



Evaluation of The Reliability , Vulnerability, and resilience for Haditha Reservoir

A Thesis

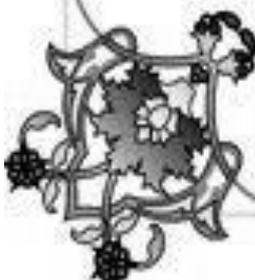
Submitted to the College of Engineering
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fulfillment of the requirements
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of Science in Civil
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By

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تقييم الأتمادية، الضعف والمرونة لخزان سد حديثه

رسالة

مقدمة إلى جامعة بابل - كلية الهندسة
كجزء من متطلبات نيل شهادة ماجستير
علوم في الهندسة المدنية

من قبل

ثائر جبار مزهر الفتلاوي

بإشراف

د.صلاح توفيق البزاز

تشرين الأول ٢٠٠٣

شعبان ١٤٢٤

Abstract

The reliability-vulnerability- and resilience-yield relationships are an important in resolving reservoir operation problems which are complicated because of inflow and yield vary from month to month. The decision maker needs to know these relationships to determine optimum operation rules. The present study examines this problem and develops the relationship between risk measurements and yield for Haditha reservoir.

Behaviour analysis is used for evaluating The reliability,vulnerability and resilience for Haditha reservoir, where Gould's procedure is used for evaluating reliability.

Data generation techniques are also used for estimating the above three measures of risk. The synthetic data is generated by using five approaches, namely, Thomas-Fiering model with log-transformation, Thomas-Fiering model with Box-Cox transformations,two-tier model,modified two-tier model and modified fragment model. These approaches are tested. The modified two-tier model and the two-tier model are found to be the best for representing the Haditha dam inflow. Then, a comparison between the results obtained by historical and generated data is made.

Depending on the results of historical and generated data, imperial equations are suggested for The reliability,vulnerability and resilience-yield relationship for using in the preliminary estimation.

The results of this study indicate that for obtaining 90% reliability the reservoir must be operated with a release of 43% of the mean monthly flow which corresponds to a vulnerability of $1.2 \times 10^9 \text{ m}^3$ and a resilience of (10-12) months. These vulnerability and resilience values are too high so that release must be decreased if lower values are preferred.

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Tha'ir Al-Fatlawi

Examining Committee Certificate

We certify that we have read this thesis titled *Evaluation The Reliability, Vulnerability, and Resilience for Haditha reservoir*, and as an examining committee, examined the student *Mr. Tha'ir Jabbar Mizhir Al-Fatlawi* in its contents and in what is connected with it, and that in our opinion it meets the standard of a thesis for the degree of *Master of Science in Civil Engineering*.

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Certification

I certify that this thesis titled “*Evaluation The Reliability, Vulnerability, and Resilience for Haditha reservoir*”, was prepared by “*Tha’ir Jabbar Mizhir Al-Fatlawi*” under my supervision at Babylon University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

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Introduction

1.1 General

As water resources are limited, there is a continuous construct reservoirs. Reservoirs are considered to be important water resources especially for drought regions.

However, reservoirs can fail structuraly or operationally. The present study concerns with the operational failure which takes place when the reservoir can not supply a specified demand .

There is no adoubt that chance has a major effect on the selection of reservoir size as well as on the reservoir operation because of the stochastic nature of inflow. This is the problem that worried the decision makers and water resources engineers. The reliability of reservoir, which is the probability that reservoir will not fail, gives an indication about the future behaviour of the reservoir and how much the decision maker can depend on his reservoir to supply the sufficient water for the served regions.

The engineers have aimed at reducing the probability of failure (i.e. increasing reliability) to the lowest value but this needs an increase of the dam height which will increase exponentially the cost of building the reservoir (**Ragab et .al**, ۲۰۰۱). There is no limitation on the probability of failure but many researchers considered the (۵%) probability of failure to be an acceptable limitation (**Harris**, ۱۹۶۵) and (**McMahon et .al**, ۱۹۷۲).



Although reliability is a central concern in the sense of achieving the long-term safe yield, reliability has at least two unacceptable assumptions (Moy et al., 1986) :

1. All failures are seemingly counted as the same; there is no differentiation between failures by magnitude and consequence.
2. Failures are treated as though their effect are independent of one another when in fact back to back shortages may be of greater consequence than are shortage periods separated by periods of adequate supply.

For covering the reservoir risk, two additional measures of risk introduced, namely, vulnerability and resilience which are the maximum shortage during the analysis of the reservoir and the maximum consecutive periods of shortage during a record, respectively.

In the present study, two reservoir capacity-yield procedures are used for estimation the reliability of Haditha reservoir in Iraq. These procedures are the behaviour procedure and Gould's procedure. These two procedures are applied because they resulted in the lowest bias and standard error of results and therefore they are more accurate (Carty and Cunnane, 1990) [quoted from Rugumayo, 2001]. The behaviour procedure is also used for estimation of the vulnerability and resilience for the reservoir . The results of the above two procedures are compared and then tested by using the generated data from five approaches of data generation . The adequency of these approaches are examined from the view point of the ability to represent the historical properties of the inflow



and the ability to give an accurate estimation for reliability, vulnerability and resilience of the reservoir.

1.2 Objectives of the research

The main objectives of the research are :

1. Evaluation the reliability, vulnerability and resilience of Haditha reservoir by using both historical and generated data and examining a suitable data generation model for Haditha reservoir, the examination takes into account the reliability, vulnerability and resilience estimate depending on the same model .
2. Suggestion a preliminary empirical equation for reliability, vulnerability, resilience-yield relationships depending on the results of the objective no. 1 .

1.3 Presentation of the thesis

To meet the above mentioned objectives, the present research is divided into the following tasks:

1. General introduction to the estimation of reliability, vulnerability and resilience is presented in chapter one .
2. A review of literature concerning the subjects involved is presented in chapter two .
3. Chapter three deals with the methods used for estimation the reliability, vulnerability and resilience of the reservoir.
4. Chapter four describes the data generation techniques used in this research.
5. Chapter five explains the general characteristics for Haditha dam as well as the application of reservoir



capacity yield procedures to the reservoir, this chapter also explains the application of data generation models and the verification of each model.

7. Conclusions abstracted from the research and recommendations suggested for further work are included in chapter six .



R

Review of Literature

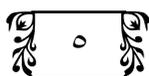
۲.۱ Reliability, Vulnerability and Resilience

Increasing competition for a water among urban, agricultural and environmental water users and the relative absence of inexpensive water resources, has led to the need to reliability and reduce the cost of water supplies. Hence reservoirs operation, drought, and probability of failure have been discussed by several researchers around the world.

Storage probability theory and related methods have been introduced by Moran (۱۹۵۹) and Gould (۱۹۶۱) [quoted from Al-Shareef, ۱۹۹۶]. Gould's method is a modified Moran model which takes in its account seasonality and serial correlation by computing the transition matrix for an annual time period which will be more detailed in chapter (۳), however, this procedure does not overcome Moran's assumptions of serially independent annual inflow.

Harris (۱۹۶۵) applied both Moran's steady state probability method and Gould's probability routing method for determining the probability of failure for Alwen reservoir in Wales. The historical inflow to Alwen reservoir was assumed to be approximately normal, a longer length of data was recommended for overcoming the variability of reservoir inflow.

McMohan et al. (۱۹۷۳) applied the behaviour and Gould approaches to six Australian rivers. A representative sequences of monthly flows were generated by Thomas-Fiering model and used for examining the two approaches. Large variation were exhibited in storage estimate by both methods,





also the behaviour estimates were found to be affected by the initial storage conditions and inadequacies in Thomas-Fiering model were noted.

Phatarfod(1970) examined the problem of the reservoir-size-reliability-draft relationship. Two main problems in reservoir theory were considered where statistics and probability were involved one is the problem of formulating a model for inflows from historical data, the other was the storage size. An analytical method of storage problem was presented by considering only non-seasonable model, which means that the inflows and releases are made on an annual basis. This assumption is a non-realistic one because of that the inflows and releases are made monthly.

Doran(1970) chose the γ -parameter lognormal distribution to test the efficiency of the divided interval technique and justified his choice that the transformed variation distributions are commonly used in hydrology. Then ten states were proposed to be sufficient to obtain an accurate estimate of reservoir capacity.

Teoh(1977)[quoted from Madhloom, 2000] analyzed ten streams with coefficient of variation between 0.19 and 1.79. The following general rule, **Table(2.1)**, was suggested for the selection of states for analyses:

Table(2.1):Teoh's suggestion for the number of states depend on coefficient of

Coefficient of variation (cv)	Number of states
$cv < 0.5$	1.
$0.5 \leq cv < 1.0$	2.
$1.0 \leq cv \leq 1.5$	3.
$cv \geq 1.5$	4.



Mitchel(1978) suggested a method of estimating the approximate yield of multiple dams using Moran model. The concept of hydrologically similar was considered for catchment areas, simple rules were derived for the computation of the approximate combined yield of two or more dams in series on a river system. These rules involve the transformation of the variable rates of inflow and draw off that are found in practice into their constant equivalents which can easily be analysed with the basic Moran dam model.

Simonovic and Mariano(1980) presented the application of reliability programming techniques to a multipurpose reservoir. This approach, in allowing reliabilities to be considered as decision variables, explicitly considered the tradeoff between benefits and risk. The solution was obtained for a reservoir with few purposes and random inflow and demands. Their procedure was illustrated with an example of a reservoir management problem with constraints on the probabilities of not exceeding the specified maximum and minimum volume of the reservoir and gave the optimal values of reservoir releases and the optimum risk levels (flood risk and draught risk).

Hashimoto et al.(1982) discussed three criteria for evaluating the possible performance of a water resource system, namely, reliability, vulnerability and resilience. Their work explained the use of these criteria to assist in the evaluation and selection of the alternative design and operating policies for a wide variety of water resources projects. The research also referred to that one can not have both the maximum possible reliability and minimum possible vulnerability.

Phaterfod(1984) made a comparison between three probability matrix procedures and two behaviour procedures. Yarra river in Australia was taken as a case study. The comparison was made from the point of view of the ease of the procedures application, their flexibility and the amount of effort required. From this point of view, the behaviour procedure was concluded to be the best.



Srinkanthan and McMahon(1980) made two separable studies based on an analysis of historical streamflows of nine Australian rivers. These two studies examined the effect of the starting month and lag-one annual autocorrelation on storage size obtained from Gould's probability matrix procedure. It was concluded that for annual routes should coincide with the minimum mean monthly flow, this is the conclusion of the first paper. The second concluded that the correlation factor to take into account the annual autocorrelation coefficient is usually less than 1.0 and it was also concluded that Gould's method is not a suitable one for rivers with significant annual autocorrelation coefficients.

Phatarfod(1986) investigated the effect of the serial correlation coefficient of the inflows on the reservoir size, when large reservoirs were involved. Specifically, it was worked out reservoir size ratios, i.e, the ratio of the reservoir size when the serial correlations are presented to the size when they are neglected, assuming the reliability and draft to be the same. When the reservoir was operated on an annual basis, it was shown that for low drafts the ratio is dependent on the inflow model, where as for limiting case when the draft ratio approaches the value 1.0, the ratio was approximately $(1+\rho)/(1-\rho)$, irrespective of the inflow model, where ρ is the annual serial coefficient. Where the reservoir was operated on a seasonal basis, the ratio considered was that of the reservoir size when all the serial correlations were present to the size when year-end seasonal correlation was neglected. He showed that for large reservoirs this ratio was mainly dependent on the annual flow parameters irrespective of the within-year pattern of inflows.

Moy et al.(1986) explored two proposed descriptions of reservoir performance in addition to the probability of failing, these were the maximum shortfall from the target (system vulnerability) and maximum number of consecutive period of deficit during record (system resilience). The shorter the



maximum length of deficit, was considered the more resilient system. The larger the maximum shortfall, was considered the more vulnerability system. A multiobjective mixed-integer, linear programming was used, the trade-off between reliability, vulnerability and resilience were examined. It was found that as reliability was increased or as resilience increased, the vulnerability of water system to larger deficit increased.

Vaugh and Maidment (1987) used both of Gould's probability matrix method and the behaviour method for estimating the probability distribution of future storage of a reservoir. Both methods were applied to the six reservoirs located on the Lower Colorado River. The mean projected level of storage determined from both methods was found approximately 87% of the system storage capacity, while the behaviour analysis using the data preserved in their historical order had a mean future level of storage converging a value approximately 82% of the storage system capacity.

Wurbs and Bergman (1990) indicated an estimates of yield versus reliability relationship. They considered that the firm and estimate of yield versus reliability relationship are fundamental to water supply planning and management. The scope of their studies was limited to estimate firm yield and yield versus reliability relationship using simulation models. They deduced that there are various factors affecting reservoir yield estimates and they can be classified as follows:

1. Compilation and development of the basic data representing basin hydrology.
2. simulation of physical characteristic and operating policies of the reservoir system.
3. modelling the impacts of the basin wide water management and use other related activities on the reservoir system of concern.



Al-Shareef(۱۹۹۶) applied the Moran model to Al-Adhaim reservoir for determining the probability of failure. It was found that the probability of failure were (۲.۹-۶.۳)% for this reservoir depending on the hypothesis of the normal and lognormal distribution for the observed values of inflow respectively. In the present study another methods which can be considered more accurate than this used by Al-Shareef,namely ,Gould's method and behaviour analysis. These two methods resulted in the lowest bias and standard error of results(**Rugumayo**,۲۰۰۱) and therefore are more accurate.

Jenkis and Lund(۲۰۰۰) used an economic engineering modeling approach for integrating urban water supply reliability analysis with shortage management options as dry year, option and spot market water transfers,water resue and long-term and short-term water conservation.

Madhloom(۲۰۰۰) applied both of behaviour procedure and probability matrix procedure for estimating the probability of failure for Al-Adhaim reservoir.This study concluded that Gould's procedure could estimate reliability accurately based only on historical data,while the behaviour procedure need synthetic data. It is an important to say here that the present study differs from Madhloom in four points which make it to be more accurate and more covered the risk analysis of reservoirs:

۱. Reliability, vulnerability and resilience are evaluated for Haditha reservoir while Madhloom evaluated the reliability of Al-Adhaim reservoir only.
۲. In the present study, the distribution that followed by annual and monthly inflows are tested by Kolomgrov-Simirnov test and Chi-square test where Madhloom exprimented three distributions and then tested the model used in generation of synthetic data which is not the best idea (because of that it is a condition to ensure that the distribution



represents the inflow data before entering it in the model of generation (Sharma et .al, 1997) and (Stedinger, et .al, 1982).

3. The present study suggested an empirical formula for firm yield-reliability, vulnerability and resilience relationships can be used for preliminary estimation.
4. Madhloom used Thomas-Fiering model only for generation where the present study uses five models and then their results are compared, namely, Thomas-Fiering model, Thomas-Fiering model with Box-Cox transformations, two-tier model, modified two-tier model and modified fragment model.

Rugumayo (2001) used the behaviour procedure and the mass curve technique to two selected catchment in Uganda in order to study their response within year storage and related it to reliability of yield. He concluded that the mass curve approach can be used to obtain an initial estimate for the capacity of reservoir to meet a specified demand and can be used for preliminary designs. Also, he concluded that the behaviour analysis gives a more specified estimate with a known reliability which can be used in final design. An empirical relationship between the capacity of the reservoir of any reliability and mean annual flow can be obtained .

Finally, **Ragab et .al (2001)** applied modified Gould probability matrix procedure on El-Qouazine catchment in Tunis. The probability of failure is calculated on a monthly basis by using the HYDROMED model. They concluded that the HYDROMED model has successfully implemented a modified Gould probability matrix method

2.2 Data Generation Techniques

Fundamentally, sampling errors resulted from measurement errors in the data generation from the shortness of the historical sample and from inadequacy of the record to satisfactorily represent the population of flows. On the other



hand, variability of streamflow data to the shape of the population and its time dependence are all an important factors led to the use of data generation techniques. The basis of this approach is the extension of the historical streamflow record using a data generation model which results an indication of future streamflow variability.

Conder and McMahon(1973) examined some aspects of lognormal streamflow generation,including the variation between the two-parameter lognormal and three-parameter lognormal seasonal models, the number of length of traces required to adequately specify storage size, and the technique to determine the size of a single reservoir. Application of these models to several Australian rivers showed that no one model satisfactorily produced both storage and flow parameter estimates.

Mejia and Rouselle(1976) proposed a modification in Schaake's disaggregation model and applied their results on 24 years of hydrologic information for two stations in watershed of the North River.

Hoshi and Burges(1979) developed a method differs from Valencia-Schaake(VS) and Mejia-Rouselle(MR) models and showed to be useful for disaggregating annual to seasonal flow volumes where the distributions of seasonal flows can be approximated with three-parameter lognormal distribution.Hoshi-Burges model showed to be successfully maintained correlations between seasons that join successive water year as well as those moments and correlations preserved in the (VS) and (MR) models.

Panu and Unny(1980) tested the synthetic realizations of monthly streamflows obtained by utilizing a feature synthesis model,the test was from the statistical and hydrological view points. The model results suggested that the synthesis of streamflows based on concept of pattern recognition is a potentially viable approach and warranted further investigation.

Klemes et .al(1981) analyzed the problem of whether the using of long memory flow models can be translated into better design of storage reservoirs. It



was appeared that the differences in reliability resulted from the replacement of one model by other were small compared both to:

١. Accuracy of measurement of the socioeconomic impact of reliability change .
٢. The accuracy of estimating the reliability itself is depending on the available streamflow records and for economically relevant length of reservoir operation period.

Abdul-Rasoul(١٩٨١) applied Thomas-Fiering model for monthly flow data to the two Iraqi rivirs (Tigris and Euphrates) and concluded that this model has a good agreement if the skewness of data is treated by Wilson-Hilferty method.

Stedinger and Taylor (١٩٨٢) drew a distinction between streamflow model verification and streamflow model validation. Model verification was considered to be a demanstration that a streamflow produced flows with specified characteritics of selected distribution for the river flows. The model validation was taken to be a process of demonstrating that a flow model generated flow sequences which produced the reservoir system performance consistent with that using the historical flow record. This study illustrated the use of both the storage capacity required to meet a prespified demand and the maximum extracting rate or yield obtained with a given size resorvoir .

This study showed that only modest differences in reservoir system performance distribution resulted from the use of a broad range of streamflow models. The using of reservoir storage capacity was preferred for model validation because it is calculated easily and should provide a better test for model validity for system with large storage capacities. The rescaled value of the reservoir storage capacity required to meet an adjusted demand was developed as another streamflow model validation system statistic.

Stedinger and Taylor(١٩٨٢) examined the impact of incorporating the uncertainty in the statistics describing the distribution of annual flows into



streamflow generation process. They concluded that the uncertainty in just the mean, variance, and correlation had a major effect on estimate of the reliability.

Srikanthan and McMahon (1982) used two generation monthly flows for Australian streams. In one model, seasonalities and periodicities in the monthly flow were removed and the resulting weekly stationary series was modelled. The second approach used the Thomas-Fiering monthly model. The results of these models were compared. They recommended a modified two-tier model for less variable streams and the method of fragments was recommended for highly variable streams.

Vogel (1986) developed a new probability plot correlation coefficient tests for the normal, log-normal and Gumbel distributional hypothesis. Fliben's test was extended for a sample of length between 100 to 10000 because of that many water resources applications required a test for samples of length greater than 100.

Vogel and stedinger (1988) illustrated the variability of required reservoir storage capacity estimates based on 20-80 years streamflow records, in their experiments an AR(1) lognormal was fit to historical flow sequences generated with four different stochastic models: AR(1) lognormal, AR(1) Gamma, AR(1) normal and ARMA (1,1) lognormal model. They showed that the use of stochastic steamflow models can lead to improvement in the precision of the reservoir design capacity estimates.

Khedar (1990) applied Thomas-Fiering model for monthly rainfalls in an arid region. The model was used to generate hydrological data for 100 years. The comparison of the monthly flow parameters of the historical and synthetic data indicated a good agreement between the two series.

Sharma, et .al (1997) used kernel estimates of the joint probability density functions to generate synthetic streamflow sequences. Streamflow was



assumed to be Markov process with time dependence characterized by a multivariate probability density function. Simulation proceeded by sequentially resampling from the conditional density function derived from the Kernel estimate of the underlying multivariate probability density function. They showed that the nonparametric method was more flexible than the conventional models in stochastic hydrology and it was capable of reproducing both linear and nonlinear dependence.

Bojilova (۲۰۰۰) applied the model of Mejia and Rouselle and the corrected Lin model (a technique was developed by **Lin** (۱۹۹۰) to derive the corrected parameter estimation equations), these two models were applied into two forms one and two disaggregation to the streamflow data of chosen river in Bulgaria. The new approach succeeded in the preservation of the additivity as well as the moment but applying the Lin model in one and two-stage disaggregation resulted in consistent parameter estimates.



Data Generation Techniques

4.1 General

The third grouping of storage estimation methods is based on the use of generated or synthetic data. In essence, however, the methods are the same as described previously; the difference is that the input streamflows are changed. The technique involves using a stochastic generation model to produce streamflow sequences with the same statistical properties as the historical record.

Over the past three decades or so, a number of models have been developed to generate monthly flows for use in the design and operation of water resources system. These models can be broadly classified under two categories, namely, monthly flow model and disaggregation processes. A monthly flow model, as its name implies, generates monthly flows usually using an autoregressive model. In this model application, it does not preserve the annual parameter (**Srikanthan and McMahon, 1982**). The disaggregation models distribute the annual flows generated by an annual model into monthly flows.

These models are applied to produce streamflow sequences used for the evaluation of reliability, vulnerability and resilience.

4.2 Inflow Data

It is not possible to determine the future sequence of flows of a natural stream. All methods, therefore, use a historical flow data or parameters derived from it, and thus implicitly assume that these data are



representative of the true streamflow characteristics. Hence, any value of risk measures (reliability, vulnerability and resilience) estimated using historical data has a sampling error.

The inflow data can be represented as a frequency distribution of flows. Often these distributions can be approximated by standard theoretical distributions such as the normal, lognormal, Gamma, Weibull, Extreme Value Type I, and log Pearson Type III. These distributions are defined by parameters of the flows, for example, mean, standard deviation, and coefficient of skewness. Another important flow parameter is the lag – one serial correlation which describes flow persistence.

If the flow volume in successive time intervals is designated as $X_1, X_2, \dots, X_i, \dots, X_n$, the parameters are defined as follows:

4.2.1 Location Parameters (Measures of Central Tendency)

The parameters, generally representing measure of the central tendency of a statistical distribution are the averages, including mean, median and mode.

The Mean

There are three kinds of mean: arithmetic, geometric, and harmonic. The familiar arithmetic mean is usually referred to simply as the mean and designated by (Chow, 1959) :

$$\bar{X} = \sum X_i / n \quad \text{-----} \quad (4-1)$$

Where: X_i : is the variant.

n: is the total number of observations

The above equation gives the sample mean, while the population mean is usually denoted by μ . It may be noted that an unbiased estimate of the population mean is equal to the sample mean.



The geometric mean is the Nth root of the product of N terms or can be designated by (Chow, 1964) :

$$\bar{X}_g = (X_1 * X_2 * X_3X_n)^{1/n} \text{ ----- } (\xi - \nu)$$

The logarithm of the geometric mean is obviously the mean of the logarithms of the individual values. In a lognormal distribution, the geometric mean has the properties analogous to those of the arithmetic mean of a normal distribution.

The harmonic mean is the reciprocal of the mean value of the reciprocals of individual values. It can be expressed as (Chow, 1964):

$$\bar{X}_h = \frac{n}{\sum (1/X_i)} \text{ ----- } (\xi - \nu)$$

The Median

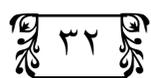
It is the middle value or the variant which divides the frequencies in a distribution into two equal portions.

The Mode

In a distribution of a discrete variables, the mode is the variant which occurs most frequently. In a distribution of continuous variables, this is the variant which has a maximum probability density, i.e. $df/dx = 0$ and $d^2 f/dx^2 \leq 0$.

4.2.2 Dispersion Parameters (Measure of Variability)

The important parameter representing variability or dispersion of a distribution are mean deviation, standard deviation, variance, range, and coefficient of variation.





The Standard Deviation

This parameter as a measure of variability is most adaptable to statistical analysis. It is the square root of the mean, squared deviation of the individual measurements from their mean and is designated by:

$$\sigma = \sqrt{\frac{\sum (X_i - \mu)^2}{n}} \quad \text{-----} \quad (\xi - \xi)$$

This equation represents the standard deviation of the population. An unbiased estimate of this parameter from the sample is denoted by S and computed by:

$$S = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}} \quad \text{-----} \quad (\xi - \circ)$$

The Variance

the square of the standard deviation is called variance which is denoted by σ^2 for the population. The unbiased estimate of the population variance is S².

The Mean Deviation

The mean of the absolute deviations of values from their mean is called mean deviation, or

$$M.D = \frac{\sum |X_i - \bar{X}|}{n} \quad \text{-----} \quad (\xi - \gamma)$$

The Range

The difference between the largest and the smallest values is the range.



