Application of Capacity-Yield Procedures to Dokan Reservoir

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Abstract

In the present study ,two procedures of capacity-yield are applied to estimate the reliability of Dokan reservoir. These procedures are the probability matrix(Gould) procedure, and the behavior analysis. Vulnerability, and resilience, are also calculated in the last procedure . The results of this study indicate that to obtain reliability of 95% , the yield is approximately 83% of mean monthly flow which corresponds to a vulnerability of 426×10^6 m^3 and a resilience of 9 month. However, in order to decrease vulnerability and resilience yield must be decreased.

Key Words: capacity-yield, reliability of reservoir, reservoir probability of failure.

الخلاصة

في هذه الدراسة طبقت طريقتان من طرق السعة–الإطلاق capacity-yield methods لتخمين اعتمادية خزان دوكان. هذه الطرق هي طريقة جولد probability matrix(Gould) procedure و طريقة تحليل السلوك behavior analysis.المرونة(resilience)والضعف(vulnerability) حسبا اعتمادا على الطريقة الأخيرة.أشارت النتائج إلى إن الحصول على اعتمادية (reliability) مقبولة(95%) يحتاج إلى تشغيل السد بإطلاق يساوي (83%) من المعدل الشهري للتصاريف الداخلة للسد مما ينتج ضعف مقداره (426×10^6 m^3) ومرونة تساوي (9) أشهر. هذه القيم لكل من المرونة والضعف تعتبر عالية على الرغم من أنها تعطي اعتمادية مقبولة وللحصول على قيم اقل للمرونة والضعف يجب تقليل الإطلاق من السد.

Introduction

One of the most important aspects of the water resources system is water regulation by reservoir. There are two aspects in building reservoirs, the capacity and the operation . Reservoir can fail structurally or operationally. The present study concerns with the operational failure which takes place when the reservoir cannot supply a specified demand.There is no limitation on the probability of failure but many researchers considered the (5%) probability of failure to be an acceptable limitation (**Harris,1965**and **McMahon et.al, 1972 ,quoted in Al-Fatlawi,2003**). **Madhloom (2000)** applied the behavior and Gould’s procedures to estimate the probability of failure for Al-Adhaim reservoir. **Hussein, (2005)** applied the Moran steady-state method of capacity-yield analysis to estimate the probability of failure for Adhaim reservoir.

In this study we applied the behavior analysis to Dokan reservoir for evaluation the reliability, vulnerability, and resilience, where Gould’s procedure is used for evaluation reliability **.**

Inflow to Dokan Reservoir

The Dokan dam is located at about 60km from the north west of Al-Sulaimania town and at about 300 km from Karkok governorate. The main purposes of the Dokan project are to store and regulate the abundant water of the Lesser Zab River, a tributary of the Tigres River, by creating a large scale reservoir, to supply irrigation water required in the area downstream of the dam, and to control discharges downstream by impounding and regulating floods. In addition to the above mentioned purposes, the discharge and head obtained by the dam are to be utilized for power generation for effective use of hydraulic energy, thereby making this a multi-purpose, for irrigation, flood control, and power generation.

Evaporation from the Reservoir

Evaporation from Dokan reservoir, according to observation records at the vicinity of the project area, is estimated to be an annual total of 1567 mm, which shown in table(1) below:

Table 1: Dokan Reservoir Monthly Free Surface Evaporation
(Planning Report on Dokan Dam Project, 2007)

Month	Jan.	Feb.	Mar.	Apr.	May	Jun	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Evapo. (mm)	20	40	56	85	175	232	280	268	204	132	65	10	1567

Elevation - Area - Storage Relationships

Many relationships were derived between the elevation, area, and storage of Iraqi reservoirs system by several past or present researchers, in order to estimate the volume of the precipitation and evaporation. One of these studies is due to,(**Muhsun 2002 ,quoted in Abdul-Bari 2006)**. This researcher suggested the following model to represent the relationship between the elevation (or the area) and the storage of all the reservoirs in Iraq, with excellent value of correlation coefficient:

$$EA = a + b \times S + c \times S^{d} \qquad \text{...(1)}$$

where:
EA = either the surface area of the reservoir in (km^2) or the water level in (m.a.s.l),
S = the reservoir storage in (10^9 m^3), and
a, b, c, d = coefficients, grapher software was used to estimate these values.

