacity is calculated as the next steps: 1- For the proposed dam site, construct a mass curve of the historical stream flows (annual or monthly data can be used for this method), 2- Determine the slope of the cumulative draft line for the graphical scales, 3- Superimpose on the mass curve the cumulative draft line for the reservoir, 4- Measure the largest intercept between the mass inflow curve and the cumulative draft line. The steps for this method is very simple and widely to understood and it takes into account seasonality, autocorrelation and other flow parameters insofar as they are included in the historical flows used in the analysis steps [15].

2.1.2 Residual Mass Curve Method

McMahon and Mein (1986), defined Residual mass curve is a slightly more complicated version of the mass curve, but with a much more appropriate graphical scale for the determination of the storage size. This method used by subtracting the mean flow from each flow value of the record, the results called residual values are plotted cumulatively and the cumulative draft line is superimposed such that the draft line is tangential to each hump of the residual curve, after that measuring the largest intercept between the mass inflow curve and the draft line [15].

2.1.3 Hardison's Generalised Method

Hardison (1965) generalied Langbein's probability routeing procedure using theoretical distributions of annual flows and assuming serial correlation to be zero. He determined capacity graphically for a given chance of deficiency and variability [20].

The annual storage estimates were shown graphically for Lognormal, Normal and Weibull distributions of annual flows. The appropriate distribution depends on parameters (mean, standard deviation, coefficient of variation and coefficient of skewness) as follows: adopt a log- normal distribution if the coefficient of skewness of the logarithms of flow is algebraically greater than -0.2, adopt a normal distribution if the coefficient of skewness of the absolute flows is algebraically less than 0.2 or if the coefficient of variation of the flows is less than 0.25 and adopt a Weibull distribution if neither a log- normal nor a normal distribution is selected except when the logarithms of the flows have a negative skew coefficient greater than 1.5. After that from graphs, the reservoir capacity can be estimated by multiply the mean with reservoir capacity (as the ratio of mean annual runoff) which taken from the graphs. For estimating carryover storage, the procedure is reasonably quick, theoretically sound and suitable for all [20].

2.1.4 Minimum Flow Approach

In a minimum flow approach, drought curves are constructed from the lowest sub-sequences of flows of varying durations from the historical record e.g. 5, 10, 20, 40, etc. consecutive months. Then a draft line is superimposed such that it passed through the origin, and the critical storage is estimated by a mass curve procedure [21]. The critical storage (C_{crit}) is a given by the maximum intercept between the draft line and the drought curve as shown in Figure 1 [15].

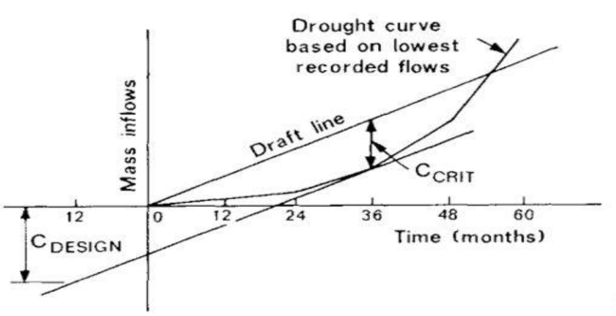

Figure 1. Reservoir capacity yield analysis by minimum flow approach.

2.1.5 Moran Probability Matrix Method

Some of the different methods used to determine the reservoir capacity give an approximate result at the end of a short calculation, while in some methods a longer result may lead to a closer result. Moran (1954) formulated the probability theory of storage systems, which has now developed into an active branch of applied probability [22]. The Moran Probability Matrix Method used in this study is not used in practice. The main reason for this is that it is more complicated than other methods without certain assumptions. However, this method gives very good results in practice [15,22].

3. Case study

The Western Mediterranean basin which is shown in Figure 2, is one of the twenty-five basins in Turkey. The precipitation area of the basin is 20.953 km^2 and average annual flow is 8.93 km^3. There are Başöz, Eşen, Dalaman, Karacay and Kargıçay streams in the basin.

Basin has seven flow gauging stations on rivers mentioned (Table 1). These stations are given in the next table [23]. The flow values of station 1962-2013 are available. In the study, it is aimed to determine the necessary storage volume with different methods in the literature. Evaporation losses are not taken into consideration since the reservoir capacities to be obtained by different methods are intended to be compared. Table 2 shows the statistical data for EIE-811 Suçatı Flow Gauging Station.

Table 1. Number and names of stations in the Western Mediterranean basin.

Number	Stream	Name
808	Başgöz Çayı	Çatallar
809	Eşen Çayı	Kavaklıdere
811	Dalaman Çayı	Suçatı
812	Dalaman Çayı	Akköprü
815	Eşen Çayı	Kınık
818	Karaçay	Kayadibi
823	Kargı Çayı	Yanıklar

Table 2. The statistical data for EIE-811 Suçatı Flow Gauging Station.