The Coefficient of Variation

The standard deviation divided by the mean is called the coefficient of variation (Chow, 1964):

$$C_v = \frac{\sigma}{\mu} \approx \frac{S}{\bar{X}} \quad \text{-----} \quad (\xi - \nu)$$

4.2.3 Skewness Parameter (Measure of Skewness)

The lack in symmetry of distribution is called skewness. The statistical parameter used to measure this property is the skewness defined as (Chow, 1964)

$$\alpha = \frac{1}{n \sum (X_i - \bar{X})^{-3}} \quad \text{-----} \quad (\xi - \lambda)$$

This equation represents the skewness of the population. An unbiased estimate of this parameter from the sample is

$$a = \frac{n}{(n-1)(n-2)} \sum (X_i - \bar{X})^{-3} \quad \text{-----} \quad (\xi - \rho)$$

The Coefficient of Skewness

One commonly used measure of skewness is the coefficient of skewness represented by (Chow, 1964)

$$C_s = \frac{\alpha}{\sigma^3} \approx \frac{a}{S^3} \quad \text{-----} \quad (\xi - \iota)$$

For symmetrical distribution, $C_s = 0$. A distribution with $C_s > 0$ is said to be skewed to the right and vice versa.



4.3 Probability Density Functions

4.3.1 Normal Distribution

The normal distribution is a symmetric and commonly used distribution in many practical applications. The main limitations of the normal distribution for describing hydrologic variables are that it varies over a continuous range $(-\infty, \infty)$, while most hydrologic variables are non negative and tend to be skewed. The probability density function is:

$$f(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2} \quad \text{-----} \quad (4-11)$$

Where: X: is the variant.

μ : is the mean value of the variant.

σ : is the standard deviation.

In this distribution, the mean, mode, and median are the same. The total area under the distribution is equal to 1. The cumulative probability of a value being equal to or less than X is (Chow, 1988)

$$F(x) = \frac{1}{\sigma \sqrt{2\pi}} \int_{-\infty}^x e^{-(x-\mu)^2/2\sigma^2} dx \quad \text{-----} \quad (4-12)$$

This represents the area under the curve between the variant of $-\infty$ and X. Values of the variant X are standardized to give a series of values as follows:

$$Z = \frac{[x - \mu]}{\sigma} \quad \text{-----} \quad (4-13)$$

The standardized variant has a mean, $\mu_z = 0$ and a variance and standard deviation, σ_z^2 and $\sigma_z = 1$. A standardized variant, Z, normally distributed, is denoted by $N(\cdot, \cdot)$, and the normally distributed original



variant by $N(\mu, \sigma^2)$. Areas for various values of X have been calculated by statisticians, and tables for such areas are available in many textbooks and handbooks on statistic. Tables of the standardized cumulative distribution function of the Normal distribution are given in table (A.۳).

۴.۳.۲ Log – Normal Distribution

If the random variable $y = \log x$ is normally distributed, then x is said to be log – normally distributed. **Chow** (۱۹۶۴) reasoned that this distribution is applicable to hydrologic variables formed as the products of other variables since if $x = x_1 * x_2 * x_3 \dots x_n$ then

$$y = \log x = \sum_{i=1}^n \log x_i = \sum_{i=1}^n y_i$$

, which tends to the normal distribution for

large n provided that x_i are independent and identically distributed. The log – normal distributed has the advantages over the normal distribution that is bounded ($x > 0$) and that the log transformation tends to reduced the positive skewness commonly found in hydrologic data, because taking logarithms reduces large numbers proportionately more than does small numbers. Some limitation of the log normal distribution are that it has only two parameters and that it requires the logarithms of the data to be symmetric about their mean. The probability density function of the log – normal distribution is given by (**Chow**, ۱۹۶۴):

$$f(x) = \frac{1}{X \cdot \sigma \cdot \sqrt{2\pi}} e^{-1/2[(y - \mu_y) / \sigma_y]^2} \dots \dots \dots (۴ - ۱۴)$$

Where: $y = \log x$.

x: is the variant.

μ_y : is the mean of y.



σ_y : is the standard deviation of y .

The cumulative probability of a value being equal to or less than x is (Chow, 1988):

$$F(x) = \frac{1}{X \cdot \sigma \cdot \sqrt{2\pi}} \int_0^X e^{-1/2[(y-\mu_y)/\sigma_y]^2} dx \quad \text{-----} \quad (\xi - 10)$$

If $y = \log x$, then the new values, y , are normally distributed. The variant is denoted by $N(\mu_y, \sigma_y)$.

4.3.3 Gamma Distribution

The probability density of this distribution is (Chow, 1988):

$$f(X) = \left(X^a e^{-X/b} \right) / \left(b^{a+1} \Gamma(a+1) \right) \quad \text{-----} \quad (\xi - 16)$$

With $b > 0, a > -1$ for $X = 0$.

$$f(X) = 0 \text{ for } X \leq 0$$

Where: a and b are constant.

$\Gamma(a+1) = a!$: is a gamma function.

The cumulative probability being equal to or less than X is known as the incomplete gamma function. Statistical parameters of the gamma distribution defined as

$$\text{Mean} = b(a+1)$$

$$\text{Variance} = b^2(a+1)$$

The cumulative probability function is

$$F(X) = \int_{-\infty}^X \left(X^a e^{-x/b} \right) / \left(b^{a+1} \Gamma(a+1) \right) dx \quad \text{-----} \quad (\xi - 17)$$



4.4 The Estimation of Parameters

To use probability distribution to estimate probabilities, values for the parameters must be available. This section discussed methods for estimating the parameter values for probability distributions. The usual procedure for estimating a parameter is to obtain a random sample x_1, x_2, \dots, x_n from the population x . This random sample is then used to estimate the parameters. Thus, $\hat{\phi}_i$, which is an estimate for the parameter ϕ_i , is a function of the observations or random variables. Since $\hat{\phi}_i$ is a function of random variables, ϕ_i is itself a random variables possessing a mean, Variance and probability distribution.

4.4.1 Method of Moments

One of the two most commonly used methods for estimating the parameters of a probability distribution is the method of moments. This method was first developed by **Kari Pearson** in 1902. He considered that good estimates of the parameters of a probability distribution are those for which moments of the probability density function about the origin are equal to the corresponding moments of the sample data (**Chow, 1988**). For a distribution with (m) parameters, the procedure is to equate the first moments of the distribution to the first (m) sample moments. These results in (m) equations which can be solved for the unknown parameters. Moments about the origin, the mean, or any other point can be used (**Chow, 1988**). For example, to estimate the parameter λ of the distribution $F(X) = \lambda e^{-\lambda X}$ for $X > 0$ by the method of moments, the first moment about the origin of $F(X)$ is

$$\begin{aligned} \mu &= \int_0^{\infty} \lambda X e^{-\lambda X} dX \\ &= \lambda \int_0^{\infty} X e^{-\lambda X} dX = 1/\lambda \end{aligned}$$



Thus the mean of $F(X)$ is $1/\lambda$ so that λ can be estimated by

$$\lambda = 1/X$$

Likewise, the second and third moments of the probability distribution can be set equal to their sample values to determine the values of parameters of the probability distribution.

4.4.2 The Maximum Likelihood Method

The second method for estimating parameters of a probability distribution is the maximum likelihood method. This method was developed by **R.A.Fisher** (1922). He reasoned that the best value of a parameter of a probability distribution should be that value which maximizes the likelihood or joint probability of occurrence of the observed sample. Suppose that the sample space is divided into intervals of length d and a sample of independent and identically distributed observations x_1, x_2, \dots, x_n is taken. The value of the probability density for $x = x_i$ is $f(x_i)$, and the probability that the random variable will occur in the interval including x_i is $f(x_i)dx$. Since the observations are independent, their joint probability of occurrence is given as the product

$$f(x_1)dx * f(x_2)dx \dots \dots * f(x_n)dx = \left[\prod_{i=1}^n f(x_i) \right] dx$$

and since the interval size is fixed, maximizing the joint probability of the observed sample is equivalent to maximizing the likelihood function

$$L = \prod_{i=1}^n f(x_i) \quad \text{-----} \quad (4-18)$$

Because many probability density functions are exponential, it is sometimes more convenient to work with the log – likelihood function.



$$\ln L = \sum_{i=1}^n \ln [f(x_i)] \quad \text{-----} \quad (\xi - 19)$$

4.5 The Goodness of Fit

The goodness of fit of a probability distribution can be tested by comparing the theoretical and sample values of the relative frequency or cumulative frequency function. There are two methods for this case. The first is the chi – square test, the other is the Kolomogorov – Smirnov test.

4.5.1 Chi – Square Test

One of the most commonly used tests for goodness of fit of empirical data to specified theoretical distributions is the chi – square test. This test makes a comparison between the actual number of observations and the expected number of observations that fall in the class intervals. The expected numbers are calculated by multiplying the expected relative frequency by the total number of observations. The test statistic is calculated from the relationship(Chow, 1988):

$$x_c = \sum_{i=1}^L (O_i - E_i)^2 / E_i \quad \text{-----} \quad (\xi - 20)$$

Where: L: is the number of class intervals.

O_i: is the observed number of observations in the ith class interval.

E_i: the expected number of observations in the ith class interval.

The distribution χ_c , table (A.1), is a chi – square distribution with L-p-1 degrees of freedom where (p) is the number of parameters estimated from the data. The hypothesis that the data are from the specified distribution is accepted if

$$x^2_c > x^2_{L-p-1}$$



4.5.2 Kolomogrov – Smirnov Test

An alternative to the chi – square goodness of fit test is the Kolomogrov – Smirnov test. This test is conducted as follows:

- a. Let $F(X)$ be the completely specified theoretical cumulative distribution function.
- b. Let $S_n(X)$ be the sample cumulative density function based on n observations. For any observed X . $S_n(X) = R / n$ where R is the number of observations less than or equal to X .
- c. Determine the maximum deviation, D , defined by

$$D = \max | F(X) - S_n(X) | \quad \text{-----} \quad (\xi - \tau)$$

- d. If the observed value of D is greater than or equal to the critical tabulated value of the Kolomogrov – Smirnov statistic, table (A.2), the hypothesis is rejected for the chosen significance level (Al-Shareef, 1996).

4.6 Stochastic Hydrology

Hydrologic data of sufficiently long duration is essential for better decision criteria in design planning and operation of water resources projects of optimum development and to avoid risks of under – designing or uneconomic costs of over – designing. However these objectives cannot be fulfilled with the generally available hydrologic data such as streamflow which is rarely available for a sufficiently long period at project sites. To help for overcoming this deficiency and because of inadequacy of traditional deterministic methods of hydrologic analysis, research investigators have drawn upon development in the field of mathematical statistics and probability theory to evolve a field of specialization called ‘stochastic hydrology’. The modeling technique developed in this field provides methods to generate a number of



streamflow sequences for a longer period by using the statistical information of observed short term data. All hydrologic processes are phenomena that change with time and are more or less stochastic in nature. If the available data record is of sufficient length for it to be considered as representative sample, the statistical parameters derived from it will enable the formulation of reliable stochastic model. The data generated by this model will qualitatively be no way better than the historical observed data. But the major advantage, of data generation techniques of stochastic hydrology is that many combinations of different patterns of data sequences can be synthetically generated for length longer than the observe data. **Chow, 1964** has rightly pointed out that these techniques provide the possibility of examining a specific design in a more rational manner.

The sequence of values of any hydrologic phenomenon, such as streamflow, arranged in order of their time of occurrence constitute a hydrologic time series. Example of hydrologic time series are sequences of annual or monthly or daily values of streamflow which represent the discrete form of time series obtained by transforming the continuous form represented by hydrograph. In comparison with annual streamflow, the monthly streamflow series is twelve times longer. Moreover, a series of monthly streamflow values display a cycle of twelve months and its subharmonic, which are masked in annual discrete series. Though continuous series or daily flow values give more statistical information, the information provided by monthly flow values are generally sufficient and are used in water resources planning of projects where flow regulation with in the year is involved.



4.7 Time Series Components

From a stochastic point of view, streamflow data can be regarded as consisting of four components (Mein and McMahon, 1978); periodic or seasonal (S_t), trend (T_t), correlation (K_t), and random (ϵ_t) components which can be explained simply as:

$$X_t = T_t + S_t + K_t + \epsilon_t \quad \text{-----} \quad (4.1)$$

These component are represented pictorially in figure (4.1)

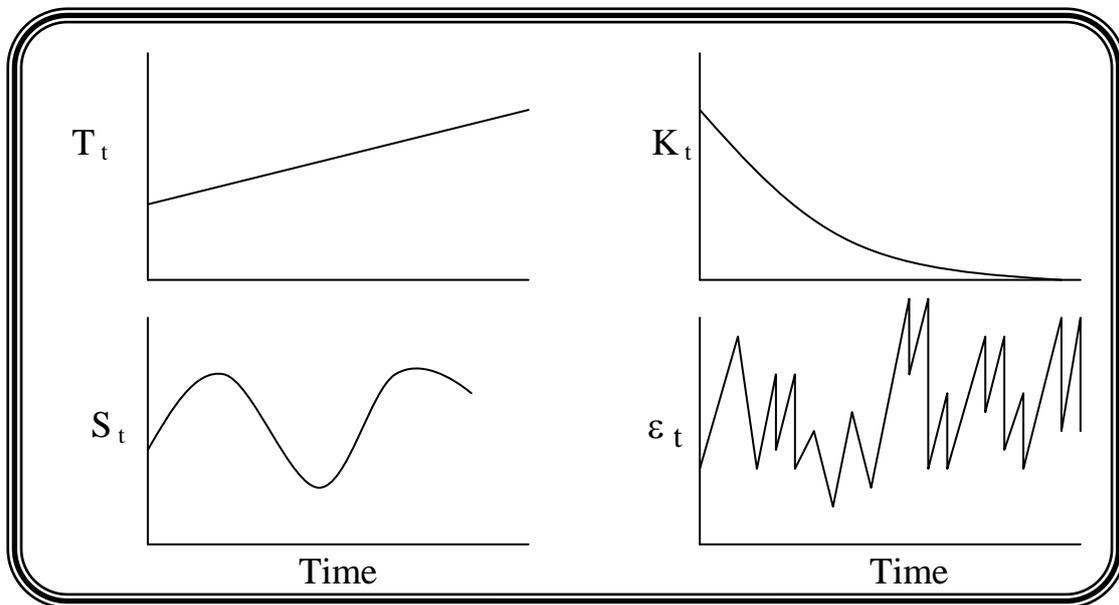


Figure (4.1): Time series components of the streamflow process.

The hydrologic time process and the time series are termed as stationary if their probability distribution does not change with time, otherwise the time series is not stationary. All hydrologic time series have some degree of non – stationarity which may be due to natural or man made change in basins or in consistency of data. The sequences of natural annual runoff from river basins may be regarded as approximately stationary time series (Seth and Chandra, 1979) where the monthly streamflows is a non – stationary time series because it composed from twelve different populations.



4.1 Random Numbers

The hydrologic time series generation requires a generation of random numbers to insure that the generating sequences obey a probability law governing a particular component of the random behaviour of the time series. In the present study, three types of random numbers are used:

1 - Uniform random numbers:

Lehmer (1956) [quoted from Kottegoda, 1980] suggested a procedure to generate a uniform random variation numbers. He proposed the following relationship.

$$Z_i = (a Z_{i-1} + C) \pmod{m} \quad \text{-----} \quad (4-23)$$

$$m = 2^W$$

or $m = 10^W$

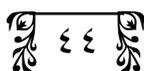
Z_i : uniform random number (represents the remainder of the division of $(a Z_{i-1} + C)$ on (m)).

a, C, Z_{i-1} : constants between zero and $m - 1$.

W : largest integer number can be used (depending on the computer memory).

Kottegoda (1980) gave a FORTRAN subroutine for generating uniform random number. Furthermore, many of computers have a library function which enables the user to generate a series of uniform random numbers.

2 - Normal random numbers with zero mean and unit variance:





Kottegoda (1980) generated normal random numbers by transforming uniform random number Z_1 and Z_2 to normal random variate t_1 and t_2 by using the following equations

$$t_1 = \cos(2\pi Z_2) \sqrt{-2 \log Z_1} \quad \text{-----} \quad (\xi - 24)$$

$$t_2 = \sin(2\pi Z_2) \sqrt{-2 \log Z_1} \quad \text{-----} \quad (\xi - 25)$$

The values of t_1 and t_2 are normally distributed with zero mean and unit variance.

3 - Normal random numbers with any mean and standard deviation:

The normal random variate t_1 and t_2 can be transformed into normal random numbers with any mean (\bar{X}) and any standard deviation (S) by using the following equations (**Khedar**, 1990) and (**Madhloom**, 2000):

$$V_1 = \bar{X} + S * t_1 \quad \text{-----} \quad (\xi - 26)$$

$$V_2 = \bar{X} + S * t_2 \quad \text{-----} \quad (\xi - 27)$$

V_1 and V_2 represent normal random numbers with any mean and standard deviation.

4.9 Stochastic Streamflow Models

Stochastic streamflow models are often used in simulation studies to evaluate the likely future performance of water resource systems. These models can be broadly classified under two categories, namely, monthly flow models and disaggregation processes (**Srikanthan and McMahan**, 1982). The present study used the following streamflow models:

4.9.1 Thomas – Fiering Monthly Model



The **Thomas – Fiering** model is a model of monthly flows which has often been used in reservoir planning studies (**Stedinger and Taylor, 1982**). This model automatically takes into account in the generation equation the seasonal variation in the monthly means, standard deviation and lag – one autocorrelation coefficient. This model is a non – stationary one (**Seth and Chandra, 1979**).

For the **Thomas – Fiering** model, synthetic $X_{j,i}$ series were generated with the recursive relationship:

$$X_{j+1,i} = \bar{X}_{j+1} + B_j (X_{j,i} - \bar{X}_j) + t_i S_{j+1} (1 - R_j^2)^{1/2} \quad \text{---- (4-28)}$$

Where:

$X_{j+1,i}, X_{j,i}$: flow during (j + 1)th and (j)th months respectively.

\bar{X}_{j+1}, \bar{X}_j : mean monthly flow during the (j + 1)th and (j)th months respectively.

S_{j+1} : standard deviation of flow during (j + 1)th month.

R_j : correlation coefficient between flows in (j)th and (j + 1)th months which can be obtained by:

$$R_j = \frac{\sum_{i=1}^{N-1} (X_{j,i} - \bar{X}_j)(X_{j+1,i} - \bar{X}_{j+1})}{\sqrt{\sum_{i=1}^{N-1} (X_{j,i} - \bar{X}_j)^2 \sum_{i=1}^{N-1} (X_{j+1,i} - \bar{X}_{j+1})^2}} \quad \text{----- (4-29)}$$

B_j : regression coefficient between flows in (j)th and (j – 1)th months which obtained by (**Mein and McMahon, 1978**):

$$B_j = \frac{R_j * S_{j+1}}{S_j} \quad \text{----- (4-30)}$$

t_i : random normal deviate with zero mean and unit variance.



The application of **Thomas – Fiering** model is restricted to normally distributed flows because the (t_i) in equation $(\epsilon - 28)$ is considered to be a normal random variate. However, the monthly flow data is not always normally distributed. Hence, modifications are required to overcome this difficulty. These modifications are:

- 1) - Normalize the original records of monthly flow by one of the following:
 - (i) Taking logs of the data which will tend to normalize them (**Codner and McMahon, 1973**) and (**Seth and Chandra, 1979**). The desired series then will be found by applying inverse transformation.
 - (ii) By applying Box – Cox transformation. This transformation is suggested by (**Box and Cox, 1964**) [quoted from **Kottegoda, 1980**]. To transform an observed value X to the normal distribution, the following equation is used:

$$Z = \begin{cases} \frac{X^\psi - 1}{\psi} & \text{if } \psi \neq 0 \\ \ln(X) & \text{if } \psi = 0 \end{cases} \quad \text{-----} \quad (\epsilon - 31)$$

Where:

X: observed values (value of inflow).

ψ : transformation power.

The parameter ψ could be chosen so that the skewness of the transformed series will be reduced to the minimum. **Hinkly (1977)** [quoted from **Muhsun, 2002**] suggested a simple procedure to provide that. For each of different values of $\psi = 0, \pm 0.5, \pm 1, \dots$ the simple mean (\bar{Z}) the standard deviation (σ_Z) and the median (Z_m) are calculated from the transformed values. Then, the statistical variable



$(d\Psi)$ of equation (4.30) is compared to find the value of (Ψ) for which the variable $(d\Psi)$ is at its minimum value.

$$d\Psi = \frac{\bar{Z} - Z_m}{\sigma_Z} \dots\dots\dots (\xi - \gamma)$$

Where all the variables as were already defined above.

Figure (4.2) shows the application of Box-Cox transformations to evaluate the value of Ψ which is found to be equal to (-0.2360) , at this value of Ψ , $d\Psi$ is approaching to zero ($d\Psi = 0.0000$).

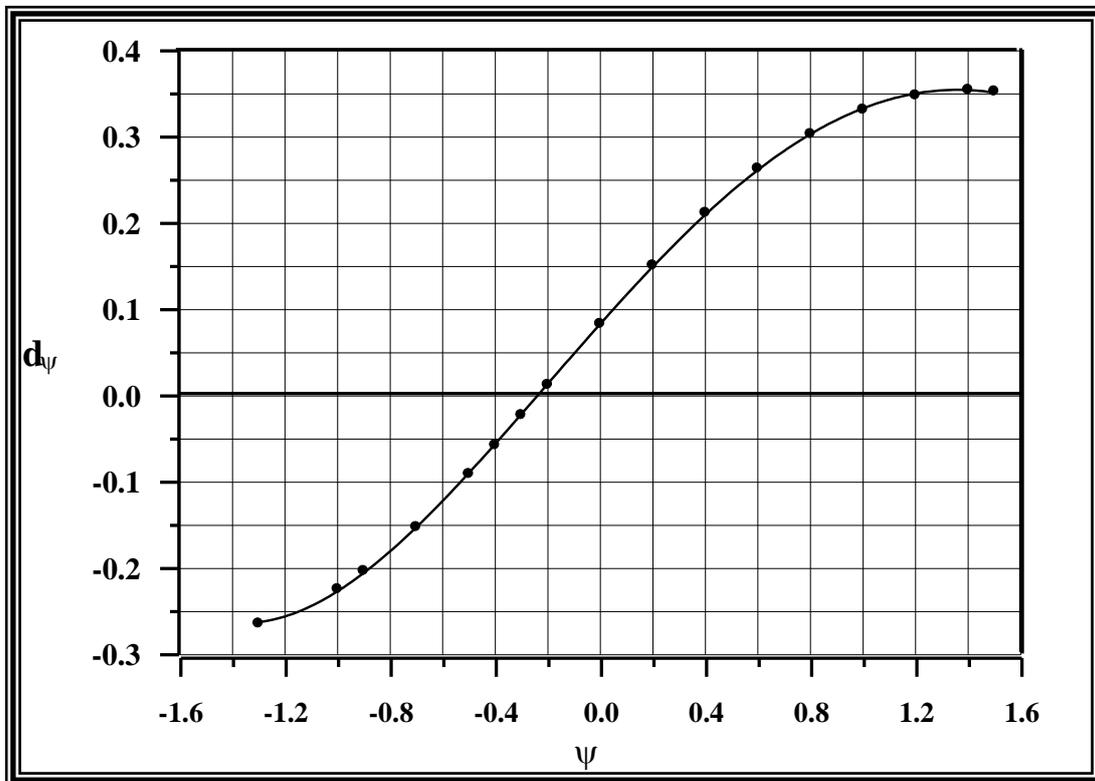


Figure (4-2): Box-Cox transformations results for Haditha reservoir.

γ - Transform the normal random variable (t_j) to a skewed variate (t_γ) which has zero mean, unit standard deviation and skewness coefficient $(\gamma_{t,j})$. This transformation is called (Like Gamma) transformation



and is done by using the Wilson – Hilferty transformation as following (Madhloom, 1999):

$$t_{\gamma} = \frac{2}{\gamma_{t,j}} \left[1 + \frac{t_i \gamma_{t,j}}{6} - \frac{\gamma_{t,j}^2}{36} \right]^3 - \frac{2}{\gamma_{t,j}} \dots (\xi - 33)$$

Where:

t_{γ} : a random variate with zero mean, unit variance

$\gamma_{t,j}$: skewness coefficient

The skewness ($\gamma_{t,j}$) is computed by the following equation:

$$\gamma_{t,j} = \frac{C_s(j) - C_s(j)R_j^3}{\sqrt{(1 - R_j^2)^3}} \dots (\xi - 34)$$

Where:

$C_s(j)$: coefficient of skewness of month (j).

R_j : correlation coefficient between month (j) and month (j - 1).

4.9.2 Two – Tier Model

Monthly models do not necessarily preserve the annual flow characteristics. To overcome this deficiency, **Harms and Camobell** (1967) [quoted from **Mein and McMahon**, 1978] extended the Thomas – Fiering model to constrain the annual and monthly flows separately, and also to preserve the annual serial correlation. Annual flows were generated by annual normal Markov model as follows:



$$X_{i+1} = \bar{X} + r_1 (X_i - \bar{X}) + t_i S (1 - r_1^2)^{1/2} \dots\dots\dots (\xi - 30)$$

Where:

X_{i+1} , X_i : annual runoffs for (i+1)th and (i)th years.

\bar{X} : mean annual historical flow.

S: standard deviation of annual flows.

r_1 : annual lag one serial correlation coefficient.