Figures (1)and(2) show the relationships of elevation-storage and area-storage of the reservoir, respectively. The topographic features of Dokan reservoir are illustrated in table (2).

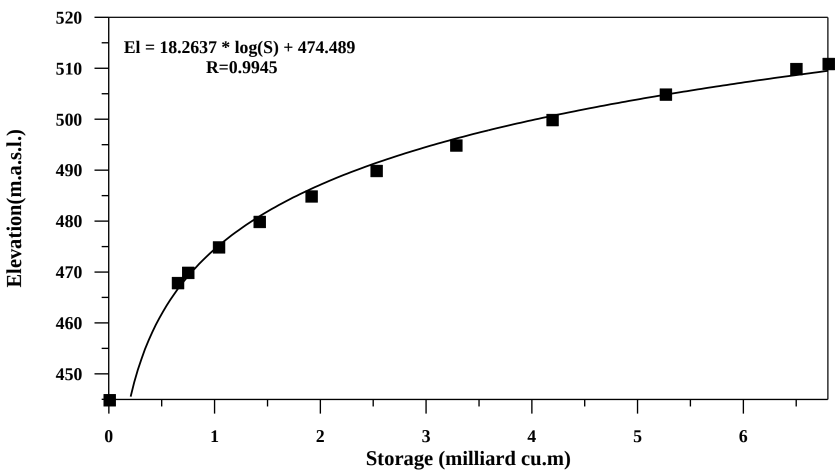

Figure 1: Elevation -Storage Relationship of Dokan Reservoir.

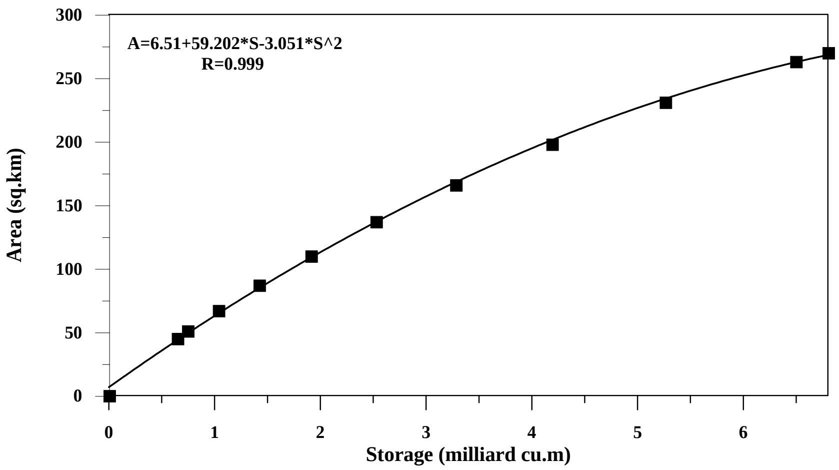

Figure 2: Area -Storage Relationship of Dokan Reservoir

Table 2: Topographic Features of Dokan Reservoir
(Planning Report on Dokan Dam Project, 2007)

Elevation (m)	Capacity($10^9 m^3$)	Area(km2)
458	0	0
468	0,646	45
470	0,742	51
475	1,034	67
480	1,418	87
485	1,909	110
490	2,524	137
495	3,279	166
500	4,188	198
505	5,260	231
510	6,495	263
511	6,800	270

Capacity – Yield Procedures

Estimation of Statistical Parameters

Statistical parameters have a major influence on the sequence of generated data and on the estimated measurements of risk. Hence, it is important to specify the statistical parameters main statistics (average, standard deviation, variation, skewness, and serial correlation coefficient) are summarized in table(3).This table shows that the mean monthly runoff varied between 54.78 m^3/s ,in September to 570.89 m^3/sec. ,in April. High monthly correlations are observed except for Februarys ,March and April with correlation coefficients less than 0.5. The monthly and annual inflows are skewed to the right, i.e., monthly and annual inflows have a positive skewness.

Table 3: Annual and Monthly Statistical Parameters.