Statistics	Monthly	Annually
Number	624	52
Mean (x_{mean})	36.45*10^6 m^3	437.4*10^6 m^3
Standard deviation (Sx)	40.09*10^6 m^3	238.38*10^6 m^3
Coefficient of variation (Cv)	1.1	0.545
Coefficient of skewness (Cs)	1.955	0.508

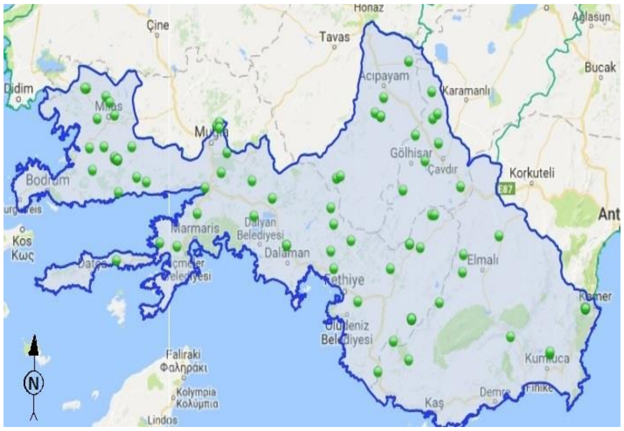

Figure 2. The study zone map at the southern west side of Turkey.

4. Applications

The preliminary design methods which used to determine the reservoir capacity at this study are critical period methods. Some critical period methods have been preferred in reservoir volume calculations as they are used more in practice. A reservoir with sufficient capacity will be discharged at the end of the critical period when it is completely full at the beginning of the critical period.

Three probabilities of failure (0%, 5% and 10%) are used for reservoir estimation. The percentage of the draft didn't identify at the official reports because of that the percentage of the draft in this paper were taken 60% and 80% for the estimation of reservoir capacity and at the end of the study, a comparison is made between the results.

4.1 Mass Curve Method

At this paper, the mass curve method was used for reservoir capacity estimation. The interval from 1962 to 2013 (52 years = 624 months) are used at calculations for this method to get the maximum available capacity to this reservoir as shown in Figures 3 and 4.

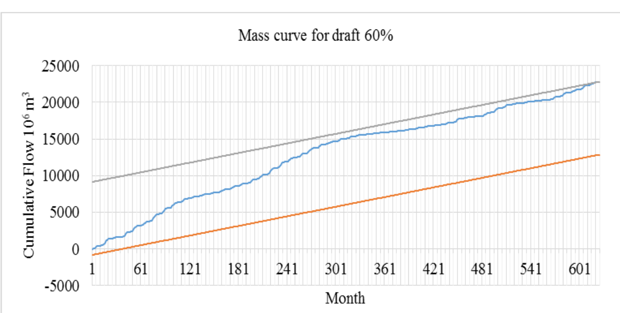

Figure 3. Reservoir capacity yield analysis by the mass curve for draft equal 60%.

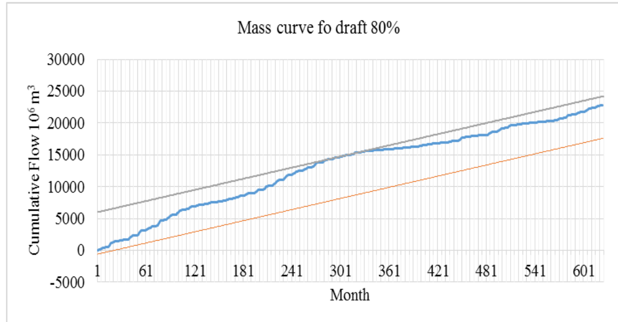

Figure 4. Reservoir capacity yield analysis by the mass curve for draft equal 80%.

The monthly data is used for reservoir estimation. For draft 60%, the slope of the draft line is 21.87 x10^6 m^3/month, taken as 60% of the mean monthly flow 36.45 x10^6 m^3. The required storage resulted 840.53 x10^6 m^3. On the other hand for draft 80%, the slope of the draft line is 29.16x10^6 m^3/month, taken as 80% of the mean monthly flow 36.45 x10^6 m^3. The required storage resulted 2043.4 x10^6 m^3.

4.2 Residual Mass Curve

The reservoir storage capacity is calculated for monthly flow at the interval from 1962 to 2013. At Residual mass curve method, draft 60 and 80% were used to estimate reservoir capacity with monthly mean 36.45 x10^{6}m^3/month. The slope of the draft line is 21.87 x10^{6}m^3/month for draft 60% and for draft 80% is 29.16 x10^{6}m^3/month. Figure 5 and 6 show the storage capacity of a reservoir with draft 60% and draft 80%.