Thomas – Fiering model was used for monthly generation, but the values were adjusted to sum to the appropriate annual values by the following equation:

$$X'_{ij} = \frac{X_{ij}}{\sum_{i=1}^{12} X_{ij}} X_i \dots\dots\dots (\xi - 31)$$

Where:

X'_{ij} : adjusted monthly generated flow volumes.

X_{ij} : unadjusted monthly generated flow volumes.

X_i : annual generated flow volumes.

i: year.

j: month.

4.9.3 Modified Two – Tier Model





It was found that the two – tier model greatly distorted the seasonal monthly parameters for highly variable streams. To improve the seasonal monthly parameter, the two – tier model was modified as follows (**Srikanthan and McMahan, 1982**):

The annual series obtained from an annual model and the series obtained by summing the monthly flows from the Thomas – Fiering model were ranked separately. The monthly flows for each twelve month period were then adjusted using equation (ε – 33) against the annual flows having the same as the summed monthly flows. The adjusted monthly flows were then rearranged according to the original sequencing of the annual series.

4.9.4 Disaggregation Processes

Disaggregation modeling is a process by which time series are generated dependent on a time series already available. Typically, the independent series have been previously generated, by any stochastic model desired (**Bojilova, 2000**). Disaggregation models distribute the annual flows generated by an annual model into monthly flows or any other season.

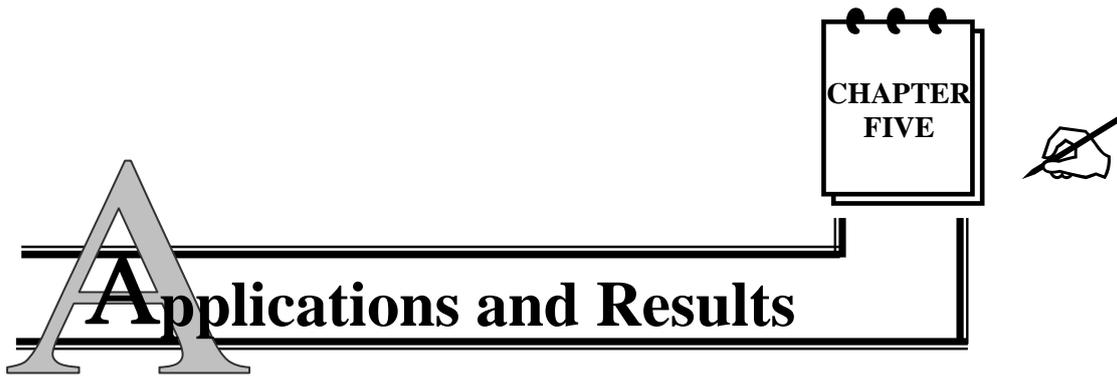
Generally, two different methods are available to disaggregate the annual flows: one uses the distribution of the observed monthly flow within a year (fragment model) where as the other uses a set of coefficients usually in the form of two matrices obtained from the historical monthly flows (**Mejia and Rousselle, 1976**) which is out of the scope of this study.

In the fragment model, the observed monthly flows are first standardized year by year by dividing the monthly flows in a year by the



corresponding annual flow model. The resulting set of standardized monthly flows in each year is referred to as a fragment.

The annual flows is generated by the Markov annual model or any of the other annual models. Then, the annual flows from the historic record (say N years long) were ranked according to increasing magnitude, and N classes were formed. Class (1) had a lower limit of zero, while class N had no upper limit. The intermediate class limits were obtained by averaging two successive flows in the ranked series. The corresponding fragments were assigned to each class as follows. The fragment obtained from the monthly flows corresponding to the smallest annual flow was assigned to class (1), the fragment obtained from the monthly flows corresponding to the second smallest annual flow was assigned the class (2) and so on. The generated annual flows were then checked one by one for the class to which they belong and disaggregated using the corresponding fragments (**Srikanthan and McMahon, 1982**).



Applications and Results

5.1 Description of Haditha Dam Project

5.1.1 General

Haditha dam is a high dam that has been constructed on the Euphrates river Valley at Abu – Shabur settlement, (5 km) to the north of Haditha town in the middle west of Iraq, figure (5.1)

The project generates (660 Mw) of electrical power a side from performing its Head control function. Central and southern parts of Iraq are mainly depending on the water from its reservoir for irrigation.

The Euphrates river at the project area flows in a south – east direction. The river depth does not exceed (2 – 3) m when the water level in the river is (102.3) m. a. s. l.

5.1.2 General characteristics of Haditha dam

In 1988, the project of Haditha dam was completed. The project comprises mainly of an dallomite dam, (9.0 km) long. The general features of the dam are outlined in table (5.1).

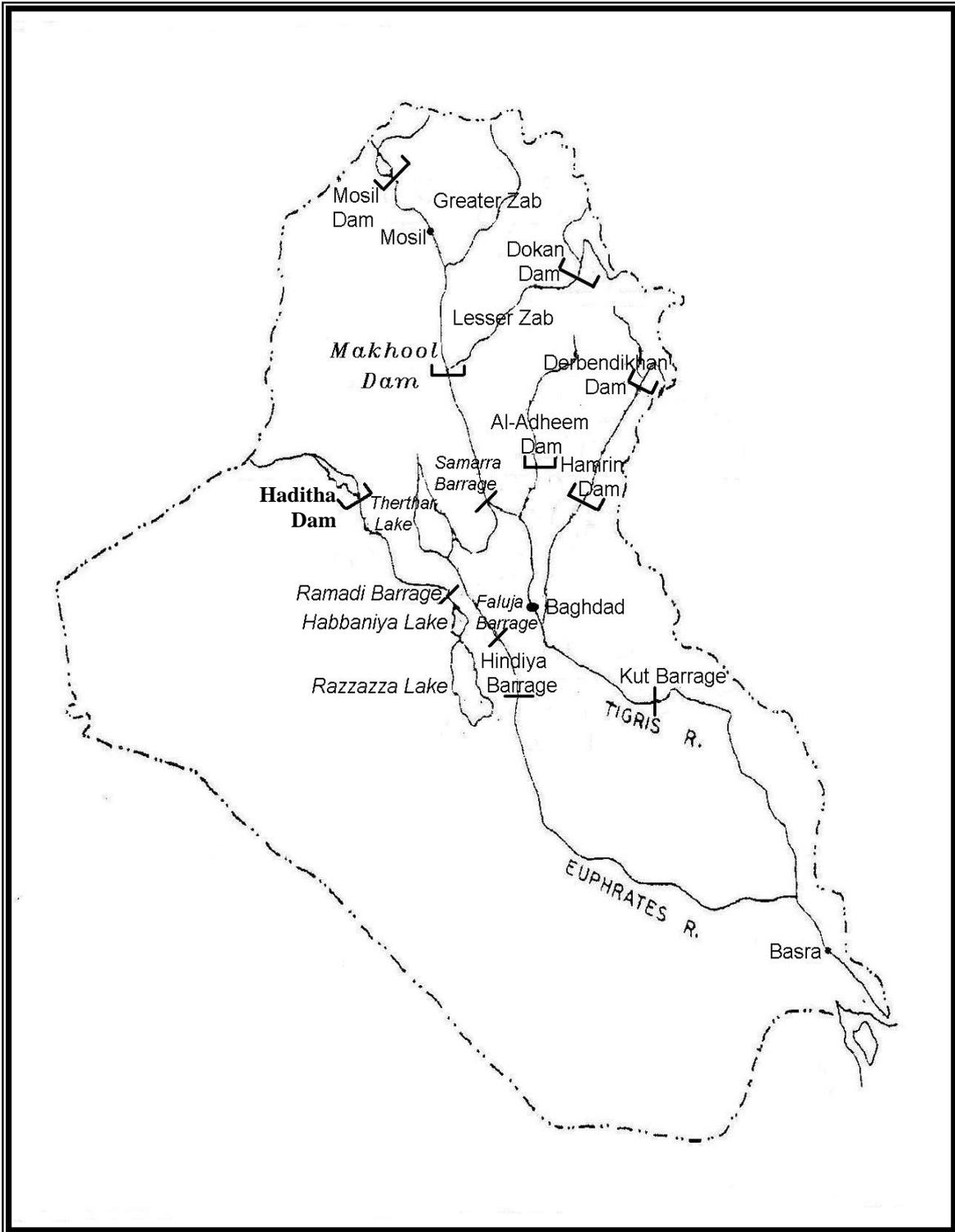


Figure (5-1): Map of Iraq showing Haditha Dam location.



Table (٥.١): Design values of the parameters of interest of Haditha dam
(Kadhun, ٢٠٠٠).

Body of the dam	
Maximum height	٥٧ m
Top width	٢٠ m
Length of the right bank	٣٣٦٨ m
Length of the river section	٤٣١ m
Length of the left bank	٥١٤٠ m
The water level in the reservoir	
Normal water level	١٤٧ m.a.s.l.
Maximum water level	١٥٠.٢ m.a.s.l.
Minimum water level	١٢٩.٥ m.a.s.l.
Dead – storage level	١١٢ m.a.s.l.

٥. ١. ٣ The Inflow Data

The Euphrates river mainly provides the water supply to the reservoir. Flow records of the Euphrates river from ١٩٣٢ to ١٩٩٩ is used in the present study which is shown in table (٥.٢).

Table (٥.٢): Monthly inflow for Haditha reservoir (Cumeccs).

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
١٩٣٢	٣٠٣	٣٠٨	٣٥٠	٣٤٣	٣٥٠	٧٥٠	١٢٧٠	١٦٢٠	٨٣٤	٣٧٥	٢٤٢	٢١٣
١٩٣٣	٢٣٢	٢٥٠	٢٧٠	٢٧٥	٣١٣	٤٨١	٥٠١	١٦٠٠	١١١٠	٤٤٣	٢٣٦	٢١٥
١٩٣٤	٢٠٩	٢٣١	٣١٧	٣٩٨	٤٤٨	٦٨٧	١٥٣٠	١٢٧٠	٩٣٠	٤١٣	٣٠٦	٢٤٢
١٩٣٥	٢٣٦	٣٤١	٢٦٨	٦٨١	٨٨٥	١٢٦٠	٢٥٦٠	٢٣٣٠	٩٣٩	٥٢٨	٣٩٧	٢٥٠
١٩٣٦	٣٥٦	٧٤٧	١٣١٠	٨٧٩	١١٤٠	١٢٩٠	٢٢٥٠	٢٥٣٠	١٦٣٠	٨١١	٥١٩	٣٣١
١٩٣٧	٣٢١	٣٨٢	٧٥٧	٥٢٥	٦٢٠	١٠٧٠	٢٠٨٠	١٨٠٠	١٠٩٠	٥٥٨	٣٤٣	٢٧٥
١٩٣٨	٢٩١	٦٧٩	١٠٩٠	١١٣٠	٩٧١	٩٦٦	٢٢٢٠	٣٢٠٠	١٤٥٠	٧٧٨	٤٦١	٣٥٥
١٩٣٩	٣٥٩	٤٩١	٥٢٨	٧٣١	٧٦١	١١٢٠	٢٠٠٠	٢٥٣٠	١٢٣٠	٦٨٥	٤٥٢	٣٧٥
Year	٣٥٢	٣٩٥	٥٨٦	١٠١٠	١٠٨٠	١٢٧٠	٣٠٦٠	٢٩٥٠	١٣٣٠	٧٠٠	٤١٨	٣٤٣



1940	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
1941	4.7	7.8	9.8	922	13..	27..	27..	242.	1.4.	049	3.3	321
1942	341	417	39.	7.3	821	122.	264.	3.3.	119.	401	281	238
1943	329	919	121.	122.	979	99.	230.	299.	119.	073	376	3.9
1944	33.	483	480	777	704	170.	220.	321.	140.	722	394	309
1945	379	734	013	9.4	727	847	177.	212.	142.	73.	308	29.
1946	3.4	371	074	08.	707	113.	217.	310.	177.	770	473	377
1947	091	712	473	87.	90.	107.	2.8.	114.	740	449	3.1	271
1948	281	049	070	004	117.	919	207.	307.	190.	749	4.8	349
1949	307	378	490	4.7	042	080	177.	220.	112.	472	319	273
1950	283	311	300	448	304	1.1.	197.	202.	113.	494	311	274
1951	310	4.1	373	004	0.3	774	187.	108.	837	371	247	227
1952	399	471	077	401	127.	114.	294.	230.	117.	008	334	281
1953	3.8	343	417	037	1.3.	131.	311.	177.	712	397	342	1.98
1954	309	483	478	744	89.	173.	382.	338.	177.	771	423	337
1955	373	0.8	717	1.9.	7.7	899	141.	172.	777	34.	228	228
1956	284	318	021	701	819	988	170.	273.	123.	008	314	279
1957	328	37.	4.2	372	441	108.	174.	279.	102.	088	293	238
1958	30.	417	749	779	744	1.8.	182.	107.	114.	414	219	197
1959	281	340	407	471	437	727	177.	149.	983	330	21.	2.1
1960	3.8	417	39.	807	710	122.	277.	277.	1.0.	472	283	244
1961	331	39.	383	472	037	434	130.	117.	443	192	87	93
1962	223	419	882	791	939	120.	173.	137.	774	279	143	149
1963	20.	289	402	780	117.	124.	247.	433.	280.	914	437	33.
1964	409	7.1	02.	447	018	130.	271.	107.	979	349	17.	170
1965	312	302	714	484	9.4	130.	221.	2.9.	971	4.1	214	187
1966	377	483	721	130.	2.9.	149.	217.	200.	141.	07.	292	271
1967	407	003	77.	9.7	880	118.	270.	488.	2.9.	912	41.	333
1968	077	1.2.	121.	127.	120.	240.	381.	420.	228.	802	411	383
1969	478	70.	104.	240.	177.	277.	477.	079.	232.	870	404	4.4
1970	080	737	739	732	894	142.	239.	140.	784	202	10.	177
1971	3.9	348	77.	413	378	999	321.	232.	127.	430	201	209
1972	370	411	011	4.4	399	792	147.	224.	133.	0.8	224	239
1973	329	407	412	317	34.	090	113.	128.	7.8	192	81	89
Year	27.	292	4.7	307	317	749	301	177	124	72	102	279



١٩٧٤	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
١٩٧٥	٢٧٦	٢٧٣	٢٧٧	٢٩٧	٢٩١	٢٦٤	٢٥٩	٢٥٢	٣٣٤	٣٩٣	٣٥٦	٣١٢
١٩٧٦	٣٥٤	٣٨٠	٤٠١	٤٢١	٤٧٢	٤٤٥	١٠٠١	١٤٢٨	١٦٧٤	١١٧٠	٨٧٤	٧٢٧
١٩٧٧	٦٤١	٧٢٧	٩٢٢	١٢٣١	٩٤١	١١٧٠	١١٧٠	١٥٠٨	١٦٩٠	٥٥٣	٥٤٨	٤٩٥
١٩٧٨	٥٩٤	٦٤٥	٧٢٣	٧٣٠	٧٠٦	١٢٢٧	٨٨٢	١٥٤٢	١٤٥٠	٥٦٣	٥٣٥	٦٢٩
١٩٧٩	٦٦٤	٧٦٥	٨٢٦	٨٦٨	١٠٠٦	٨٩٨	٧٨٨	٦٨٣	٦٨١	٧٤٥	٨٢٧	٧٥٤
١٩٨٠	٦٢٢	٧٩٦	٦٢٠	٦٤٣	٦٥٢	٦٩٧	١٩٨٧	١٨٥٠	١٠٧٧	٦٥١	٥٩٩	٦٩٨
١٩٨١	٧٥٢	٧٩٩	٨٩٥	١٠٦٢	١١١١	١١٩٣	١٠١٩	١٠٠٠	٧٩٢	٦٨١	٧٣٩	٥٧٣
١٩٨٢	٧٤٠	٨٠٦	٨٥٢	٧١١	٧١٥	٧٥٣	٦٧٢	١٣١٢	١١٧٩	٩٤٨	٩٨٥	٩٣٣
١٩٨٣	١٠٨٩	١٠٠١	٩٤٥	٩٨٨	٩٤٤	٩٣٠	٩٣٢	٧٥٠	٧٩٥	٥٠٨	٧٠٣	٤٩٤
١٩٨٤	٤٠٩	٥٥٧	٥٩٠	٧٤٣	٦٥٠	٥٠٥	٣٩٤	٣٤٧	٣٩٨	٤١١	٤٩٧	٥٠٧
١٩٨٥	٥٧٢	٩١٢	٩٥٥	٧٩٩	١٠٣١	٧٨٦	٧٨٣	٤١٦	٤٩٣	٣٤٦	٤٧٨	٤٨٦
١٩٨٦	٤٩٠	٤٩٠	٤٩٠	٤٩٠	٤٦٧	٤٢٤	٣٦٩	٤٤٦	٤٧٠	٥٤٨	٥٦٩	٦٠٠
١٩٨٧	٤٧٠	٥٩٧	٦٢٥	٥٢٨	٣٩١	٦٨٨	٣٦٢	٤٠٣	٧٠٣	٨٧٢	٦٢٩	٦٣٧
١٩٨٨	٤١٦	٦٦٤	٧٩٤	١٣٨٢	١٦٥١	١٨٩٧	٢٥٠٦	٢٧٩٩	٢١٦٧	٩٦٨	٧٣٤	١٠٢١
١٩٨٩	٩٧٧	١٢٥٣	١٥٧٩	١٧٠٠	١٣٢٤	١٢١٥	٥٥٤	٣٢١	١٩٤	١٧٦	١٤٣	١٩٧
١٩٩٠	٢٣٣	٢٨٦	١٧٩	١٧٥	٢٢٥	١٨٥	٢١٠	١٧٧	٢٥٣	٣٧٥	٣٤٢	٢٩٦
١٩٩١	٢٦٥	٣٦٤	٥٥٨	٤٨٧	٤١٤	٣١٦	١٩١	٤٢٨	٣٥٣	٣٦١	٤٠٧	٣٢٠
١٩٩٢	٢٧٠	٢٨٦	٥٦٣	٥١١	٥٧٣	٣٣١	٢٦٨	٢٨٣	٣٢٤	٢٨٥	٢٦٠	٢٤٩
١٩٩٣	٣٧٥	٤٤١	٤٥٣	٣٦١	٣٠٧	٣٤٢	٣٠٩	٤٥٩	٣٥٠	٣٠٩	٣٠٣	٢٦٣
١٩٩٤	٤٣٢	٤٣٠	٥٣٨	٤٩٢	٦١٣	٤٤٨	٤٧٢	٣٦٤	٣٧٢	٤٨٩	٥٢٠	٧١٤
١٩٩٥	٩٤٥	١٠٩٩	١١٣٣	١٢٤٣	١١٧٨	٨٢٠	٦٦٦	٣٦١	٣٠٠	٣٦٤	٤٩٥	٥١٩
١٩٩٦	٥٩٠	١٠٨٣	٩٢٠	١١٦٩	١٣٠٩	١٤١١	١٤٧٩	٨١٥	٥٠٢	٦٩٦	٧٥٣	٦٦٣
١٩٩٧	٧٤٥	٨٨٠	٩٤٢	١٠٦٢	١٣٠٧	١١٢٥	١٠٦٠	٧٢٤	٧٥٩	٨٣٤	٥٩٦	٥٠٩
١٩٩٨	٧١٦	٩٨٧	١٢٢٠	١١٣٨	١٣٥١	١٤٤٥	٨١٥	٨٦٣	٥٨٠	٥٩٠	٦٧٥	٦٤٥
١٩٩٩	٧٩٦	٣٨١	١٠٤٥	١٠١٤	٩٤٤	٦٢٦	٤٣٠	٣٧٠	٣٢٢	٢٦٣	٢٥٦	٣٠٣

٥. ١. ٣ Haditha Dam Climate

In general, the climate in the study area is characterized by two well defined seasons: a dry and hot summer and a mild winter with small precipitation and evaporation in the project region. The values of precipitation and evaporation of the study area are shown in table (٥.٣)



Table (٥.٣): The average values of precipitation and evaporation from Haditha reservoir (Kadhum, ٢٠٠٠).

Time	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Rainfull (mm)	١٨.٨	١٦.٩	٢٠.٤	٢٢.٢	٥.٧	٥.٣	٩.٨	٢٢.٥	١٢١.٦
Evaporaton (mm)	٤٨	٧٢	١٢٠	١٩٢	٢٦٤	٣٣٦	٤٠٨	٣٦٠	٢٦٤	١٩٢	٩٦	٤٨	٢٤٠

٥. ١. ٤ Elevation, Area – Storage Relationships

Table (٥.٤) illustrates the natural topography of the reservoir under the study. They are used to find the relationships between the storage, surface area and the elevation of water for the reservoir, which are required to estimate the quantity of water that is added or subtracted from the storage due to precipitation and evaporation, respectively.

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. Some of these studies are, MUHSUN, ٢٠٠٢. The 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, which is:

$$EA = a + b \times S + c \times S^d \text{-----} (٥.١)$$

Where:



EA = either the surface area of the reservoir in (sq. Km) or the water level in (m. a. s. l.)

S = the reservoir storage in milliared cubic meters a, b, c, d = coefficients, these values could be produced by using nonlinear optimization methods. In this work, (STATISTICA PACKAGE) was used to estimate these values.

Figure (٥.٢) and Figure (٥.٣) show the relationships of the elevation, area – storage of the reservoirs.

Now, the effect of monthly (gain or loss) from the reservoir area could be given by:

$$ET_j = AVR * (P_j - EV_j) \text{ -----} (٥.٢)$$

Where:

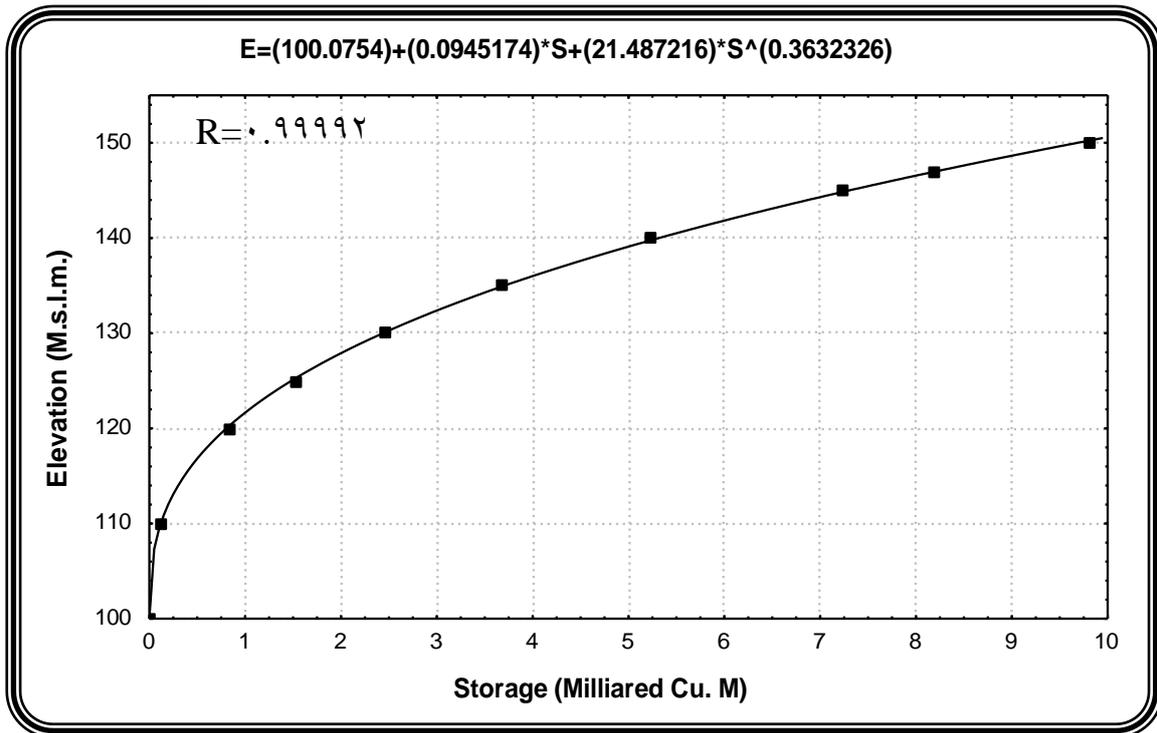
ET_J =The net monthly water (gain or loss) from the surface area during the Jth month, in million cubic meter.

AVR = the average area of the reservoir in sq. Km at the beginning and end of each Jth month of the corresponding storage.