Months	Mean (cumecs)	Sd (cumecs)	Variation Coefficient	Skewness Coefficient	Lag-12 Correlation Coefficient
Jan.	192.45	105.626	0.549	1.061	0.622
Feb.	309.11	155.011	0.501	0.903	0.422
Mar.	461.15	312.981	0.677	2.031	0.358
Apr.	570.89	724.424	1.269	5.962	0.256
May	295.71	159.682	0.540	1.283	0.909
Jun	136.10	67.801	0.498	0.971	0.836
July	76.18	38.499	0.505	1.198	0.751
Aug.	61.27	37.55	0.613	3.252	0.771
Sep.	54.78	24.059	0.44	0.762	0.749
Oct.	58.89	22.776	0.387	0.2414	0.476
Nov.	102.05	63.91	0.626	1.889	0.449
Dec.	152.58	110.36	0.723	2.269	0.674
Annual	2472.16	1261.49	0.51	1.896	0.171

Estimation of Reservoir Reliability by the Behaviour Procedure

Behavior analysis is one type of the critical period procedures. The change in storage content of Dokan reservoir are calculated by using a mass equation, which is given as **(Mein and McMahon, 1986):**

$$S_{t+1} = S_t + Q_t - D_t - \Delta E_t - L_t \quad \text{...(2)}$$

Subject to $0 \leq S_{t+1} \leq C$

Where:

S_{t+1}=storage at the beginning of the t+1th period,
S_t= storage at the beginning of the tth period,
Q_t=inflow during the tth period(including rainfall),
D_t= yield during the tth period,
ΔE_t=net evaporation loss from reservoir during the tth period,
L_t=other losses, and
C=active storage capacity.

Equation(2) is applied to historical inflow sequence month by month, thereby updating the reservoir level for over month simulation. The monthly yield is assumed as a percentage of the mean inflow. The monthly evaporation is taken in to account and depends on the surface area of water in the reservoir. Other losses are comparatively small and are usually neglected.

Mein and McMahon (1986) gave a detailed procedure to calculate step by step the probability of failure. These steps can be summarized as follows:

1. Assume the reservoir is initially full (S_0=C),
2. Apply equation(2)month by month on the historical monthly flows,
   if (S_{t+1})>(C),then (S_{t+1})=(C),and the excess water will be considered as overflow, on the other hand,
   if (S_{t+1})≤(S_{min}),then the reservoir is considered to be empty,
3. Plot(S_{t+1}) against time on a yearly time scale figure(3),

4. Compute the probability of failure by using the following equation:

   $$P_e = \frac{N_e}{N} \quad \text{……………………………………………………………..(3)}$$

   Where:
   P_e=probability of failure,
   N_e=the number of time units during which the reservoir is empty,
   N= the total number of time units in the stream flow sequence.

5. Compute the reliability(R_e) by using the following equation:

   $$R_e = 1 - P_e \quad \text{……………………………………………………………..(4)}$$

6. The vulnerability of the reservoir is computed by choosing the minimum negative storage of (S_{t+1}).The maximum number of consecutive months of failure that occur (zero storage) represent the resilience.

Figure (3) shows the behavior diagram for Dokan reservoir using historical data and yield equal to 83% of the mean flow. It can be seen from the figure that the system could be operated throughout the first eight years without difficulty when the required storage and probability of failure of the reservoir are (6800 * 10^6 m^3) and (4.85%), respectively.

According to the definition of critical period which is the period during which a reservoir goes from a full condition to an empty condition without spilling during the interval selected. The start of a critical period is when the reservoir full, the end of it is when the reservoir first empties (**Mien and McMahon,1978**).Thus, only one failure can occur during a critical period. Figure(3) shown two critical period occurring during the available historical data.