The monthly data (624 months) is used for reservoir estimation. For draft 60%, the required storage resulted 858.23 x10^6 m^3. On the other hand for draft 80%, the required storage resulted 2071.92 x10^6 m^3.

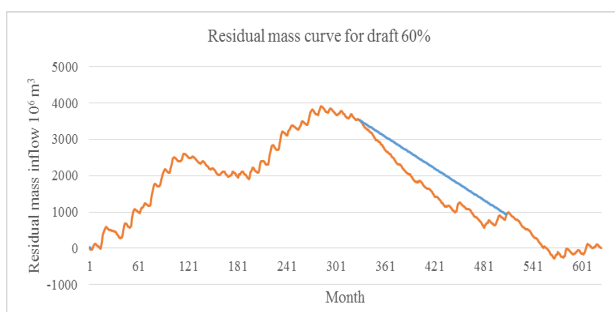

Figure 5. Residual mass curve method for determining the storage capacity of a reservoir with draft 60%.

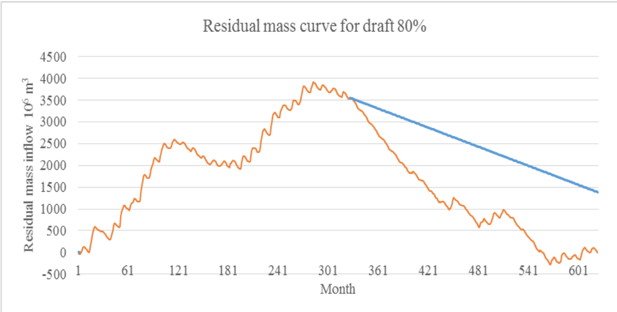

Figure 6. Residual mass curve method for determining the storage capacity of a reservoir with draft 80%.

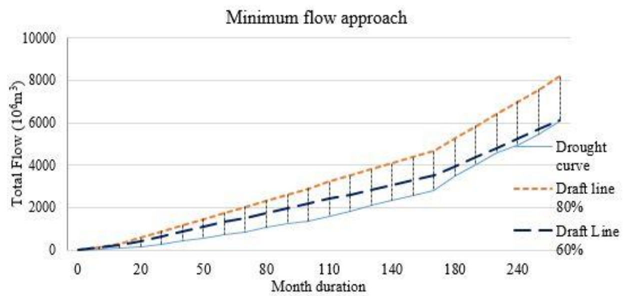

Figure 7. Minimum flow approach for determining the storage capacity of a reservoir with various drafts.

4.3 Hardison's Generalised Method

According to the results in Table 5, the reservoir capacity for draft 60% probability of failure 5% resulted in 949.16 x10^6 m^3 and for probability of failure 10% resulted in 612.36 x10^6 m^3. On the other hand, for draft 80% probability of failure 5% resulted in 2152.01 x10^6 m^3 and for probability of failure 10% resulted in 1421.55 x10^6 m^3.

Table 3. Storage capacity required by Hardison's generalised method.

Draft %	Probability of failure %	Weibull reservoir capacity as ratio	C (10^6 m^3)	C $_{adjust}$ (10^6 m^3)
60	5	0.8	306.18	949.16
	10	0.5	218.7	612.36
80	5	1.5	656.1	2152.01
	10	1	437.4	1421.55

Reservoir capacity for Suçatı Station has to be adjusted to compensate for the annual autocorrelation is obtained from appendix A (Fig. A-3) McMahon and Mein (1986), this capacity is represented at table C adjust.

4.4 Minimum Flow Approach

The reservoir storage capacity is calculated for monthly variation flow for 624 months with draft 60% and 80%, for 60% draft the mean resulted 13646.9 x10^6 m^3/month and for 80% draft the mean resulted 18195.872 x10^6 m^3/month. Reservoir capacity in draft 60% resulted in 814.22 x10^6 m^3 but for the draft, 80% resulted in 2145.74 x10^6 m^3 as shown in Table 3 and 4. Figure 7 shows both of the results for 60% draft and 80% draft.

Table 4. Minimum flow estimation table for the draft 60%.

Duration (months)	**Lowest Total Flow for that period (10^6 m^3)**	**Draft 60% (10^6 m^3)**	**Reservoir Capacity (10^6 m^3)**
5	11.42	109.35	97.93
10	75.7	218.7	143
20	179.83	437.4	257.57
40	433.1	874.8	441.7
60	709.55	1312.2	602.65
80	1047.56	1749.6	702.04
100	1382.41	2187	804.59
110	1591.48	2405.7	**814.22**
120	1821.71	2624.4	802.69
180	3468.25	3936.6	468.35
200	3997.83	4374	376.17
240	4926.48	5248.8	322.32
260	5435.87	5686.2	250.33

Table 5. Minimum flow estimation table for the draft 80%.