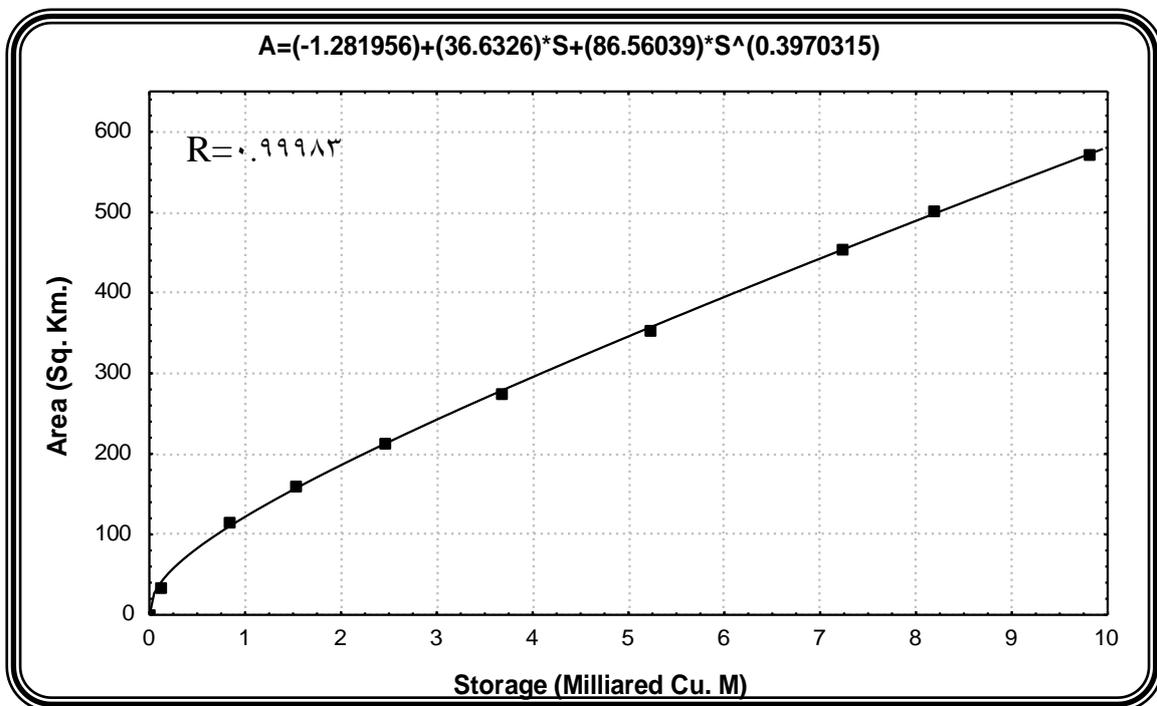
P_j and EV_j = the average precipitation and evaporation over the surface area during the Jth month in meter, respectively.

Table(٥.٤): Topographic features of Haditha reservoir.

Elevation (m.a.s.l.)	Area (sq. Km)	Volume (milliared cu. m)
١٠٠	٠	٠
١١٠	٣٣	٠.١٠٨
١٢٠	١١٥	٠.٨٣٥
١٢٥	١٦٠	١.٥٢٠
١٣٠	٢١٣	٢.٤٥٠
١٣٥	٢٧٤	٣.٦٦٨
١٤٠	٣٥٢	٥.٢٢٦
١٤٥	٤٥٥	٧.٢٣٧
١٤٧	٥٠١	٨.١٩٣
١٥٠	٥٧٢	٩.٨٠٢



Figure(5.2): Storage-elevation relationship of Haditha reservoir.



Figure(5.3): Storage –area relationship of Haditha reservoir.



5.2 Statistical Analysis of historical data

5.2.1 Estimation of Statistical Parameters

Statistical parameters influence the sequences of generated data and so that on the estimated value of risk. Hence, it is important to specify the statistical parameters of river inflows to the reservoir. Table (5.5) gives the annual and monthly streamflow parameters for Haditha reservoir. These parameters are calculated by using the equations mentioned in chapter three.

This table indicates that the mean monthly flow for one month can not be regarded as equal to another, high correlation was observed between all month (0.779 – 0.882). Also, it is shown that the mean monthly flow has a minimum value of (380.26) cumecs in September and a maximum value of (1812) cumecs in May. The coefficients of skewness for monthly as well as annual inflows are all positive, i.e., the hypothetical distributions which represent the monthly and annual inflows are skewed to the right.

Table (5.5): Annual and monthly statistical parameter of Haditha reservoir.

Month	Mean Cumecs	Standard deviation Cumecs	Coefficient of variation	Coefficient of skewness	Month	Correlation coefficient	Regression coefficient
Oct.	430.279	192.783	0.448	1.496	Oct-Nov	0.840	1.048
Nov.	540.191	239.222	0.438	1.023	Nov-Dec	0.817	1.043
Dec.	661.088	300.303	0.456	1.070	Dec-Jan	0.810	1.010
Jan.	740.338	382.7	0.513	1.630	Jan-Feb	0.788	0.782
Feb.	807.400	379.666	0.470	0.784	Feb-Mar	0.779	0.917
Mar.	1037.382	513.233	0.490	1.142	Mar-Apr	0.733	1.438
Apr.	1678.382	1000.087	0.599	0.400	Apr-May	0.840	1.022
May	1812.309	1216.030	0.671	0.826	May-Jun	0.882	0.411
Jun.	1040.406	567.230	0.540	0.734	Jun-Jul	0.708	0.276
Jul.	540.161	221.232	0.41	0.449	Jul-Aug	0.728	0.633
Aug.	398.008	192.420	0.483	0.878	Aug-Sep	0.820	0.904
Sep.	380.264	211.971	0.557	1.470	Sep-Oct	0.790	0.718
Annual	10076.87	3762.730	0.373	0.769		0.518	



5.2.2 Testing The Goodness of Fit

The chi – square and Kolomogrov – Smirnov indices are calculated for Haditha reservoir inflow (monthly and annual inflow) and the results are presented on the hypothesis of the normal, lognormal and gamma distributions [Figures (5.4) to (5.9)].

5.2.2.1 Chi – square index

There are no theoretical rules to guide the choice of class intervals for the purpose of computing the chi – square index. A rule commonly used by many statisticians states that the number of class interval is at least three (Kottegoda, 1980). The STATISTICA PACKAGE has been used to compute the chi – square value on the hypothesis of the normal, lognormal and gamma distributions (for both monthly and annual inflow). The chi – square test accepted the normal distribution for annual inflow and lognormal distribution for monthly inflow for Haditha reservoir. The details of computations are shown in tables [(5.6) to (5.11)].

5.2.2.2 Kolomogrov – Smirnov index

The STATISTICA PACKAGE has been used to compute the Kolomograv – Smirnov index of each of the hypothesis of normal, lognormal and gamma distributions. The details of the computations are shown in tables [(5.6) to (5.11)]. These results show that, on the basis of this test, all distribution tested are accepted for annual inflow and all of them are rejected for monthly inflow, respecticely.

Lastly,table (5.12) shows the summary of the above two test computation.



distribution: Normal									
Kolmogorov-Smirnov d = .10.962.									
Chi-Square: 136.36, df = .									
upper boundary	observed freq-cy	cumulatv observed	percent observed	cumul. % observed	expected freq-cy	cumulatv expected	percent expected	cumul. % expected	observed-expected
<=914.29	060	060	69.24	69.24	441.111	441.11	04.14	04.14	123.18
1828.07	180	740	22.00	91.3	300.80	747.66	37.48	91.62	-120.80
2742.86	49	794	6.00	97.30	60.11	812.77	7.98	99.60	-16.11
3657.14	10	804	1.83	99.14	3.18	810.96	0.39	99.99	11.81
4571.43	4	813	0.49	99.63	0.34	816	0.04	99.99999	3.96
5485.71	2	815	0.245	99.87	7.73E-00	816	9.48E-00	1.00	1.99999
Infinity	1	816	0.122	1.00	.	816	.	1.00	1

Table(0.6): Chi-square test and Kolmogorov-Smirnov test results with the hypothesis of normal distribution for monthly inflow.

distribution: Gamma									
Kolmogorov-Smirnov d = .023128									
Chi-Square: 30.04920, df = 1									
upper boundary	Observed freq-cy	cumulatv observed	percent observed	cumul. % observed	expected freq-cy	cumulatv expected	percent expected	cumul. % expected	observed-expected
<=914.29	060	060	69.24	69.24	022.31	022.31	64.00	64.00	47.68
1828.07	180	740	22.00	91.249	237.10	709.46	29.06	93.07	-07.10
2742.86	49	794	6.00	97.30	47.42	806.88	0.81	98.88	1.07
3657.14	10	804	1.83	99.14	7.76	814.60	0.90	99.83	7.23
4571.43	4	813	0.49	99.63	1.108	810.81	0.14	99.97	2.84
5485.71	2	815	0.24	99.87	0.164	810.97	0.02	99.99	1.83
Infinity	1	816	0.12	1.00	0.26	816	0.03	1.00	0.97

Table(0.7): Chi-square test and Kolmogorov-Smirnov test results with the hypothesis of Gamma distribution for monthly inflow.

Distribution: Lognormal									
Kolmogorov-Smirnov d = .0146332									
Chi-Square: 3.639311, df = 2									
upper boundary	observed freq-cy	cumulatv observed	percent observed	cumul. % observed	expected freq-cy	cumulatv expected	percent expected	cumul. % expected	observed-expected
<=914.29	060	060	69.24	69.24	063.17	063.17	69.01	69.01	1.82
1828.08	180	740	22.00	91.29	193.76	706.94	23.74	92.76	-13.76
2742.86	49	794	6.00	97.30	41.40	798.34	0.7	97.83	7.09
3657.10	10	804	1.83	99.14	11.32	809.67	1.38	99.22	3.67
4571.43	4	813	0.49	99.63	3.74	813.41	0.40	99.68	0.20
5485.72	2	815	0.24	99.87	1.41	814.83	0.17	99.80	0.08
Infinity	1	816	0.12	1.00	1.16	816	0.14	1.00	-0.16

Table (0.8): Chi-square test and Kolmogorov-Smirnov test results with the hypothesis of lognormal distribution for monthly inflow.



distribution: Normal									
Kolmogorov-Smirnov d = .056191.									
Chi-Square: 1.83478, df = 1									
Upper boundar	observed freq-cy	cumulatv observed	percent observed	cumul. % observed	expected freq-cy	cumulatv expected	percent expected	cumul. % expected	observed-expected
<=30000	2	2	2.94	2.94	2.73	2.73	4.02	4.02	-0.73
70000	14	16	20.58	23.02	11.32	14.00	17.60	20.67	2.67
100000	22	38	32.30	55.88	22.98	37.04	33.80	54.47	-0.98
140000	23	61	33.82	89.70	20.80	57.89	30.66	80.1	2.14
170000	0	61	7.30	97.00	8.4	66.30	12.43	97.07	-3.40
210000	1	62	1.47	98.52	1.02	67.32	2.24	99.31	-0.52
240000	1	63	1.47	100	0.12	67.44	0.17	99.99	0.87
Infinity	0	63	0	100	0.04	68	0.06	100	-0.04

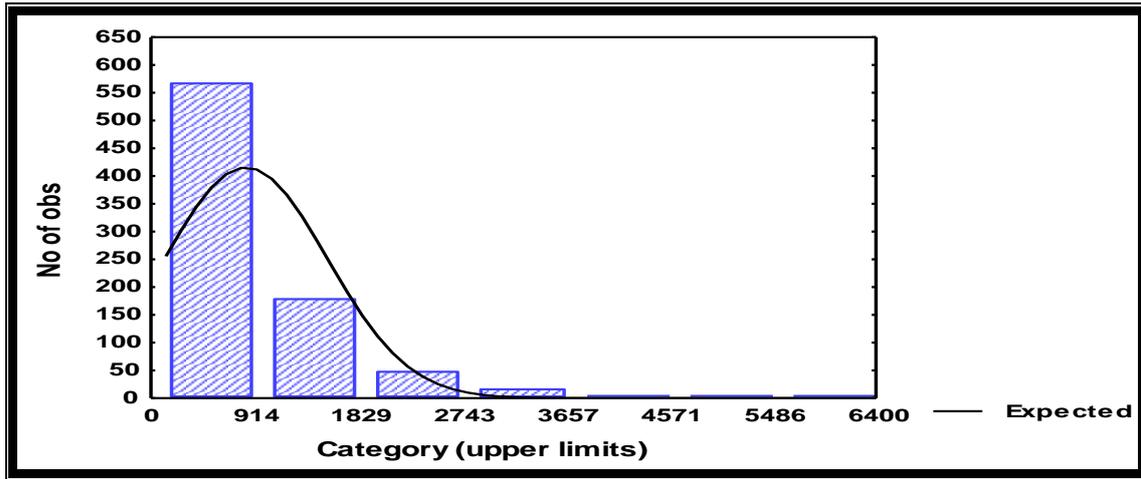
Table(0.9): Chi-square test and Kolmogorov-Smirnov test results with the hypothesis of normal distribution for annual inflow.

distribution: Gamma									
Kolmogorov-Smirnov d = .047036									
Chi-Square: 3.260872, df = 1									
Upper boundary	observed freq-cy	cumulatv observed	percent observed	cumul. % observed	expected freq-cy	cumulatv expected	percent expected	cumul. % expected	observed-expected
<=30000	2	2	2.94	2.94	0.88	0.88	1.30	1.30	1.11
70000	14	16	20.58	23.02	14.10	14.99	20.74	22.00	-0.10
100000	22	38	32.30	55.88	20.33	35.33	37.26	59.31	-3.33
140000	23	61	33.82	89.70	17.46	52.80	20.68	80.00	0.03
170000	0	61	7.30	97.00	7.26	60.07	10.68	90.69	-2.26
210000	1	62	1.47	98.52	2.22	62.29	3.27	93.96	-1.2
240000	1	63	1.47	100	0.00	62.29	0.817	99.78	0.44
Infinity	0	63	0	100	0.148	63	0.21	100	-0.14

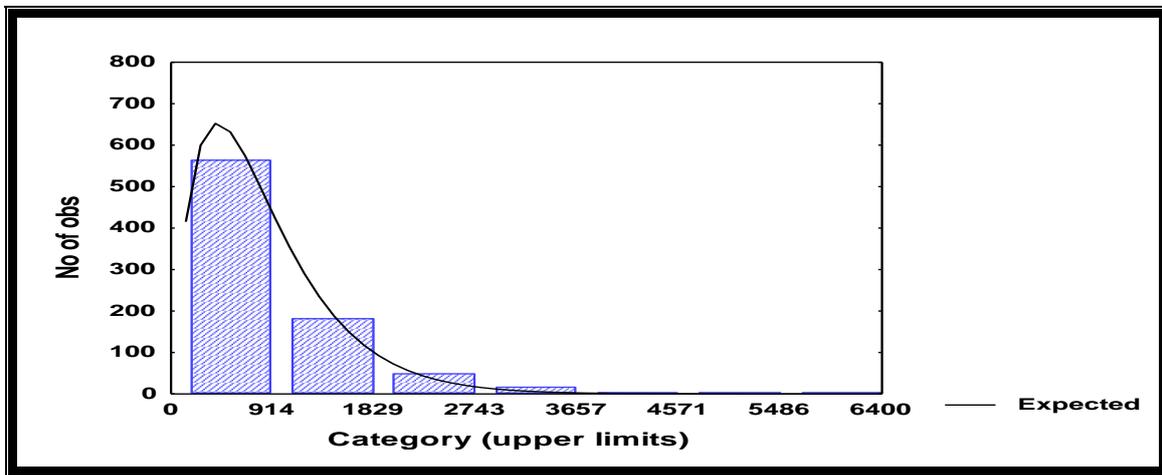
Table(0.10): Chi-square test and Kolmogorov-Smirnov test results with the hypothesis of Gamma distribution for annual inflow.

distribution: Lognormal									
Kolmogorov-Smirnov d = .070892									
Chi-Square: 0.03160, df = 1									
upper boundary	observed freq-cy	cumulatv observed	percent observed	cumul. % observed	expected freq-cy	cumulatv expected	percent expected	cumul. % expected	observed-expected
<=30000	2	2	2.94	2.94	0.02	0.02	0.77	0.77	1.47
70000	14	16	20.58	23.02	10.63	11.16	22.99	23.77	-1.63
100000	22	38	32.30	55.88	20.44	31.60	37.41	61.18	-3.44
140000	23	61	33.82	89.70	10.47	42.08	22.70	83.94	7.02
170000	0	61	7.30	97.00	6.72	48.81	9.89	93.84	-1.72
210000	1	62	1.47	98.52	2.60	51.41	3.83	97.67	-1.60
240000	1	63	1.47	100	0.97	52.38	1.43	99.10	0.02
Infinity	0	63	0	100	0.60	63	0.89	100	-0.60

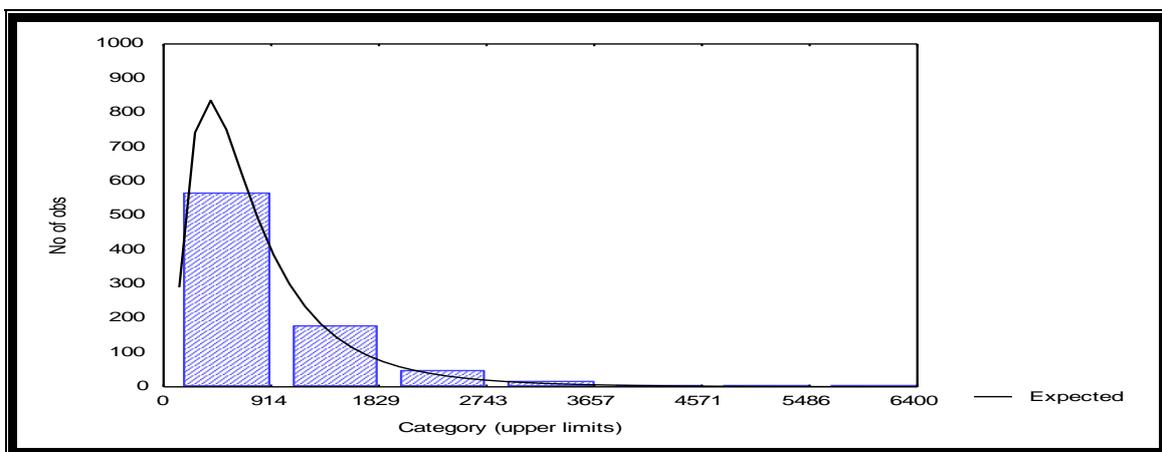
Table(0.11): Chi-square test and Kolmogorov-Smirnov test results with the hypothesis of lognormal distribution for annual inflow.



Figure(5.4): Monthly inflow histogram with the hypothesis of normal distribution for Haditha reservoir.



Figure(5.5): Monthly inflow histogram with the hypothesis of gamma distribution for Haditha reservoir.



Figure(5.6): Monthly inflow histogram with the hypothesis of lognormal distribution for Haditha reservoir.

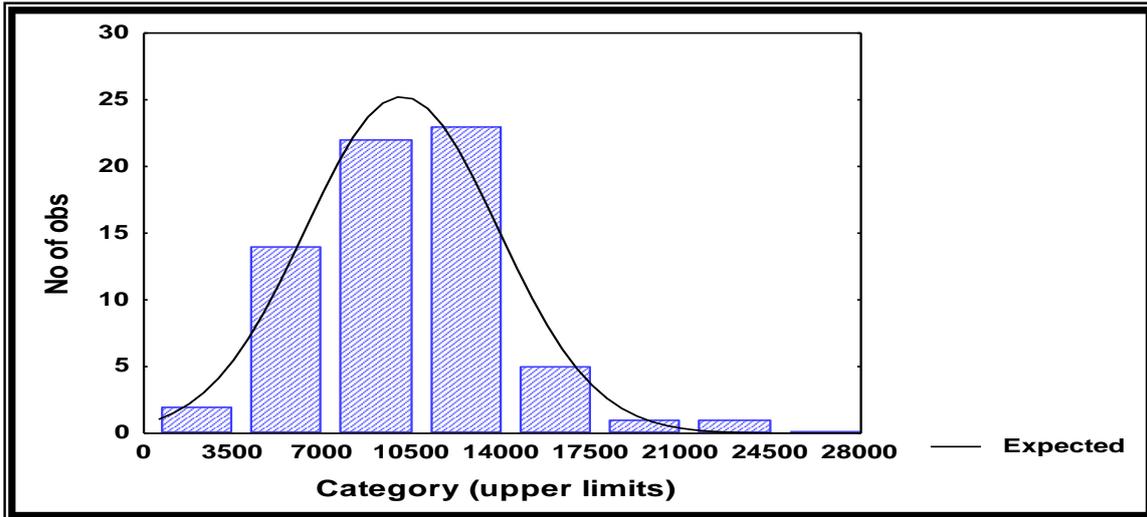


Figure (٥.٧): Annual inflow histogram with the hypothesis of normal distribution for Haditha reservoir.

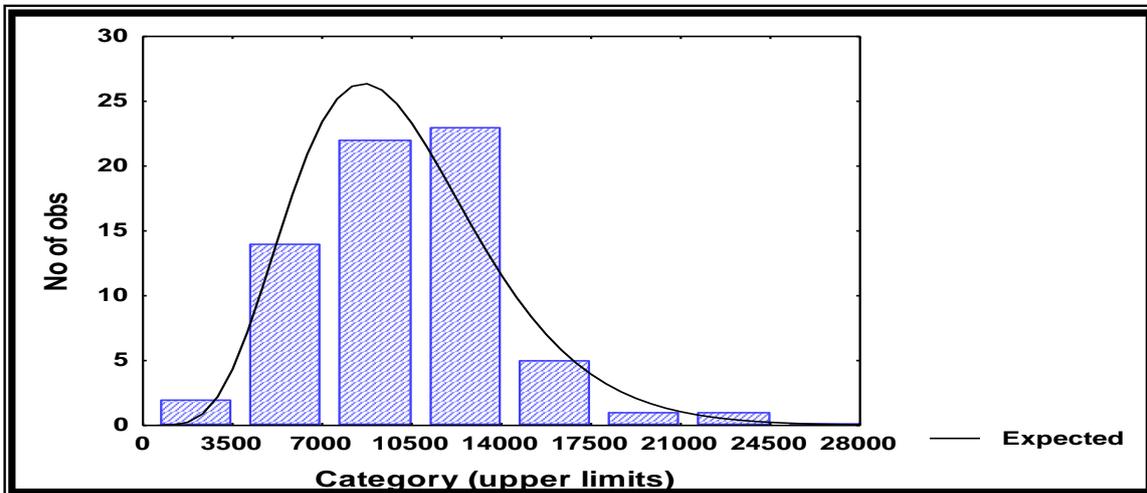


Figure (٥.٨): Annual inflow histogram with the hypothesis of gamma distribution for Haditha reservoir.

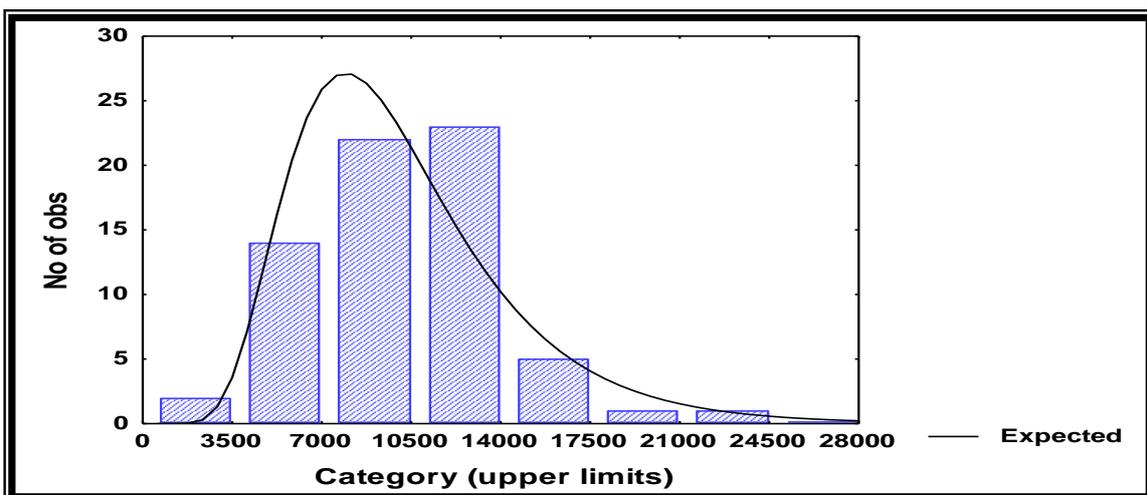


Figure (٥.٩): Annual inflow histogram with the hypothesis of lognormal distribution for Haditha reservoir.