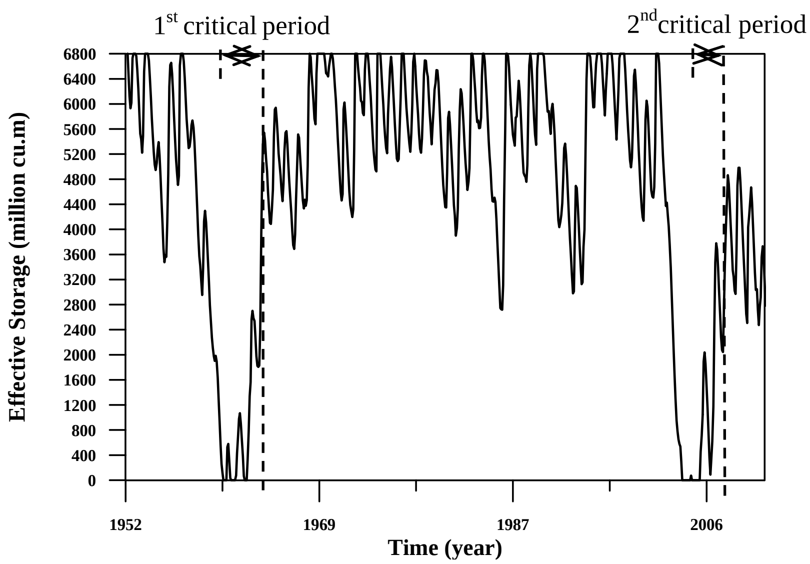

Figure 3: Behavior Diagram for Dokan Reservoir (Yield =83%).

Estimation of Reservoir Reliability by Gould's Procedure

The Gould procedure requires a computer for efficient solution; therefore the computer program is constructed. The steps of reliability estimation by this procedure are described in the following sub-items:

Input Data

The input data are monthly evaporation, inflow data, and monthly abstraction data based on information on a real extent of irrigation.

Number of Zones

An initial step one has to take in applying this method is to decide the number of zones. **Teoh (1977)** stated that the number of required zones depends on the coefficient of variation for annual flow, Cv **(Srikanthan and McMahon, 1985a)**. For Dokan reservoir, Cv is equal to (0.53), therefore; (20) zones are used as shown in figure (4).The volume of each zone including the top and bottom ones is given from the following equation:

$$W = \frac{C}{K-2} \quad \ldots\ldots(5)$$

Where:
W=volume of each zone,
K=number of zones.

The full and empty reservoir zones signify that storage is at capacity and minimum pool levels, respectively.

Computation of Transition Probability Matrix

The continuity equation (Eq.2) is applied on a monthly basis for reservoir for each of the years of data available and tally the number of times the reservoir end up in each of the zones. This is done for each starting zone (0, w/2, 3w/2, 5w/2, …….., C).

Table (4) shows the transition matrix of (20x20) for the historical data and 83% of mean flow as a demand from the reservoir. For illustration, if the reservoir was empty at the beginning of the year, the probability of storage content is (0.055) at the end of the year being in state (8), also the reservoir has a probability of (0.073) for being in zone (9) of the end of the year if the reservoir was at zone (9) at the beginning of this year, and so on.

The Steady State Probability Matrix

The steady state probability gives the long –term or the steady of the reservoir contents being in any of the (k) states . The steady state matrix is given in table (5).

Estimation of Reservoir Reliability

Reservoir reliability is estimated by using equation (3). The overall probability of failure is calculated by using the following equation :

$$P_e = \sum_{i=1}^{k} P_i \times Y_i \quad \ldots\ldots(6)$$

Where:
P_i= steady state probability that the reservoir contents at state i,and
Y_i= conditional probability of failure during any month of year.

Table (6) is obtained the probability of failure for Dokan reservoir, is about (4.35%) at 83% yield, which is based on historical data.