Duration (months)	**Lowest Total Flow for that period (10^6 m^3)**	**Draft 80% (10^6 m^3)**	**Reservoir Capacity (10^6 m^3)**
5	11.42	145.8	134.38
10	75.7	291.6	215.9
20	179.83	583.2	403.37
40	433.1	1166.4	733.3
80	1047.56	2332.8	1285.24
100	1382.41	2916.01	1533.6
110	1591.48	3207.61	1616.13
120	1821.71	3499.21	1677.5
180	3468.25	5248.81	1780.56
200	3997.83	5832.01	1834.18
240	4926.48	6998.41	2071.93
260	5435.87	7581.61	**2145.74**
280	6109.26	8164.81	2055.55

4.5 Moran Probability Matrix Method

By using Moran Probability Matrix method and assuming the reservoir capacity equal 1280 x 10^6 m^3, the interval was divided to 140 x 10^6 m^3 for annual data 52 years. With make matrix 8 x 8 and start iteration till result be to zero the final matrix and summation for 8 rows at every column equal one as shown in the Table 6.

Table 6. Final matrix after a high number of iterations for Moran's method.

Units	0	1	2	3	4	5	6	7	8
0	0.71	0.52	0.33	0.06	0	0	0	0	0
1	0.13	0.19	0.19	0.27	0.06	0	0	0	0
2	0.10	0.13	0.19	0.19	0.27	0.06	0	0	0
3	0.06	0.10	0.13	0.19	0.19	0.27	0.06	0	0
4	0.00	0.06	0.10	0.13	0.19	0.19	0.27	0.06	0
5	0.00	0.00	0.06	0.10	0.13	0.19	0.19	0.27	0.06
6	0	0.00	0.00	0.06	0.10	0.13	0.19	0.19	0.27
7	0	0	0.00	0.00	0.06	0.10	0.13	0.19	0.19
8	0	0	0	0.00	0.00	0.06	0.15	0.29	0.48
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 7 shows the final matrix iteration by using Moran Probability Matrix method for reservoir capicity estimation.

Table 7. Final result to matrix iterations for Moran's method.

0.053
0.014
0.011
0.008
0.004
0.002
0
0
0

4.6 Reservoir Capacity Results

The final results by using Different Methods for EIE-811 Suçatı Flow Gauging Station data are represented at Table 8, which shows that the probabilities of failure and draft percentages which used at calculation procedures.

Table 8. Reservoir Capacity results by Different Methods.

Method	Probability of failure	Storage estimate (10^6 m^3)	
		Draft 60%	Draft 80%
Mass Curve	0%	840.53	2043.4
Residual Mass Curve		858.23	2071.92
Minimum flow approach		814.22	2145.74
Moran Probability Matrix	5.3%	1280	
Hardison's method	5%	949.16	2152.01
Hardison's method	10%	612.36	1421.55

According to the offical documents the reservoir capacity is estimated with value equal 545.71 hm^3 (545.71*10^6 m^3) which less than the estimated results in Table 8. This value mean that the percentage of Draft was less than 60%.

5. Conclusion

The effect of the method selection on the reservoir volume to be determined is clearly visible, from Table 8, which shows the reservoir volumes obtained for different methods. As a result of the evaluation of the applied methods it is possible to make the following comments:

- Six design techniques (Mass Curve, Residual Mass Curve, Moran Probability Matrix Method, Hardison's method and Minimum flow approach) are used in determining reservoir capacity, monthly and annual mean flow data observed for a period between 1962-2013, of EIE-811 Suçatı Flow Gauging Station on Dalaman River in West Mediterranean Basin in Turkey are used as case study.
- Three probabilities of failure (0%, 5% and 10%) and two percentage drafts (60% and 80%) are used for reservoir estimation. For 5% and 10% probability of failure three methods (Hardison's method and Moran Probability Matrix Method) are used to discover the range of difference between the two probabilities of failure. For 0% probability of failure the highest reservoir capacity resulted for methods Mass Curve, Residual Mass Curve and Minimum flow approach at the range between 814.22 to 852.74 *10^6 m^3 for draft equal 60% and at the range between 2043.4 to 2145.74 *10^6 m^3 for draft equal 80% by using the monthly data. On the other hand, when a high value of probability of failure (5% and 10%) are used for estimation, the reservoir capacity values were resulted lower than the other methods which estimated with a probability of failure equal zero.
- There is no relationship between storage volume and risk in critical period approaches such as minimum flow method, which changes the volume of the reservoir over time. Large volumes are usually estimated by these methods, for example, because evaporation losses cannot be taken into consideration since the reservoir is initially assumed to be full.
- Choosing a method with acceptable assumptions for the distribution of the data array will increase the reliability of the results.

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