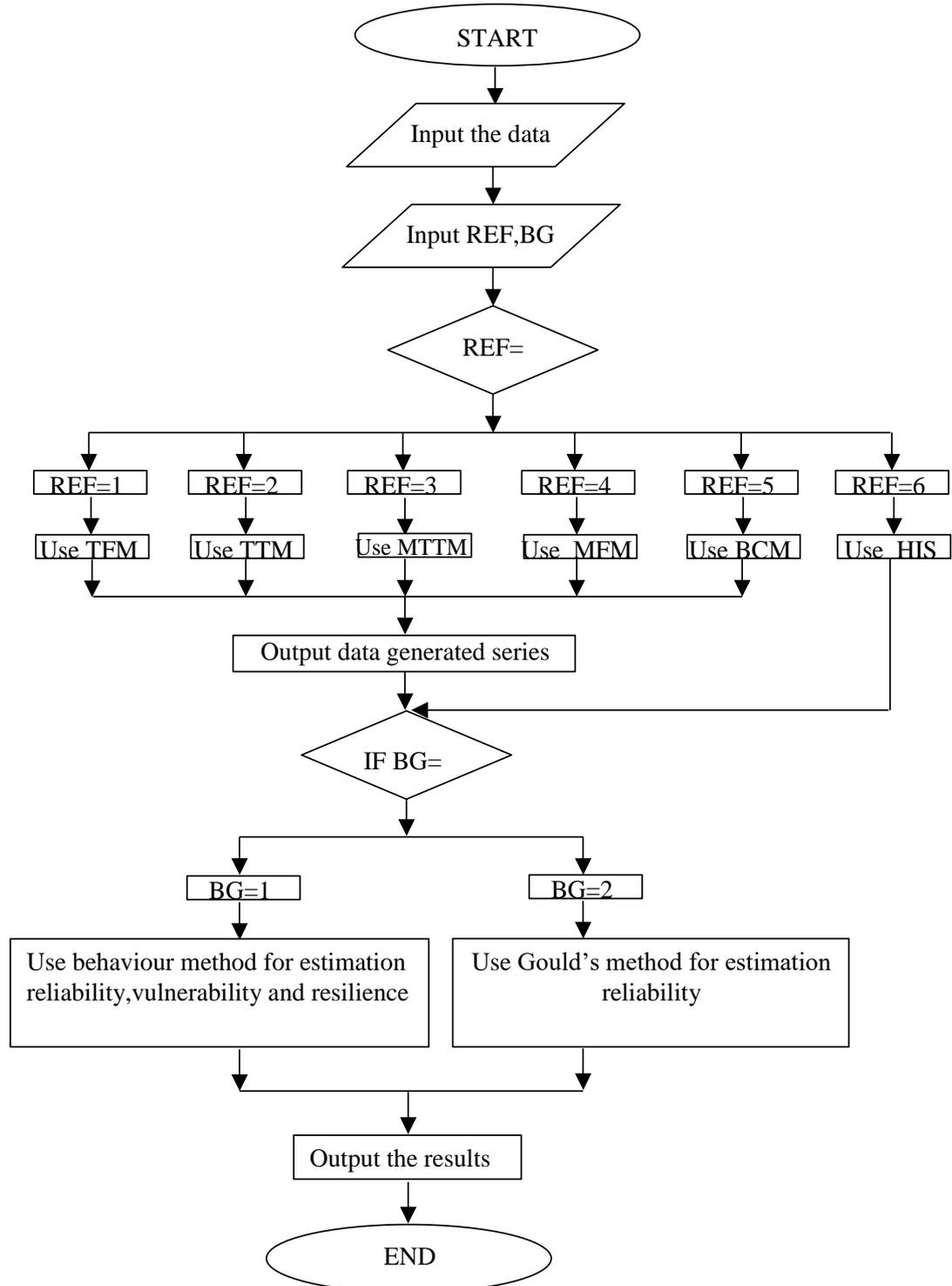
Table (5-12): Summary of Chi-Square test and Kolomogrov-Smirnov test results.

	Chi- square test result			
	distribution	Chi- Square index	Critical Chi-Square index	Result
Monthly inflow	normal	136.36	.	Not acceptable
	lognormal	3.74	0.99	acceptable
	gamma	30.04	3.48	Not acceptable
Annual inflow	normal	1.483	3.48	acceptable
	lognormal	0.311	3.48	Not acceptable
	gamma	3.261	3.48	acceptable
	Kolomogrov-Smirnov test result			
	distribution	Kolomogrov-Smirnov index	Critical Kolomogrov-Smirnov index	Result
Monthly inflow	normal	0.101	0.048	Not acceptable
	lognormal	0.146	0.048	Not acceptable
	gamma	0.002	0.048	Not acceptable
Annual inflow	normal	0.046	0.160	acceptable
	lognormal	0.008	0.160	acceptable
	gamma	0.047	0.160	acceptable



5.3 Computer Program

A QUICK BASIC program is constructed (Appendix-B) for evaluating the risk performance measures. The figure in below shows the flow chart of the logical steps of computations. In this figure, REF is an index used to turn the program to one of the data generation techniques which are used in this study where BG is an index to tell the program either uses behaviour analysis (BG=1) or Gould's procedure (BG=2).





5.4 Estimation of Risk Performance Measures By The Behaviour Procedure

The behavior procedure is used to estimate the reliability, vulnerability and resilience of the reservoir. Equation (5-1) is applied month by month for the whole (historical and generated) inflow data. The release from the reservoir is assumed as a percentage of the mean flow (0%, 10%, 20%, 30%, 40%, 50% and 100%). The evaporation and precipitation loss and gain are evaluated as mentioned in section (5.1.4), other losses are comparatively small so that they assumed to be zero. The initial storage is assumed full, the error in the estimation of risk performance of the reservoir results from this assumption can be overcome by using the generated data techniques (Srikanthan and McMahon, 1985). The volume balance index (S_{t+1}) represents the volume of water storage at the ending of the current month (or storage at the beginning of the next month). If (S_{t+1}) is greater than the capacity of the reservoir (C), the water storage at the beginning of the next month will be equal to (C). On the other hand, if (S_{t+1}) is equal or less than zero ($S_{t+1} \leq S_{min}$), the reservoir is considered to be empty. The probability of failure and the reliability of reservoir is computed by using equations (5-2) and (5-3), respectively.

The vulnerability is found by choosing the maximum storage during the analysis (the minimum negative value of (S_{t+1})), where the resilience is computed as the maximum number of consecutive failing months.

A QUICK BASIC computer program (Appendix B) is applied for achieving the above computations.

Figure (5-1) shows the behavior diagram for Haditha reservoir with a release of 20% from the mean flow using the historical data.

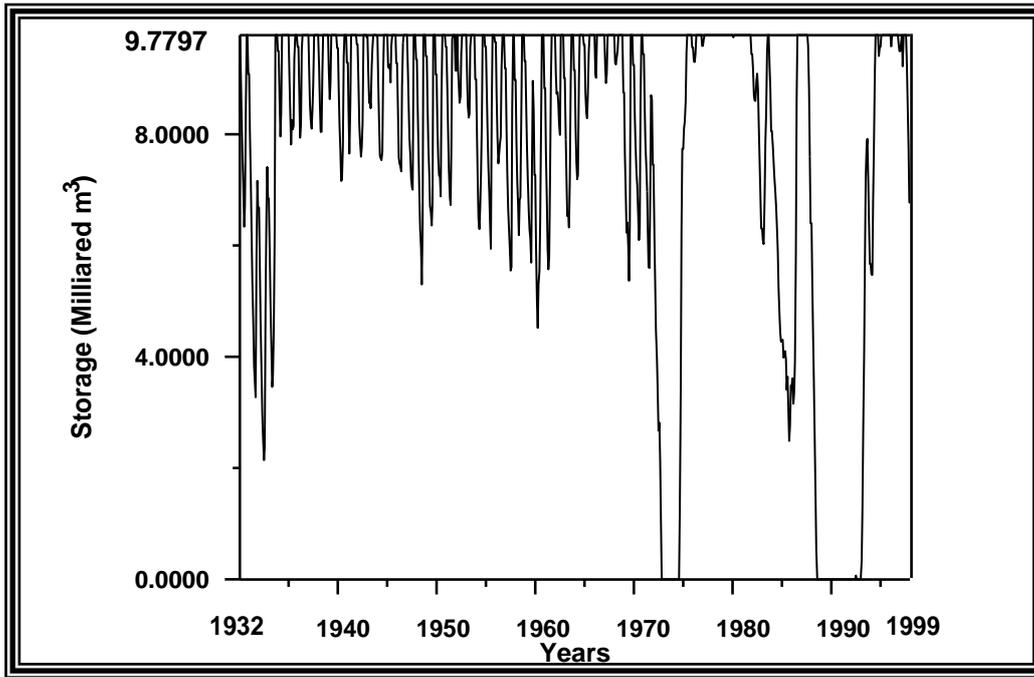


Fig.(5.10): Behaviour diagram for Haditha reservoir

From this figure, it can be noted that the system may be operated for the first approximately (30) years without failing. The figure also indicates that the system may suffer from (3) failures during the (66) months used in the analysis.

5.2 Estimation of Reservoir Reliability By Gould's Procedure

To illustrate the reliability computations steps for Haditha reservoir, this section will be subdivided into the following subsections:

5.2.1 The Reservoir States

As mentioned in chapter two, **Teoh**, 1977 stated that the number of required states depends on the annual flow coefficient of variation. **Ragab**, 2001 recommended the using of (20) zones or more to be sufficient. However, the present study found that the reliability estimate for Haditha reservoir is slightly affected by the number of states as shown in figure (5 - 11). However, the present study used (20) zones for reliability computation.

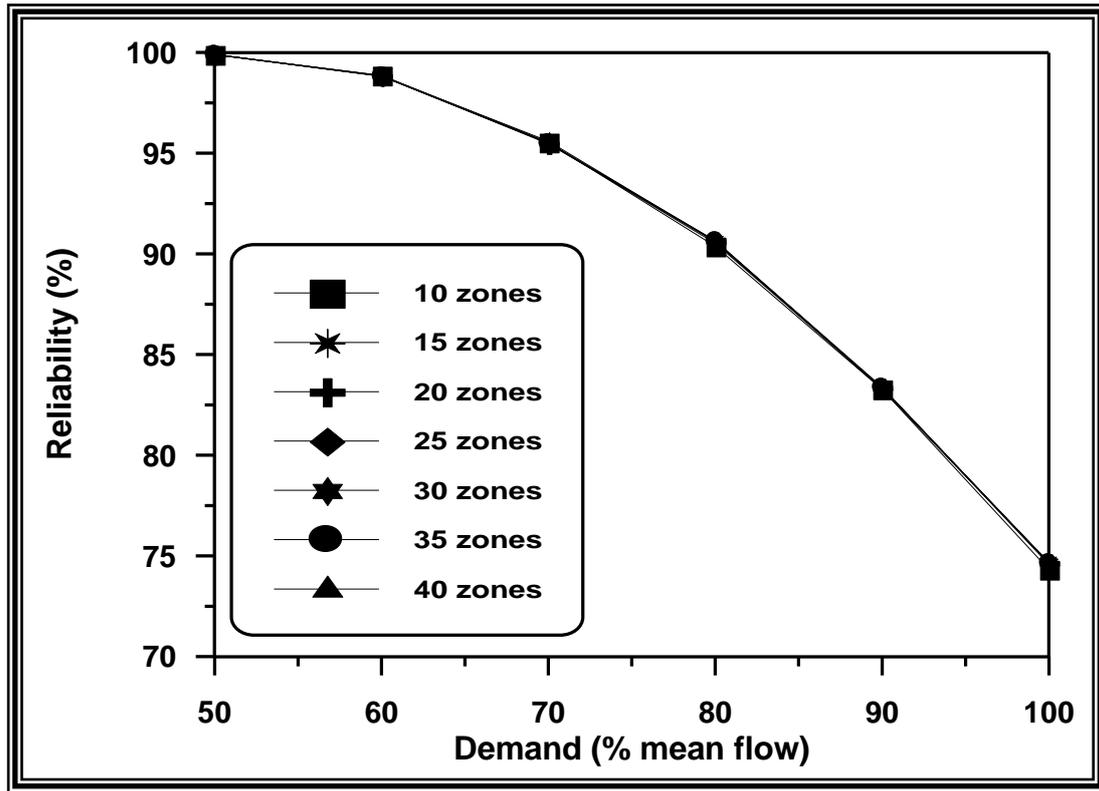


Figure (5.11): Effect of number of zone on the estimation of the reliability by Gould's procedure.

Figure (5.12) shows a schematic representation of the finite reservoir. The left side represents the initial state while the right side represents the final state, each state has a volume of (W), where $W = C / (K - 2)$ and k is the state number.

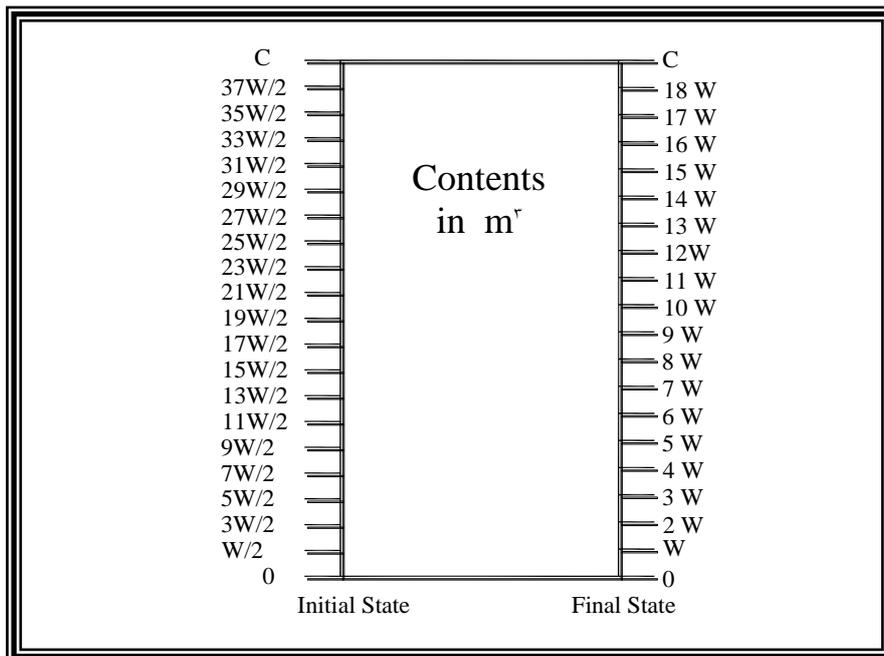


Figure (5.12): Haditha reservoir divided into 20 zones.



The empty and full condition states signify that the reservoir exactly at the minimum pool elevation and at capacity, respectively. The initial state begins at the center of each zone and the reservoir considered to be at any final state if the storage of the reservoir, at the end of the routing during one year, lies between the two boundaries enclosed this state.

5.5.2 Construction of The Transition Matrix

Section (3.4.5) described the construction of the transition matrix. The mass storage equation is applied on a monthly basis for every year of data separately starting in each zone, then the reservoir content at the end of each year will lie in one of the ending zone. This is done for all starting zones (\cdot , $W/2$, $3W/2$, $5W/2$, -----, C).

Table (5.13) shows the transition matrix of (2×2) zones for the historical data and $v\%$ mean flow used as a demand from the reservoir. This table shows that if the reservoir was at the zone (\cdot) at the beginning of the year, this reservoir has a probability of ($\cdot\cdot^{11}$) for being in zone ($1\cdot$) at the end of this year, also the reservoir has a probability of ($\cdot\cdot^{12}$) for being in zone (ϵ) of the end of the year if the reservoir was at zone ($1\cdot$) at the beginning of this year, and so on.

5.5.3 Construction of The Steady – State Probability Matrix

The steady – state probability is the probability of the certain state after a long period. As mentioned in chapter three, there are three methods used for computing the steady – state probability. The present study adopted the method which finds these probabilities by solving a system of simultaneous equations.

The resulting matrix (table (5.14)) represents the probabilities of the initial and final states if ($t \rightarrow \infty$).

Table (٥.١٣): The transition matrix for Haditha reservoir (٧٠٪ mean flow, ٢٠ zones).

Zone	٠	١	٢	٣	٤	٥	٦	٧	٨	٩	١٠	١١	١٢	١٣	١٤	١٥	١٦	١٧	١٨	١٩
٠	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١١٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٧٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٢٩	٠.٠٢٩
١	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٤٤	٠.٠٢٩	٠.٠٢٩	٠.٠٤٤	٠.٠٥٩	٠.٠١٥	٠	٠	٠	٠	٠	٠.٠١٥	٠.٠٢٩	٠	٠	٠.٠١٥	٠.٠١٥
٢	٠	٠	٠	٠	٠.٠١٥	٠	٠	٠.٠١٥	٠.٠٤٤	٠.٠١٥	٠	٠	٠	٠	٠	٠.٠١٥	٠.٠٢٩	٠	٠	٠
٣	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠١٥	٠.٠١٥	٠.٠٢٩	٠.٠٧٤	٠.٠٢٩	٠	٠	٠	٠	٠	٠.٠١٥	٠.٠٢٩	٠.٠١٥	٠
٤	٠	٠	٠	٠	٠	٠.٠١٥	٠.٠١٥	٠	٠	٠	٠.٠٥٩	٠.٠٢٩	٠	٠	٠	٠	٠	٠.٠١٥	٠.٠١٥	٠.٠٢٩
٥	٠.٠١٥	٠.٠١٥	٠	٠	٠	٠	٠.٠١٥	٠.٠١٥	٠	٠	٠	٠.٠٥٩	٠.٠٢٩	٠	٠	٠	٠	٠	٠.٠١٥	٠.٠١٥
٦	٠.٠٢٩	٠.٠٢٩	٠.٠٤٤	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٤٤	٠.٠١٥	٠	٠	٠	٠.٠٥٩	٠.٠٢٩	٠	٠	٠	٠	٠	٠
٧	٠.٠١٥	٠.٠١٥	٠.٠١٥	٠.٠٢٩	٠.٠١٥	٠.٠١٥	٠.٠١٥	٠	٠.٠٤٤	٠.٠١٥	٠	٠	٠	٠.٠٥٩	٠.٠٢٩	٠	٠	٠	٠	٠
٨	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٤٤	٠.٠١٥	٠.٠١٥	٠.٠٢٩	٠.٠١٥	٠.٠٥٩	٠.٠٢٩	٠.٠٢٩	٠.٠١٥	٠.٠١٥	٠.٠٧٤	٠.٠٥٩	٠.٠١٥	٠.٠١٥	٠.٠١٥	٠.٠١٥
٩	٠	٠	٠	٠	٠	٠.٠٢٩	٠	٠	٠.٠١٥	٠	٠.٠٤٤	٠	٠.٠١٥	٠	٠	٠.٠٤٤	٠.٠٥٩	٠	٠	٠
١٠	٠.٠٤٤	٠.٠٤٤	٠.٠٢٩	٠.٠١٥	٠	٠	٠.٠٢٩	٠	٠	٠.٠١٥	٠	٠.٠٤٤	٠	٠.٠١٥	٠.٠١٥	٠.٠١٥	٠.٠٤٤	٠.٠٧٤	٠.٠٢٩	٠.٠٢٩
١١	٠	٠	٠.٠١٥	٠.٠١٥	٠.٠١٥	٠	٠	٠.٠٢٩	٠	٠	٠.٠١٥	٠	٠.٠٤٤	٠	٠	٠	٠	٠.٠٢٩	٠.٠٤٤	٠.٠١٥
١٢	٠.٠٧٤	٠.٠٧٤	٠.٠٥٩	٠.٠٧٤	٠.٠٥٩	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٥٩	٠.٠٢٩	٠.٠٢٩	٠.٠٤٤	٠.٠٢٩	٠.٠٧٤	٠.٠٤٤	٠.٠٢٩	٠.٠٢٩	٠.٠٢٩	٠.٠٥٩	٠.٠٨٨
١٣	٠.٠٢٩	٠.٠٢٩	٠.٠٤٤	٠.٠٢٩	٠.٠٥٩	٠.٠١٣	٠.٠٧٤	٠.٠٧٤	٠.٠٧٤	٠.٠١٣	٠.٠٨٨	٠.٠٨٨	٠.٠١٣	٠.٠١٣	٠.١٣٢	٠.١٣٢	٠.١١٨	٠.١١٨	٠.١١٨	٠.١١٨
١٤	٠.٠٨٨	٠.٠٧٤	٠.٠٧٤	٠.٠٨٨	٠.٠٧٤	٠.٠٧٤	٠.٠١٣	٠.٠١٣	٠.٠١٣	٠.٠١٣	٠.١١٨	٠.١١٨	٠.١١٨	٠.١١٨	٠.١١٨	٠.١٣٢	٠.١٤٧	٠.١٣٢	٠.١٣٢	٠.١٣٢
١٥	٠.١٤٧	٠.١٤٧	٠.١٣٢	٠.١٣٢	٠.١٤٧	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٣٢	٠.١٤٧	٠.١٣٢
١٦	٠.١٧٦	٠.١٧٦	٠.١٩١	٠.١٧٦	٠.١٦٢	٠.١٧٦	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٤٧	٠.١٦٢
١٧	٠.٠٧٤	٠.٠٨٨	٠.٠٤٤	٠.٠٥٩	٠.٠٥٩	٠.٠٤٤	٠.٠٧٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٤٤	٠.٠٥٩
١٨	٠.٠٤٤	٠.٠٢٩	٠.٠٧٤	٠.٠٥٩	٠.٠٧٤	٠.٠٨٨	٠.٠٨٨	٠.١١٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨
١٩	٠.٠٢٩	٠.٠٤٤	٠.٠٤٤	٠.٠٥٩	٠.٠٥٩	٠.٠٥٩	٠.٠٥٩	٠.٠٥٩	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨	٠.٠٨٨

3.3.4 Construction of Conditional Probability of Reservoir Failure Matrix

This matrix represents the probability that the reservoir content (S_{t+1}) is equal to or less than zero. The matrix computed by routing, for each state, the inflows and outflows through the reservoir and accounting the number of times in which the reservoir content will be equal or less than zero. This routing made for each year of Haditha reservoir records. Then, the number of times that the reservoir lies in the failure region is divided into $(12 * N)$ to convert this numbers to probabilities.

Table (3-10) shows the conditional probability of the reservoir failure matrix.

3.3.5 Estimating The Reservoir Reliability

The test steps of estimation the reliability are the computation of the probability of failure by using equation (3-10), then the reliability of the reservoir is found by using equation (3-11). Table (3-10) shows the computation of Haditha reservoir reliability with a release of 70% from the mean flow.



Table (5.15): The computation of probability of failure by Gould's probability matrix method (70% mean flow demand).

Zone	Steady state probability of failure(%)	Conditional probability of failure(%)	Over all probability of failure(%)
0	6.90E-02	3.09E-01	2.13E-02
1	1.30E-02	3.01E-01	4.07E-03
2	8.30E-03	2.44E-01	2.04E-03
3	1.16E-02	1.79E-01	2.07E-03
4	6.39E-03	1.29E-01	8.22E-04
5	6.01E-03	9.80E-02	5.89E-04
6	1.09E-02	7.30E-02	7.98E-04
7	1.30E-02	5.27E-02	7.09E-04
8	3.10E-02	4.76E-02	1.44E-03
9	1.73E-02	4.04E-02	7.00E-04
10	0.020013	3.19E-02	8.13E-04
11	9.60E-03	3.19E-02	3.07E-04
12	4.88E-02	2.40E-02	1.20E-03
13	0.100999	2.08E-02	2.21E-03
14	0.122241	1.72E-02	2.10E-03
15	0.134319	1.23E-02	1.60E-03
16	0.101641	9.80E-03	1.49E-03
17	4.80E-02	7.30E-03	3.07E-04
18	8.42E-02	4.90E-03	4.13E-04
19	8.18E-02	3.78E-03	3.01E-04
Probability of failure			4.04E-02

5.6 Verification of Data Generation Techniques

The models which are used in this study are designated by the following: TFM = Thomas – Fiering monthly model with hypothesis of log – transformation; TTM = two – tier model using Markovian annual flows; MTTM = modified two – tier model; MFM = modified fragment model; and BCM = Thomas – Fiering monthly model with Box – Cox transformations.



The verification of data generation techniques is based on two approaches: the first depends on the comparison of the cumulative probability function for the two series from historical and generated data (**Abdul – Rasoul, 1981**), the second depends on the comparison of statistical parameters calculated from the historical data and generated sequences.

In the second approach, for the purpose of simplicity in comparison of seasonal parameters, the relative error (as a percentage) was calculated (**Bajilvia, 2000**) and (**Srikanthan and McMahon, 1982**). The relative error was obtained from:

$$\text{Relative error} = \frac{\text{Generated value} - \text{Historic value}}{\text{Historic value}} * 100\%$$

Figure (5.12) shows the cumulative probability function curves for Haditha reservoir inflows based on historical and generated data. This figure indicates that the MTTM is the closest to historical curve. Also, it can be noticed that only the modified fragment model curve is significantly differs from that produced from historical data, while the TFM, TTM and BCM could be considered an acceptable from the point of view of this comparison.

Figures (5.13) to (5.18) show the relative error of mean, standard deviation, coefficient of variation, coefficient of skewness, correlation coefficient and regression coefficient, respectively. It can be seen that the TFM, TTM and MTTM models preserved the seasonal monthly parameters better than the BCM and MFM models except of the coefficient of skewness which preserved by MFM is better than the TFM and MTTM. However, there was only a small differences between the TFM and MTTM results, especially for coefficient of skewness, coefficient of variation, correlation coefficient and regression coefficient.

There is a worthness to say here that it is not a condition that the model preserved the statistical parameters to be the best model for the reliability, vulnerability and resilience estimation but this will give more trust for this estimation.