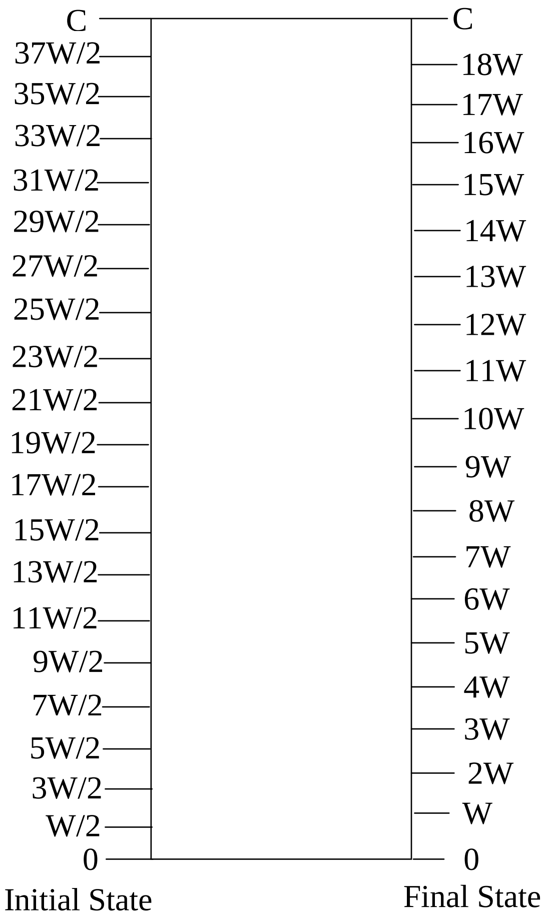

Figure 4: Dokan Reservoir Divided into 20 Zones.

Table 6: Calculation of Probability of Failure for Dokan Reservoir by Gould's Procedure, Draft=83%.

Zone	Steady State Probability of Failure (P_i)	The Conditional Probability of Failure (Y_i)	Overall Probability of Failure(%)
0	0.0537	0.3485	0.0187
1	0.0271	0.3424	0.0093
2	0.0349	0.2015	0.0070
3	0.0349	0.0970	0.0034
4	0.0277	0.0561	0.0016
5	0.0314	0.0364	0.0011
6	0.0449	0.0242	0.0011
7	0.0395	0.0167	0.0007
8	0.0371	0.0091	0.0003
9	0.0389	0.0061	0.0002
10	0.0529	0.0015	0.0001
11	0.0470	0.0000	0.0000
12	0.0497	0.0000	0.0000
13	0.0526	0.0000	0.0000
14	0.0640	0.0000	0.0000
15	0.0967	0.0000	0.0000
16	0.1405	0.0000	0.0000
17	0.1076	0.0000	0.0000
18	0.0181	0.0000	0.0000
19	0.0009	0.0000	0.0000
Probability of Failure (Pe)			$\sum$=0.0435

Reliability, Vulnerability and Resilience – Yield Relationships

These relationships are important for examining the policy of reservoir operation and give preliminary estimations of reliability, vulnerability and resilience for various demand downstream the Dokan dam. Figures (5),(6) ,(7),and (8) show these relationships and the empirical equation suggested. These relationships have a correlation factor of 0.9999, 0.9992, 0.9673 , and 0.992 for reliability, vulnerability and resilience using behavior analysis and reliability using Gould's procedure ,respectively.

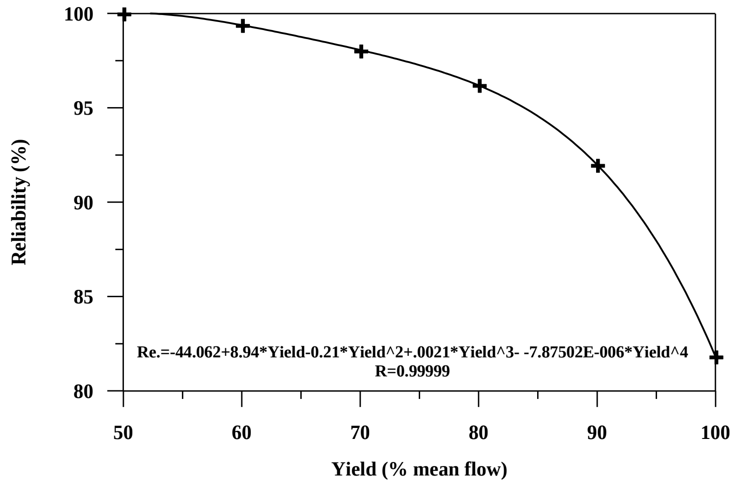

Figure 5: Reliability – Yield Relationship by Behavior Analysis.