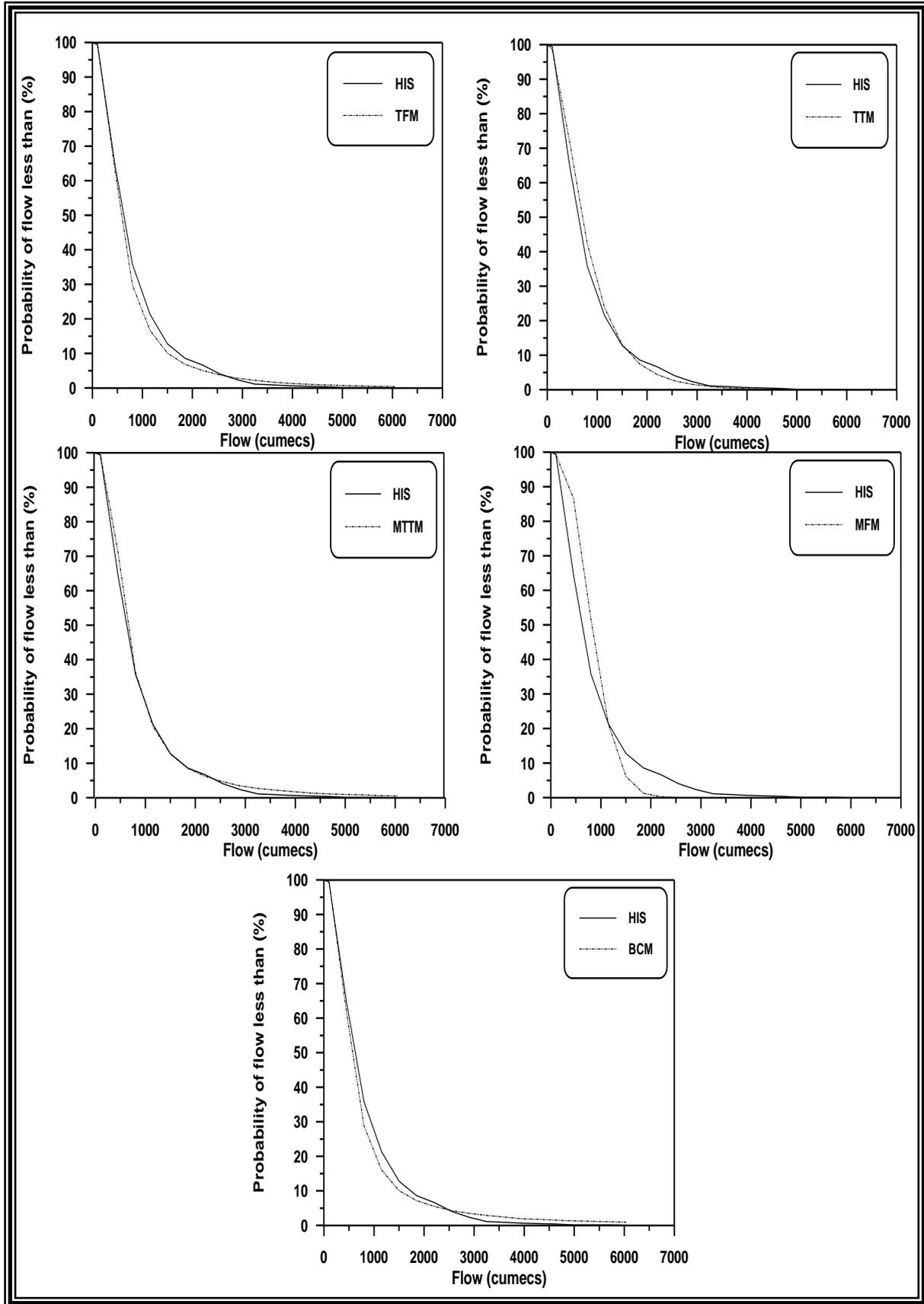
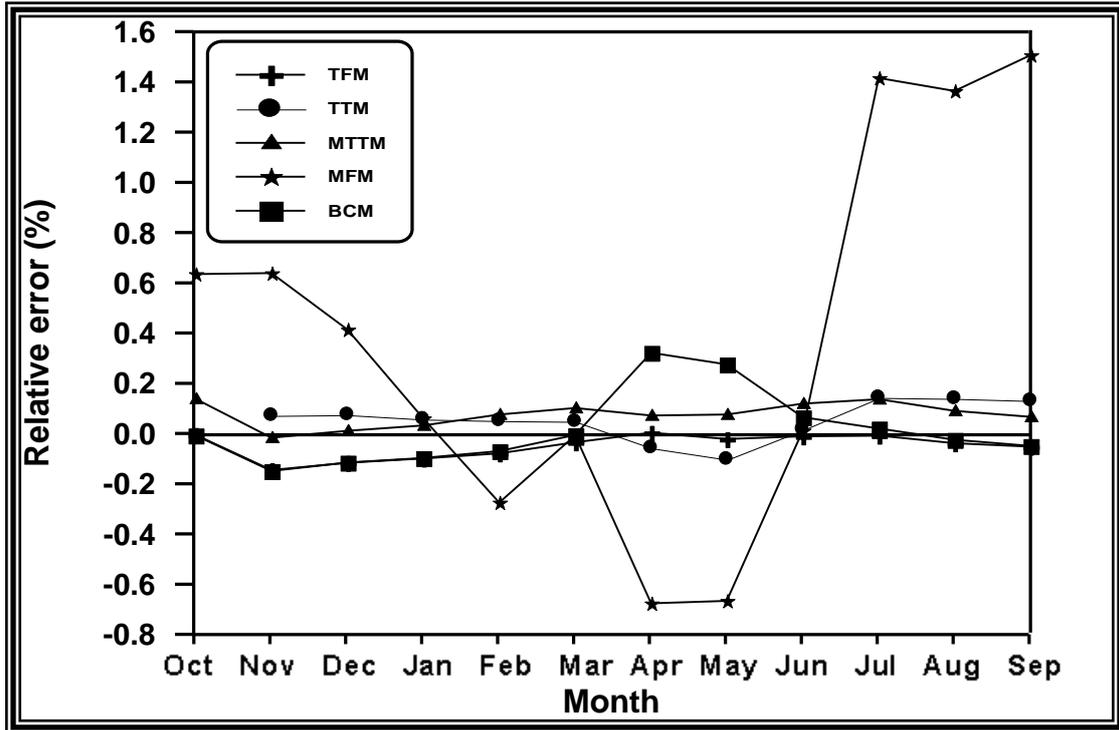
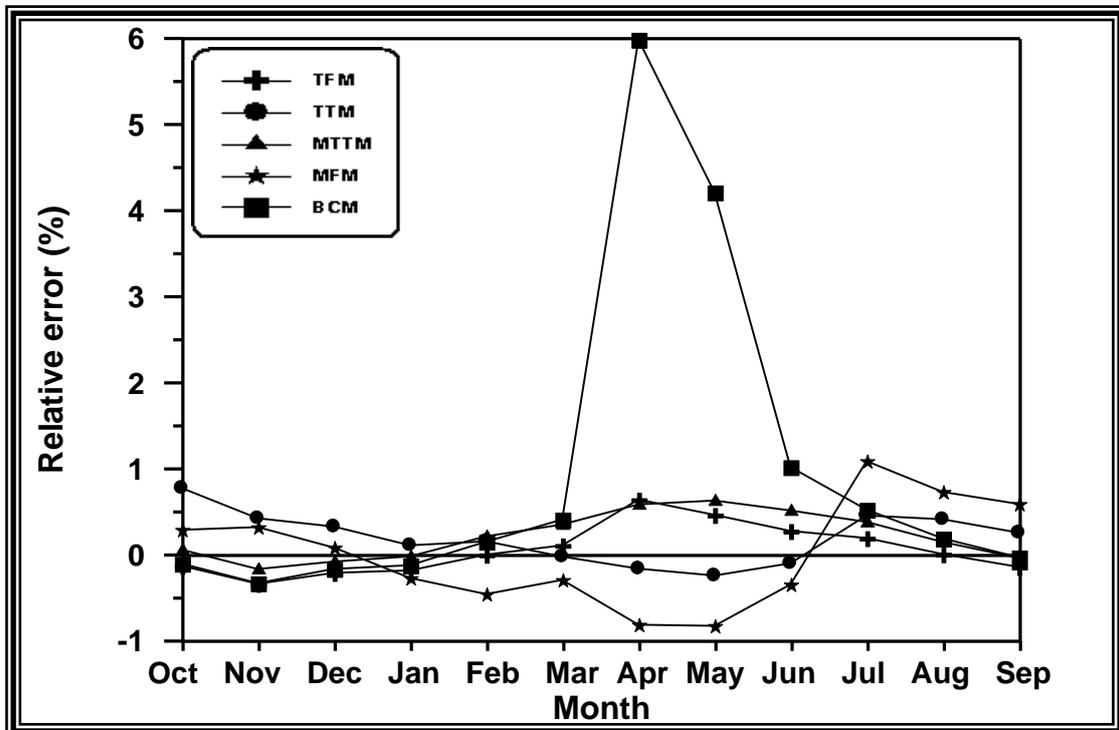


Figure (٥.١٢): Cumulative probability function for Haditha reservoir inflow by using both of historical and generated data.



Figure(5.13):Relative error of the mean of generated data with respect to historical data.



Figure(5.14): Relative error of the standard deviation of generated data with respect to historical data.

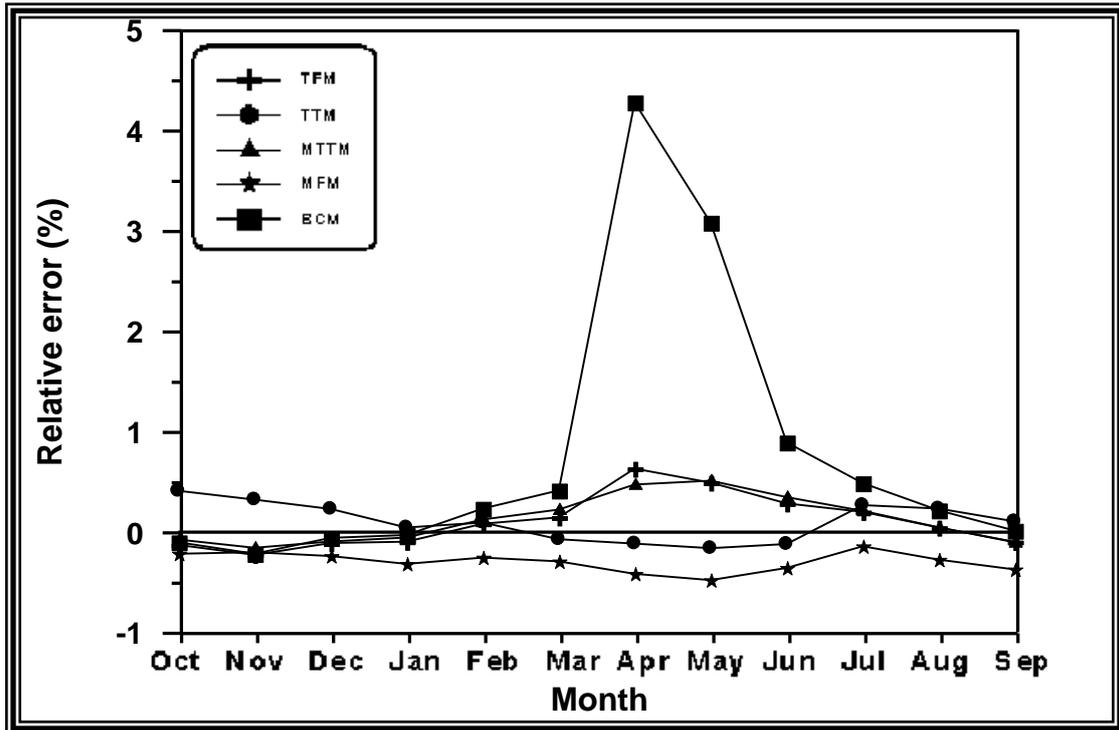


Figure (5.15): Relative error of the coefficient of variation of generated data with respect to historical data.

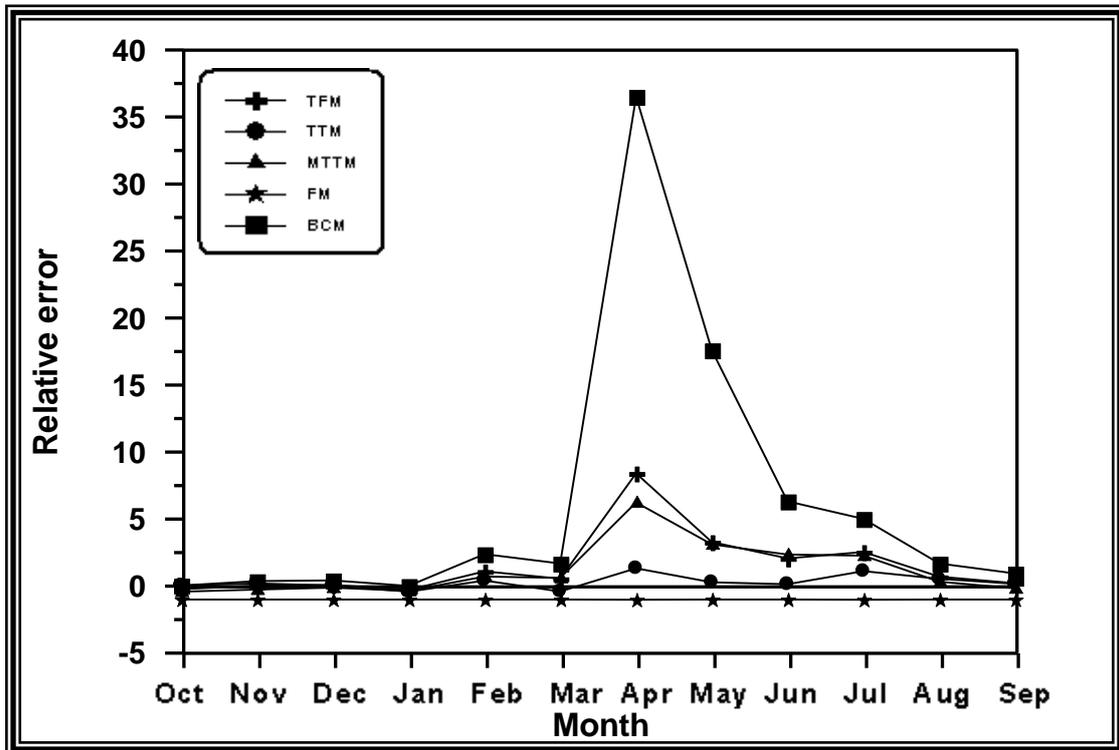


Figure (5.16): Relative error of the coefficient of skewness of generated data with respect to historical data.

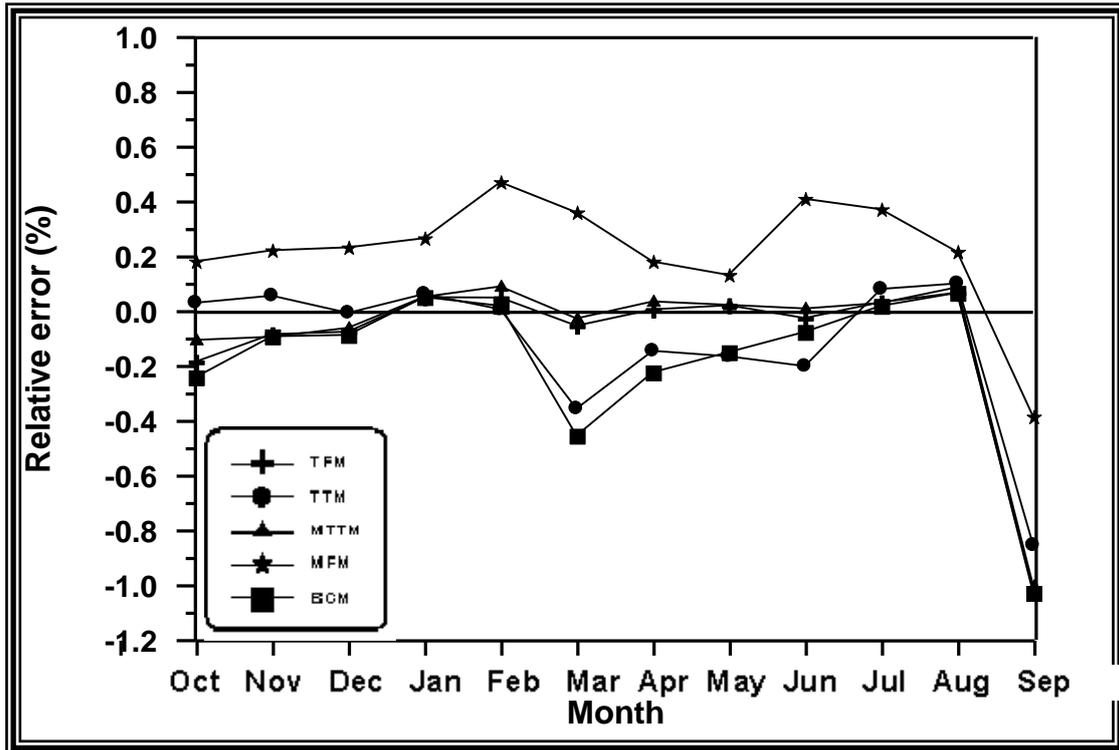


Figure (5.17): Relative error of the correlation coefficient of generated data with respect to historical data.

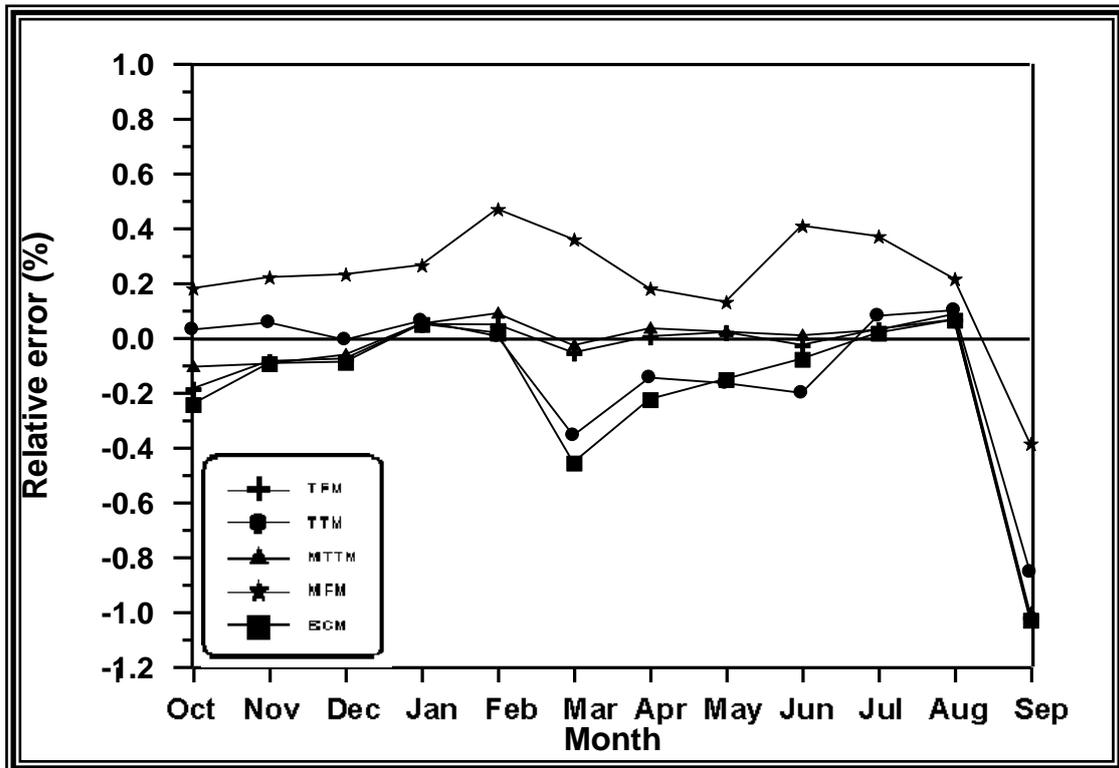


Figure (5.18): Relative error of the regression coefficient of generated data with respect to historical data.



5.7 Analysis of The Results

Figure (5.19) explains the effect of the number of years used in the analysis on the estimation of reliability by behavior procedure for the five approaches of generation used in this study. It could be seen that the (18) year estimation series of reliability diverges a way from this comes from longest series. Furthermore, the using of the longest and longest series will converge the results one to another.

Figure (5.20) shows the same effect of figure (5.19) but by using the Gould's procedure. This figure indicates that the sensitivity of results by using Gould's procedure will be less than this of behavior procedure. Also, it could be seen that Gould's estimation of reliability almost less than the behavior estimation.

Figure (5.21) and figure (5.22) show the effect of the length of time series used in the reservoir analysis for the vulnerability and resilience, respectively. Figure (5.21) shows that the estimated vulnerability tends to move on approximately straight line and converge from one model of generation to another under the effect of time series length with increasing the monthly release from the reservoir. Figure (5.22) shows that there is a high variation in the estimated value of resilience under the effect of number of years used in the analysis and, as in reliability, the longest and longest series will converge the results.

As a result, the using of longest series in the behavior analysis to estimate the reliability, vulnerability and resilience of reservoir will make the results more accuracy because of the starting month problem and the assumption of initially full reservoir will be overcome by using such series.

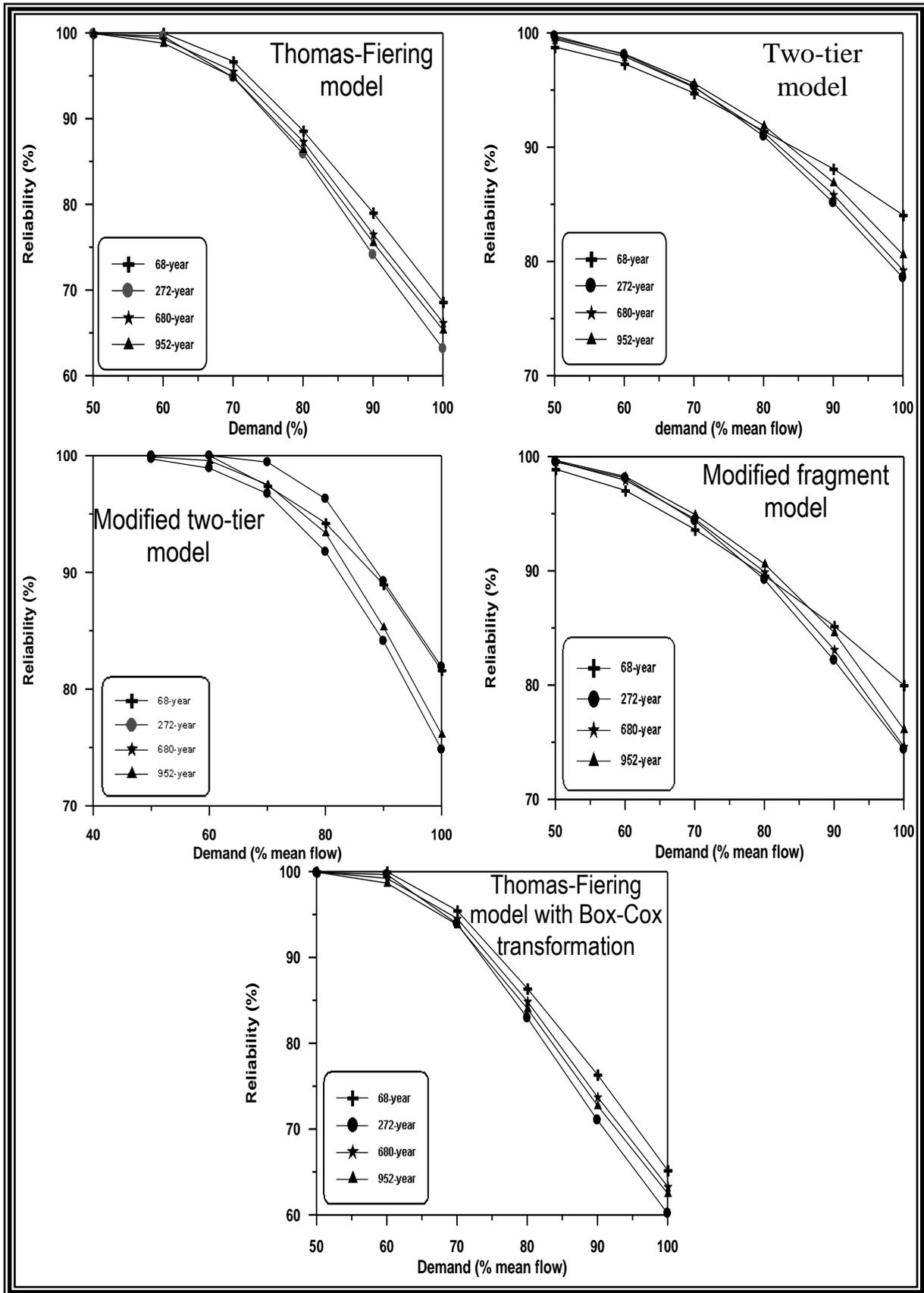


Fig. (5.19): Effect of number of years used in generation on the estimation of reliability by behaviour procedure.