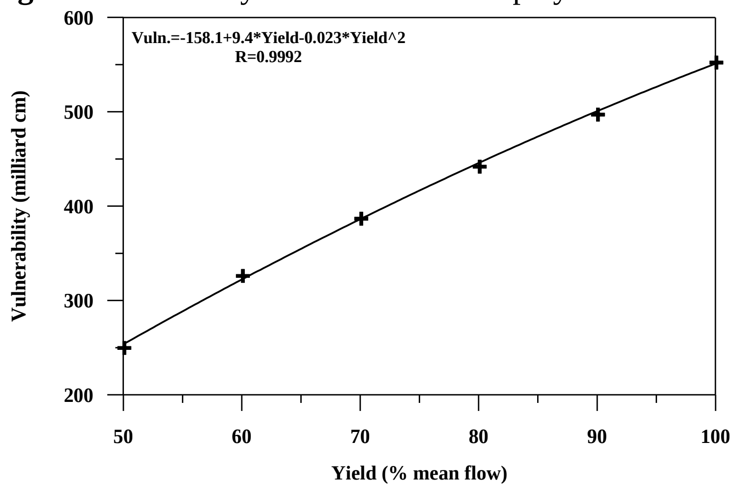

Figure 6:Vulnerability – Yield Relationship by Behavior Analysis.

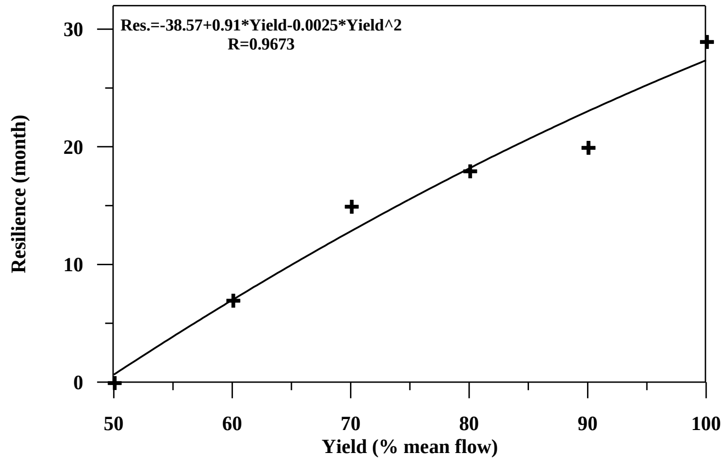

Figure 7:Resilience – Yield Relationship by Behavior Analysis.

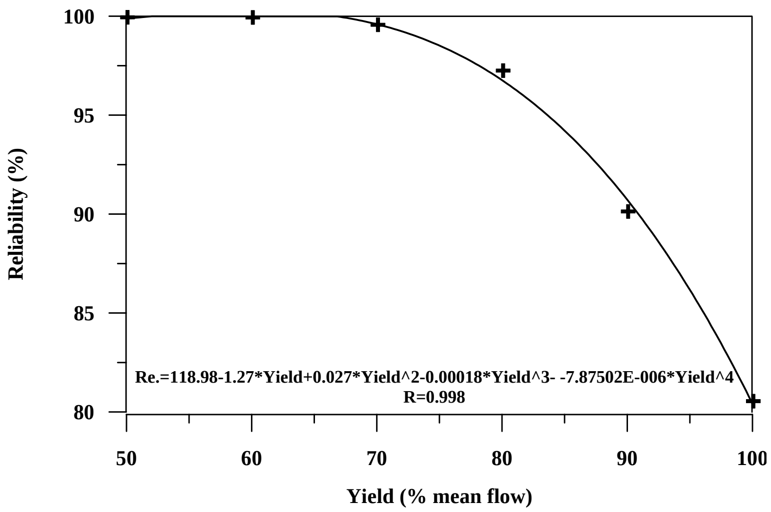

Figure 8: Reliability – Yield Relationship by Gould procedure.

Conclusions

For this study , the following conclusions are deduced:

1. For an eefective storage capacity of $6.8\times10^2 m^3$ with reliability of 95% , the yield is approximately 83% of mean monthly flow which corresponds to a vulnerability of 426×10^6 and a reslience of 9 month.However, in order to decrease resilience and vulnerability yield must be decreased.

2. In Gould procedure, the estimation of Dokan reservoir reliability is slightly affected by the number of zones that the reservoir capacity will divide into.

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