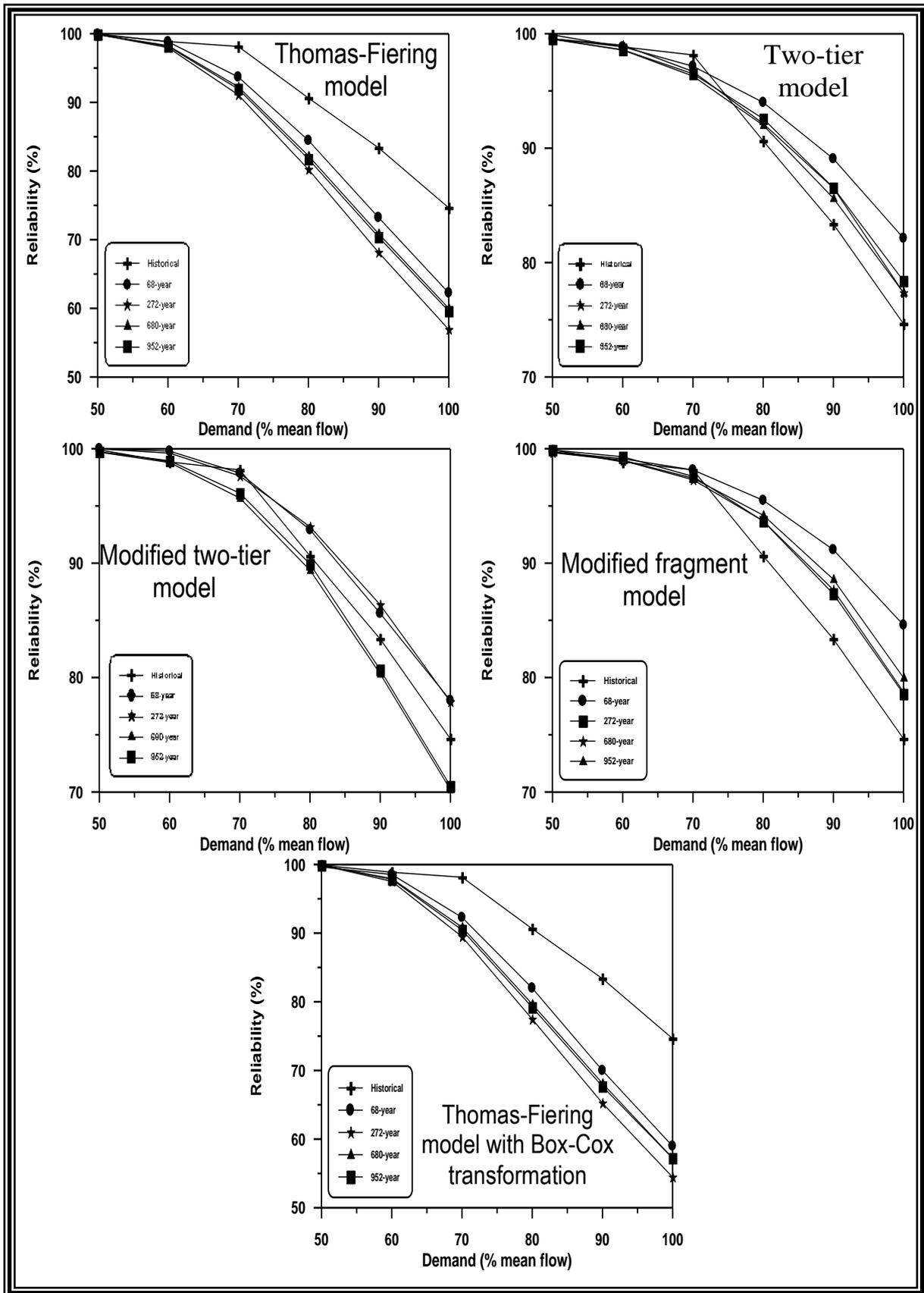


Fig. (5.20): Effect of number of years used in generation on the estimation of reliability by Gould's procedure.

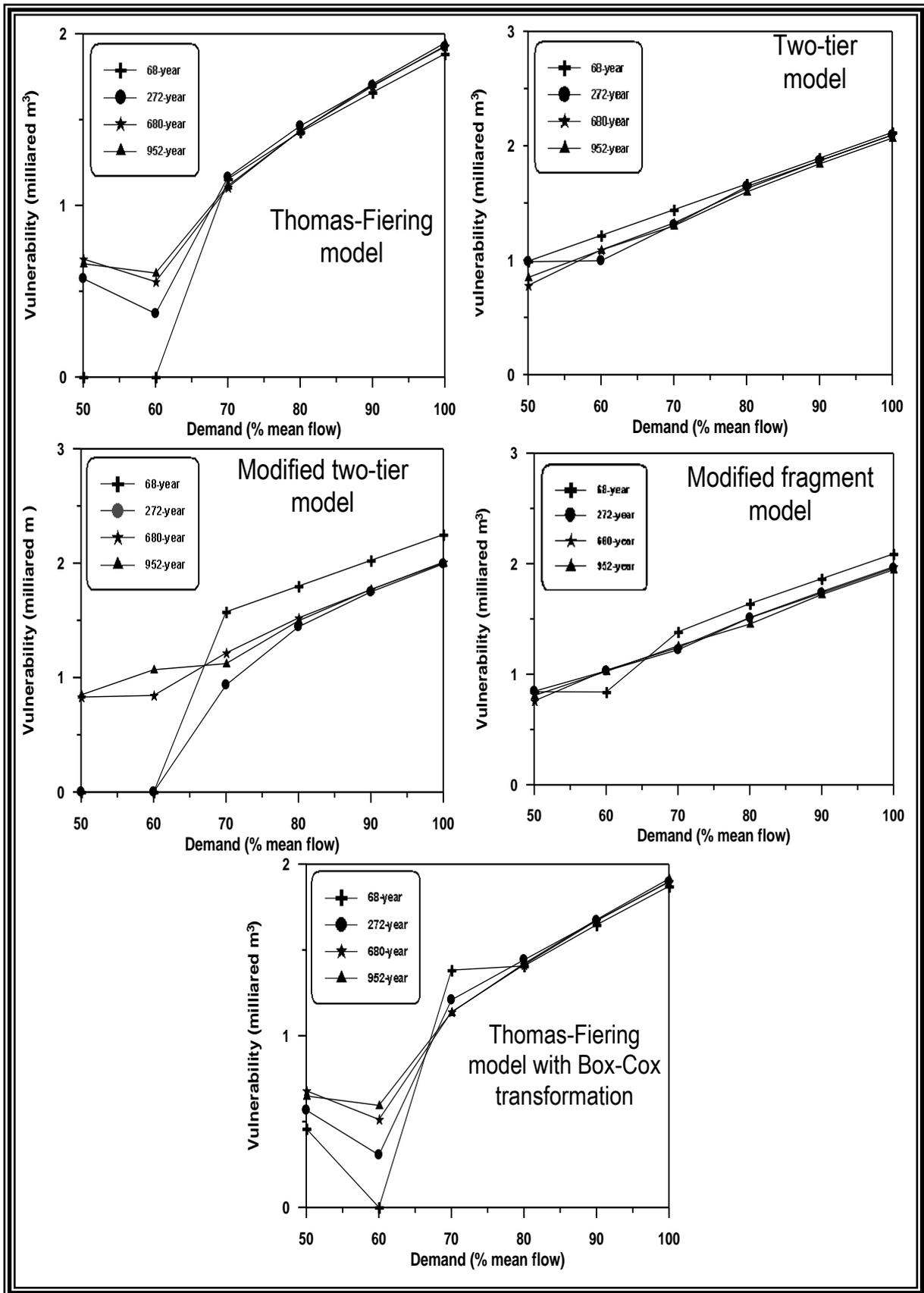


Fig. (5.21): Effect of number of years used in generation on the estimation of vulnerability by behaviour procedure.

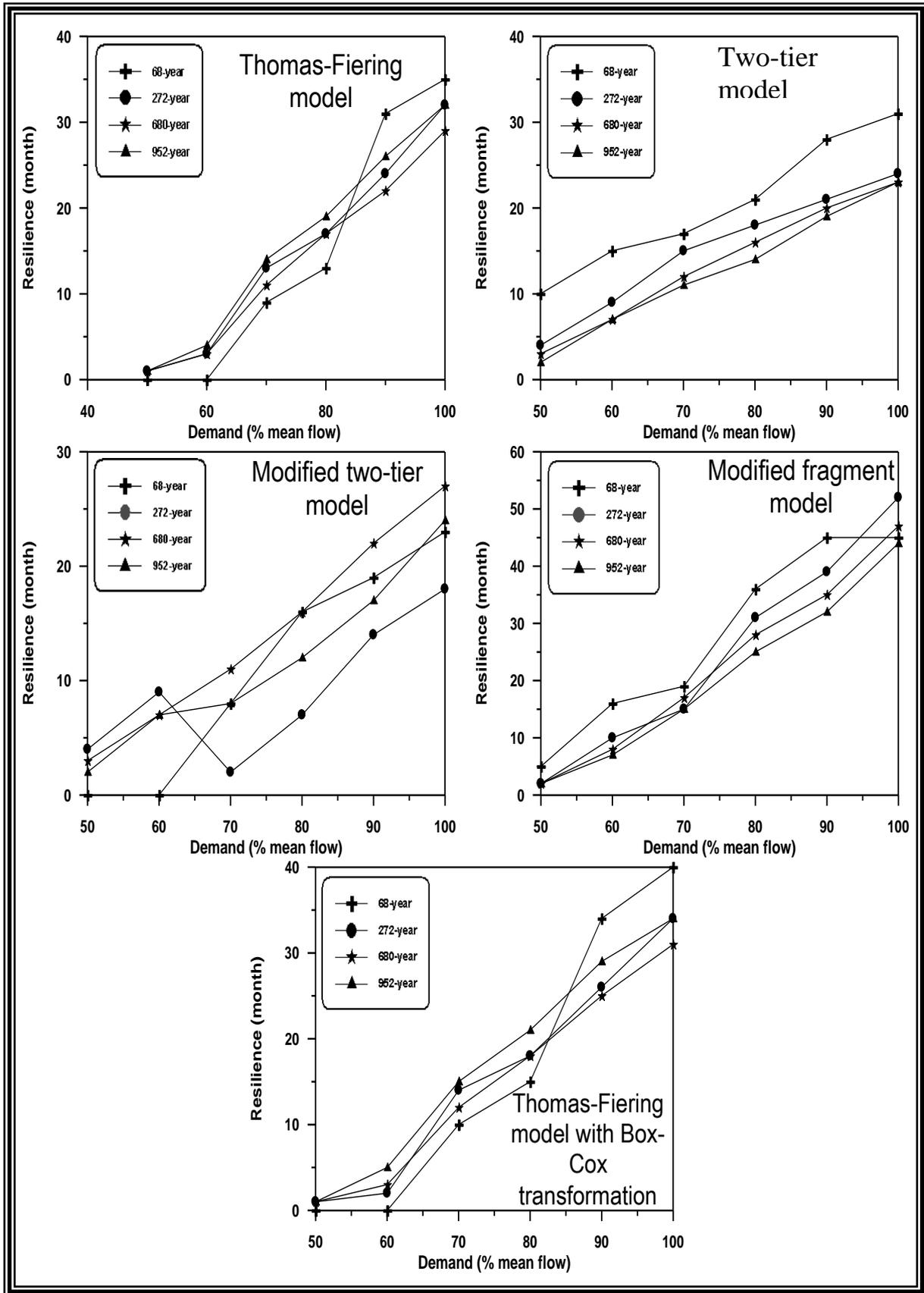


Fig. (۵.۲۲): Effect of number of years used in generation on the estimation of resilience by behaviour procedure.



Figures (5.23) and (5.24) show the reliability – yield relationship by using Gould and Behaviour procedures, respectively. Figure (5.23) indicates that the BCM and TFM give a smaller reliability estimate than the other models where MTTM and TTM results converges to the results based on the historical data which considered to be a reasonable one by many researcher in literature. This means that the MTTM and TTM could be considered the best to represent the inflow of Haditha reservoir. Behaviour estimation of reliability is almost more than the case of using Gould's procedure for Haditha reservoir. The 90% reliability, which is considered to be an acceptable limit of reliability (**Harris, 1990**) and (**McMahon et .al, 1992**), could be obtained with a release of (70%- 76 %) and (72% - 70 %) from the mean flow depending on Behaviour analysis and Gould's procedure, respectively.

Figure (5.25) shows the vulnerability – yield relationship and indicates that the vulnerability of reservoir increasing and tends to be a straight line with the increasing of the release (decreasing the reliability) by using the historical and generated data.

Figure (5.26) shows the resilience yield relationships and indicates that there is a high difference between the historical and generated data estimate. It is also obvious that reservoir resilience increases with the increasing of the release from the reservoir.

Figure (5.27) shows the reliability – resilience relationship. The high difference in results by using the historical data and the data generated by MFM is obvious which ensures that both approaches are not suitable for using in the evaluation of reservoir risk measures. This figure also indicates that the resilience of reservoir decreasing with the



increasing of reliability. Also it is shown that the (90%) reliability of reservoir found with a resilience of (10 – 12) months and to decreasing this value to another desirable one, if need, it must increase the reliability, i.e., decreasing the release.

Figure (5.28) shows the reliability – vulnerability relationship. This figure indicates that the vulnerability of reservoir decreased with the increasing of reliability. The (90 %) reliability is found with a vulnerability of (1.2 – 1.4) milliared m³.

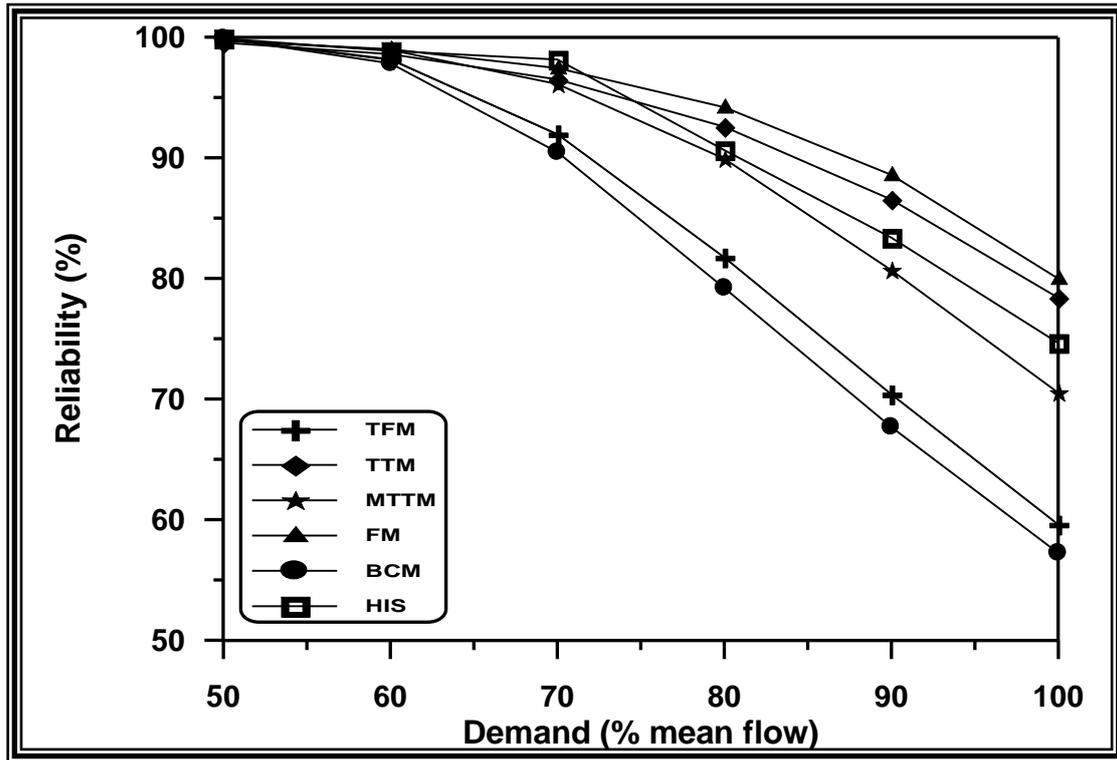


Fig. (5.23): Reliability-yield relationship of Haditha reservoir depending on Gould's procedure by using both historical and generated data (902 years of generation).

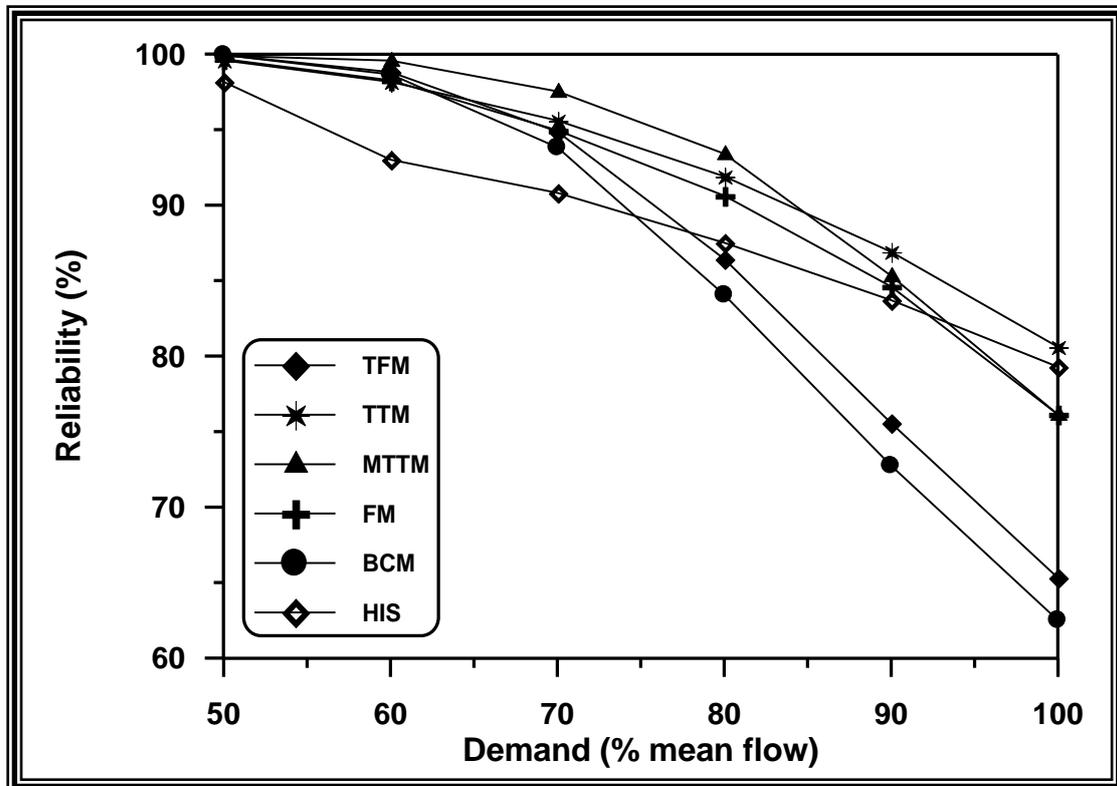


Fig. (5.24): Reliability-yield relationship depending on behaviour procedure by using both historical and generated data (902 years of generation).

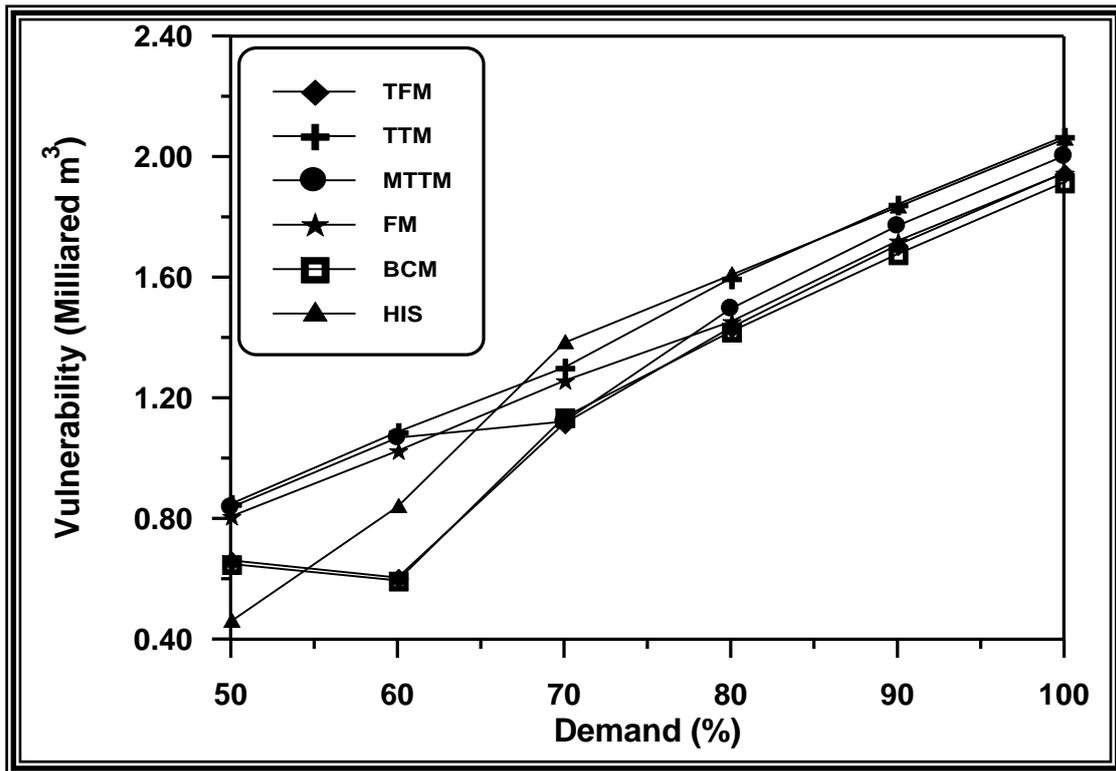


Fig. (5.25): Vulnerability-yield relationship depending on both historical and generated data (902 years of generation).

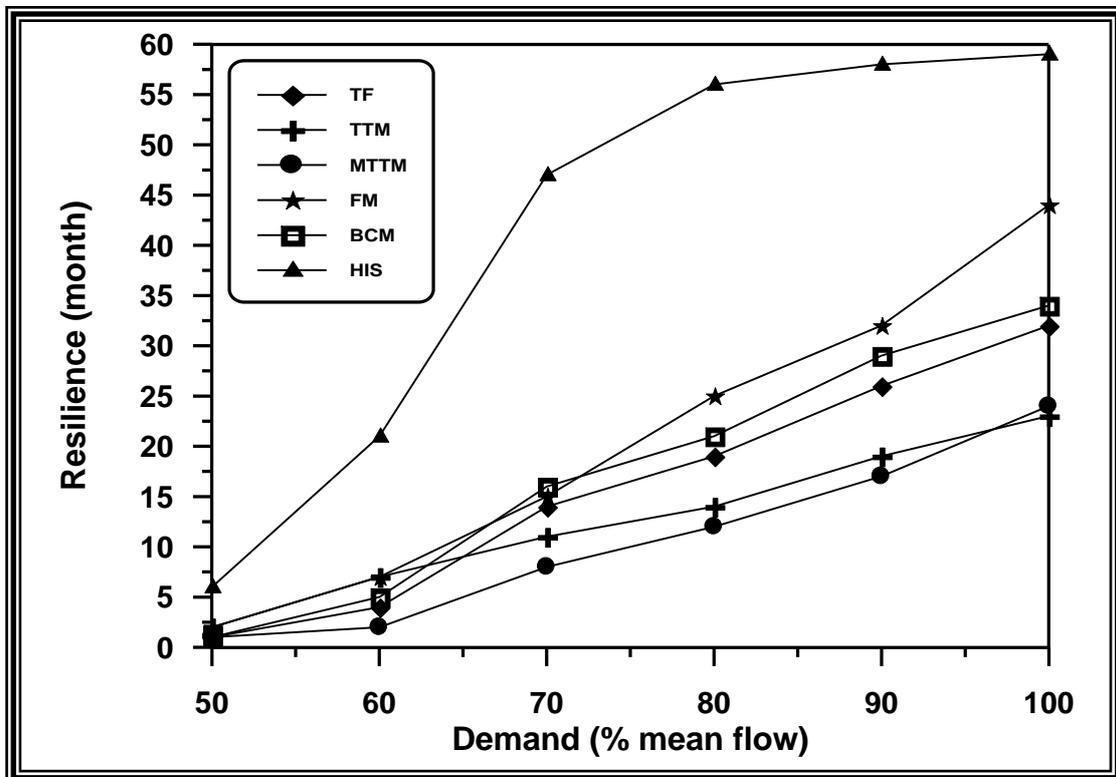


Fig. (5.26): Resilience-yield relationship depending on both historical and generated data (902 years of generation).

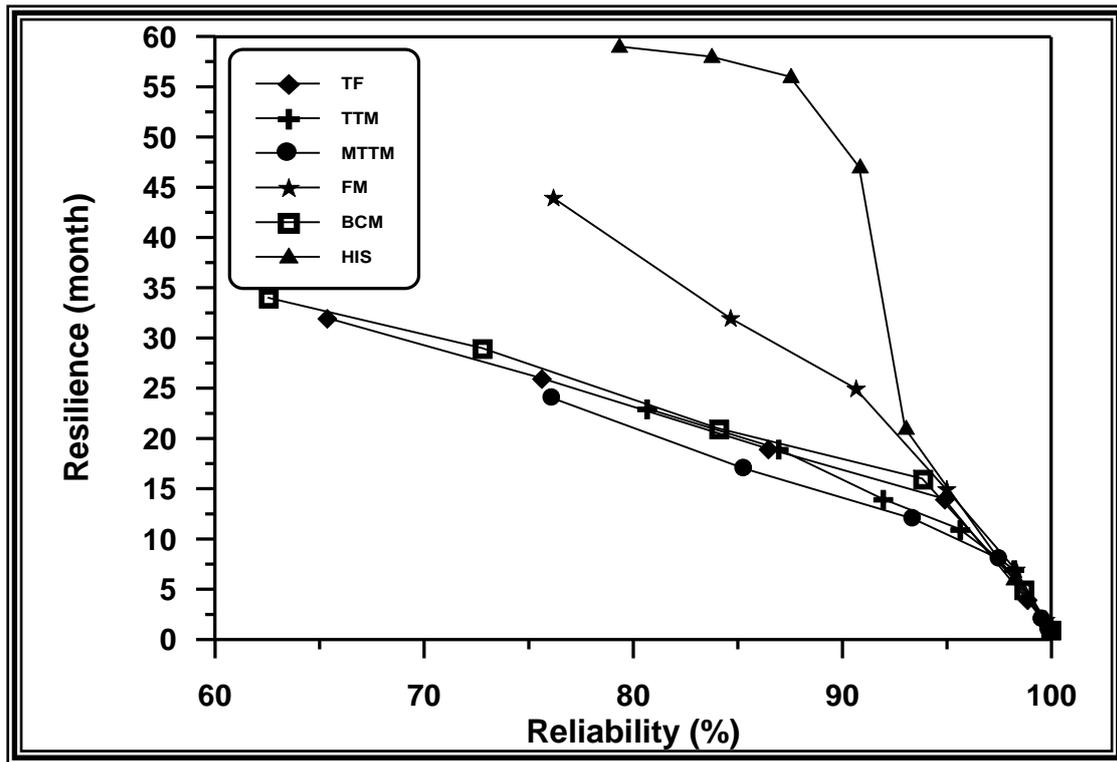


Fig. (5.27): Reliability-resilience relationship depending on both historical and generated data (902 years of generation).

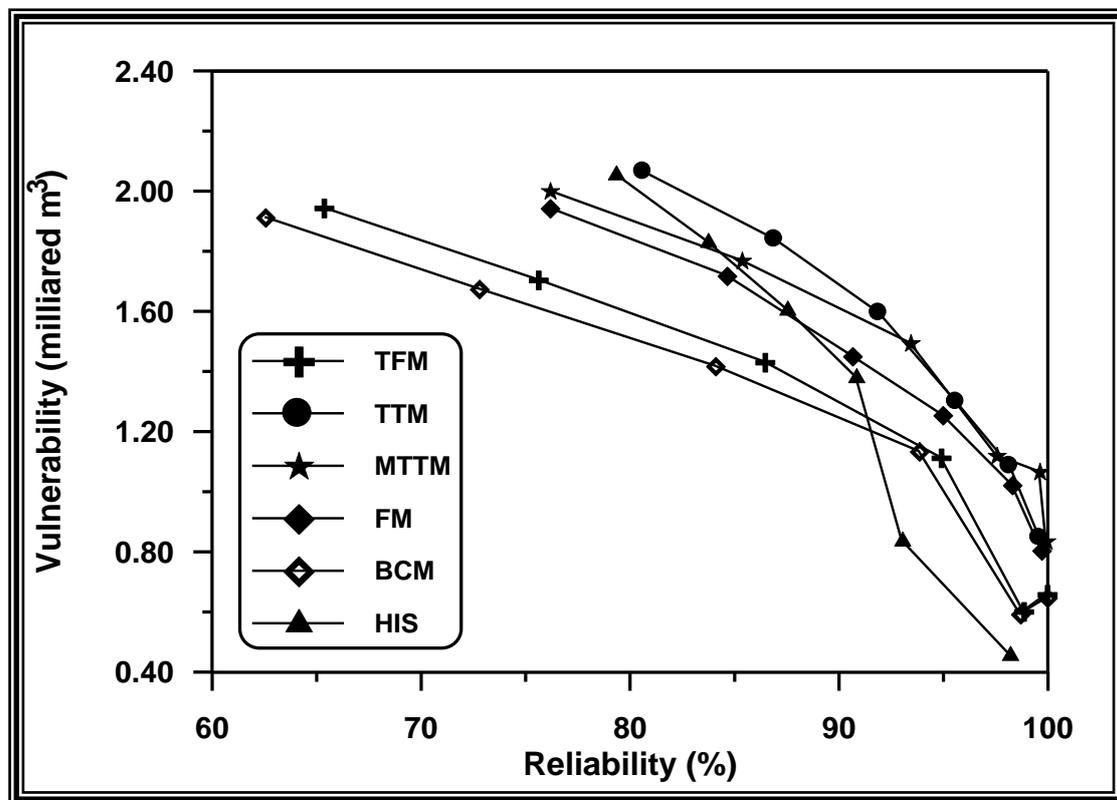


Fig. (5.28): Reliability-vulnerability relationship depending on both historical and generated data (902 years of generation).

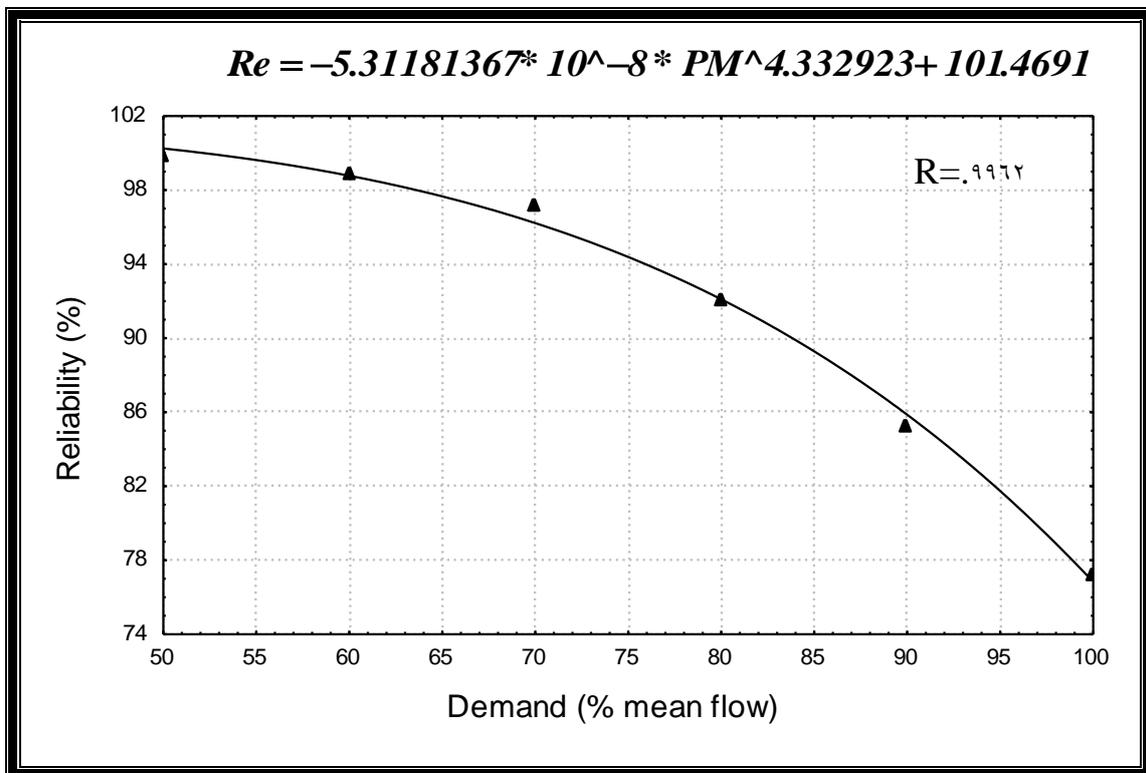


5.8 Reliability, vulnerability and resilience-yield relationships

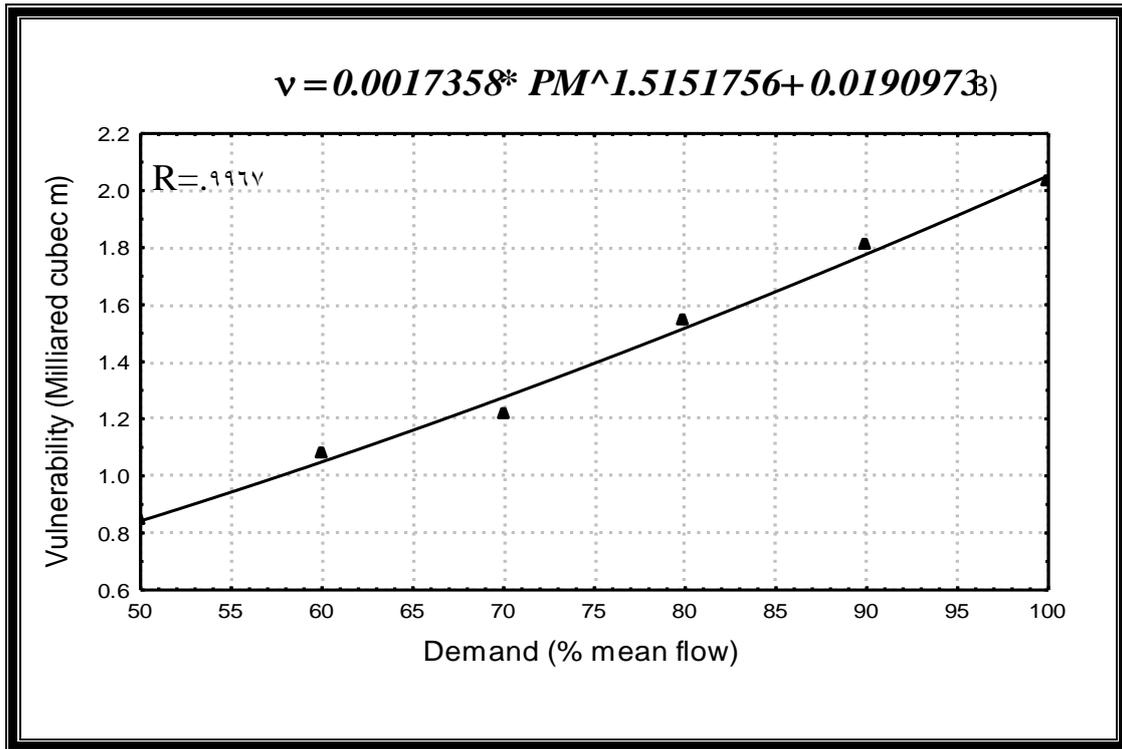
This section deals with reliability-vulnerability-resilience-yield relationships (yield taken as percentage from the mean flow, PM) which are important relationships for examining the policy of reservoir operation. These relationships give preliminary estimations of reliability, vulnerability and resilience for various demands downstream of the dam.

The STATISTICA PACKAGE is used for the estimation of these relationships, the reliability-yield relationship depended on the average of Gould’s method using historical data results and the behaviour method results using both MTTM and TTM, where vulnerability and resilience-yield relationships depended on the average of behaviour method results using MTTM and TTM.

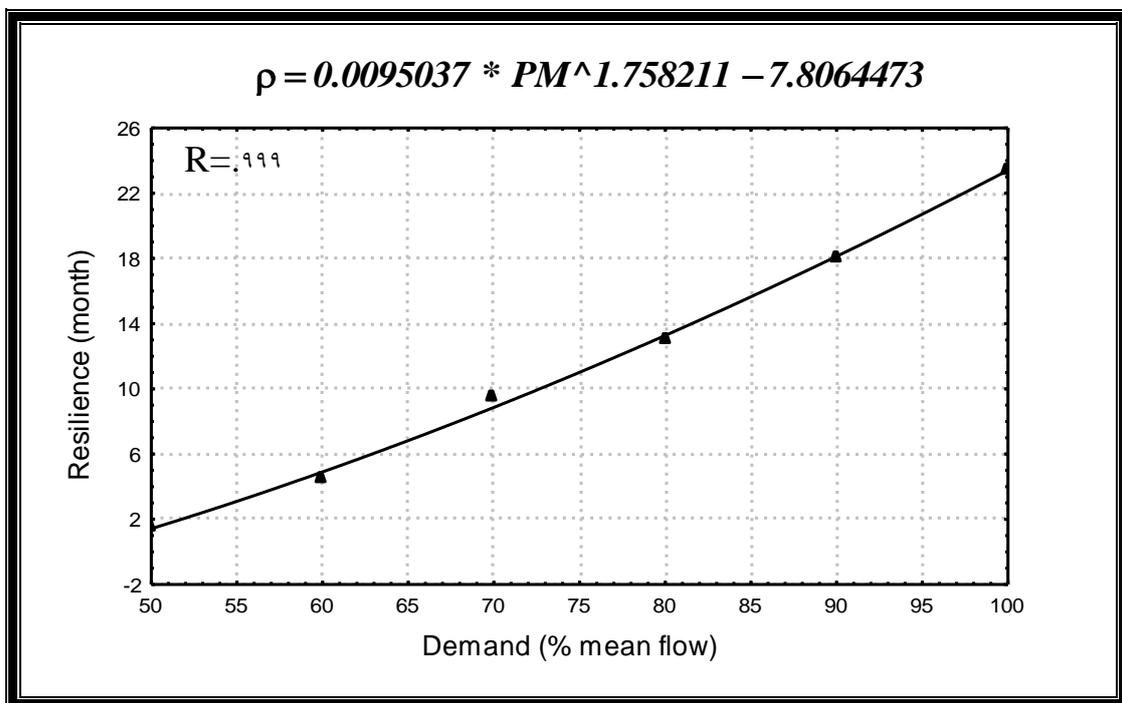
Figures (5-29), (5-30), and (5-31) show these relationships and the empirical equation suggested. These relationships have a correlation factor of 0.9962, 0.9967, and 0.999 for reliability, vulnerability and resilience, respectively.



Figure(5-30): Reliability-yield relationship



Figure(5-31): Vulnerability-yield relationship



Figure(5-32): Resilience-yield relationship



C onclusions and Recommendations

6.1 Conclusions

Based on the results of this research, the following conclusions can be drawn:

1. The reliable yield which can be released from Haditha reservoir is (73%) of the mean monthly flow. The vulnerability corresponding to this release is very high ,i.e., $1.2 \times 10^9 \text{ m}^3$, the resilience is also high, i.e., (10-12) month. Therefore release must be reduced for being in acceptable policy.
2. Comparisons of sequences generated by TFM, TTM, MTTM, MFM and BCM with the historical results indicate that the MTTM and TTM are the best for generating monthly inflows of Haditha reservoir.
3. Basing on the chi-square test and Kolomogrov-Smirnov test, it is found that the lognormal and normal distributions are the best for representing the monthly and annual inflow for Haditha reservoir, respectively.
4. Both resilience and vulnerability are decreased with increasing the reliability of reservoir.



- . The behaviour procedure using data generation techniques is satisfactory for estimating the reservoir reliability, vulnerability and resilience while Gould's procedure using historical data is satisfactory for estimating the reservoir reliability.
- ٦. Gould's procedure results are almost less than those of behaviour procedure basing on both historical and generated data.
- ٧. The estimation of reliability, vulnerability and resilience is significantly affected by the length of sequences used in the analysis.
- ٨. In Gould's procedure, the estimation of Haditha reservoir reliability is slightly affected by the number of zones that the reservoir capacity will divide into.

٦.٢ Recommendations for future works

For making this work as the best and for arriving to the best results that serve science and mankind , great efforts have been made , and perfection is a speciality of God only , therefore ; this research may be followed by further works and achievements in this field in the future considering the following recommendations :

- ١. Using a multi-objective, mixed-integer linear programming model with an objective function takes into account the reliability, vulnerability and resilience.
- ٢. Estimating reservoir risk measures based on short time period such as (١٥ days, ١٠ days,.....)



۳. Applying other capacity-yield procedures and other generation models to other Iraqi reservoir.
۴. Using a variable monthly demand for estimating reservoir reliability, vulnerability and resilience.

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List of Symbols

Symbol	Description
B_j	Regression coefficient
C	Capacity of the reservoir
C_s	Coefficient of skewness
C_v	Coefficient of variation
Df_t	Deficit in the reservoir at time (t)
D_t	Release during the (t)th time period
ΔE_t	Net evaporation loss from reservoir during the (t)th time period
I_t	Deficit indicator
K_t	Correlation component of time series
M.D	Mean deviation
$P.$	Probability of failure of reservoir
P_i	The probability of being in a state at the beginning of a year
P_{ij}	Annual transition matrix probability
[P]	Steady state probability matrix
Q_t	Inflow during the (t)th time period
Re	Reliability of reservoir
R_i	The probability of being in a state at the ending of a year
R_j	Correlation coefficient
[T]	The transition matrix
S_{min}	Dead storage
S_t	Storage at any time (t)
T_t	Trend component of time series
v	Vulnerability of reservoir
ρ	Reservoir resilience
\bar{X}	Sample mean
μ	Population mean
\bar{X}_g	Geometric mean
\bar{X}_h	Harmonic mean
σ	Population standard deviation
S	Sample standard deviation
Γ	Gamma function
x_c	Chi-square index
ε_t	Random component of time series
Ψ	Transformation power

Note: Other samples are defined as they first appear.

APPENDIX- A

Table (A-1): The normal distribution (Normal Table)

Z	F(z)	Z	F(z)	Z	F(z)
-3.0	.0013499	-2.9	.18407013	1.2	.884493033
-2.9	.00187081	-2.8	.21118004	1.3	.90319902
-2.8	.00255013	-2.7	.24196737	1.4	.91924334
-2.7	.00343797	-2.6	.27420312	1.5	.93319280
-2.6	.00457119	-2.5	.30853704	1.6	.94520071
-2.5	.00606427	-2.4	.34483077	1.7	.95542004
-2.4	.00800437	-2.3	.38293861	1.8	.96378761
-2.3	.01049721	-2.2	.42276529	1.9	.97037324
-2.2	.01364314	-2.1	.46430517	2.0	.97590044
-2.1	.01755657	2.0	.50000000	2.1	.98076212
-2.0	.02226401	2.1	.53982784	2.2	.98494620
-1.9	.02777429	2.2	.57926371	2.3	.98841419
-1.8	.03409302	2.3	.61794114	2.4	.99115004
-1.7	.04121171	2.4	.65575174	2.5	.99312288
-1.6	.04913144	2.5	.69274577	2.6	.99432666
-1.5	.05785986	2.6	.72894268	2.7	.99477033
-1.4	.06740622	2.7	.76433804	2.8	.99442606
-1.3	.07778371	2.8	.79894262	2.9	.99328396
-1.2	.08898644	2.9	.83283861	3.0	.99134471
-1.1	.10101023	3.0	.86603329		
-1.0	.11486554	3.1	.89759004		

From Al-Khalidi (2003)

Table (A-2): Critical statistics for the Kolmogorov-Smirnov test

Sample size	$\alpha=0.1$	$\alpha=0.05$	$\alpha=0.01$
5	.51	.56	.67
10	.37	.41	.49
15	.30	.34	.40
20	.26	.29	.35
25	.24	.26	.32
30	.22	.24	.29
40	.19	.21	.25
Large n	$1.22/\sqrt{n}$	$1.36/\sqrt{n}$	$1.63/\sqrt{n}$

From Kottegoda (1980)



Table (A-3): Critical statistics for the Chi-square test

α	0.990	0.99	0.975	0.95	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	0.05	0.025	0.01	0.005
1	0.000	0.0002	0.001	0.0039	0.40	1.74	2.71	3.48	0.42	1.74	2.71	3.48	0.42	1.74	2.71	3.48	4.88
2	0.010	0.020	0.051	0.103	1.39	3.22	4.71	0.99	0.99	1.39	2.71	3.48	0.99	1.39	2.71	3.48	5.02
3	0.072	0.110	0.217	0.302	2.37	4.74	6.25	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
4	0.207	0.30	0.484	0.71	3.36	0.99	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
5	0.512	0.50	0.831	1.10	4.35	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
6	0.777	0.87	1.24	1.74	0.50	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
7	0.989	1.24	1.74	2.17	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
8	1.34	1.70	2.18	2.73	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
9	1.73	2.09	2.70	3.33	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
10	2.16	2.57	3.20	3.94	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
11	2.60	3.00	3.72	4.57	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
12	3.07	3.57	4.40	0.23	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
13	3.57	4.11	0.01	0.89	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
14	4.07	4.78	0.73	1.07	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
15	4.60	0.23	1.26	1.26	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
16	0.14	0.81	1.91	1.97	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
17	0.70	1.41	1.07	1.77	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
18	1.26	1.02	1.23	1.59	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
19	1.84	1.83	1.91	1.12	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
20	2.43	1.26	1.09	1.80	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
21	3.02	1.90	1.028	1.09	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
22	3.62	1.04	1.098	1.23	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
23	4.22	1.020	1.169	1.09	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
24	4.82	1.086	1.240	1.280	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
25	5.42	1.152	1.311	1.461	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
26	6.02	1.218	1.382	1.642	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
27	6.62	1.284	1.453	1.823	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
28	7.22	1.350	1.524	2.004	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
29	7.82	1.416	1.595	2.185	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
30	8.42	1.482	1.666	2.366	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
31	9.02	1.548	1.737	2.547	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
32	9.62	1.614	1.808	2.728	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
33	10.22	1.680	1.879	2.909	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
34	10.82	1.746	1.950	3.090	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
35	11.42	1.812	2.021	3.271	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
36	12.02	1.878	2.092	3.452	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
37	12.62	1.944	2.163	3.633	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
38	13.22	2.010	2.234	3.814	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
39	13.82	2.076	2.305	3.995	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
40	14.42	2.142	2.376	4.176	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
41	15.02	2.208	2.447	4.357	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
42	15.62	2.274	2.518	4.538	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
43	16.22	2.340	2.589	4.719	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
44	16.82	2.406	2.660	4.900	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
45	17.42	2.472	2.731	5.081	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
46	18.02	2.538	2.802	5.262	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
47	18.62	2.604	2.873	5.443	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
48	19.22	2.670	2.944	5.624	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
49	19.82	2.736	3.015	5.805	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25
50	20.42	2.802	3.086	5.986	1.39	1.41	1.41	1.41	1.41	2.37	3.48	4.71	1.41	2.37	3.48	4.71	6.25

From Al-Khalidi (2003)



Computer Program

```
'$DYNAMIC
'THIS PROGRAM FOR ESTIMATING THE RELIABILITY,VULNERABILTY AND
RESILIENCE
DIM Q(1000, 12), R(12), CV(12), Q1(12000), CS(12), MO(12),
REV(12), S(100), Z(12000), Q2(12), ST(12), B(12), YR(1000),
Z(1000, 12), DLIM(200), FF(200), A(90, 90), Q3(12000)
CLS
INPUT K, C, DT, N, X, BG, REF, N1
NM1 = N1
NM = N
INPUT "input file name for input data"; A$
INPUT "input file name for output data"; B$
INPUT "INPUT FILE NAME FOR OUTPUT DATA"; C$
INPUT "INPUT FILE NAME FOR OUTPUT DATA"; D$
INPUT "input file name for input data"; E$
INPUT "input file name for input data"; F$
R$ = "D:\TH\"
OPEN R$ + A$ + ".Dat" FOR INPUT AS #1
OPEN R$ + B$ + ".Dat" FOR OUTPUT AS #2
OPEN R$ + C$ + ".DAT" FOR OUTPUT AS #3
OPEN R$ + D$ + ".Dat" FOR OUTPUT AS #4
OPEN R$ + E$ + ".Dat" FOR INPUT AS #5
OPEN R$ + F$ + ".Dat" FOR INPUT AS #6
FOR I = 1 TO N
FOR J = 1 TO 12
INPUT #1, Q(I, J)
NEXT
PRINT
NEXT
FOR J = 1 TO 12
INPUT #5, REV(J)
NEXT
FOR J = 1 TO 12
INPUT #6, MO(J)
NEXT
IF REF = 1 OR REF = 2 OR REF = 3 THEN 1 ELSE 4
1 FOR I = 1 TO N
FOR J = 1 TO 12
Q(I, J) = LOG(Q(I, J) + .001)
NEXT
NEXT
CLS
4 FOR I = 1 TO N
FOR J = 1 TO 12
V = V + 1
Q1(V) = Q(I, J)
NEXT
PRINT
PRINT #2,
NEXT
FOR J = 1 TO 12
SUM = .
FOR I = 1 TO N
SUM = SUM + Q(I, J)
```



```

NEXT I
QY(J) = SUM / N
NEXT J
FOR J = 1 TO 12
SUM = .
FOR I = 1 TO N
SUM = SUM + (Q(I, J) - QY(J)) ^ 2
NEXT I
ST(J) = (SUM / (N - 1)) ^ .5
NEXT J
FOR J = 1 TO 12
CV(J) = ST(J) / QY(J)
NEXT J
FOR J = 1 TO 12
SM = .
SM1 = .
SM2 = .
FOR I = 1 TO N - 1
Q(I, 12) = Q(I + 1, 1)
QY(12) = QY(1)
SM = SM + (Q(I, J) - QY(J)) * (Q(I, J + 1) - QY(J + 1))
SM1 = SM1 + (Q(I, J) - QY(J)) ^ 2
SM2 = SM2 + (Q(I, J + 1) - QY(J + 1)) ^ 2
NEXT I
R(J) = SM / (SM1 * SM2) ^ .5
NEXT J
FOR J = 1 TO 11
B(J) = (R(J) * ST(J + 1) / ST(J))
NEXT J
B(12) = R(12) * ST(1) / ST(12)
FOR J = 1 TO 12
SUM = .
FOR I = 1 TO N
SUM = SUM + (Q(I, J) - QY(J)) ^ 2
NEXT I
A = N * SUM / ((N - 2) * (N - 1))
CS(J) = A / (ST(J) ^ 2)
NEXT J
FOR J = 1 TO 12
PRINT #1, QY(J); ST(J); CV(J); CS(J); R(J); B(J)
PRINT #1,
NEXT
IF REF = 2 OR REF = 3 THEN 1 ELSE 9
1 FOR I = 1 TO N
FOR J = 1 TO 12
Q(I, J) = EXP(Q(I, J)) - .001
NEXT
NEXT
9 FOR I = 1 TO N
FOR J = 1 TO 12
YR(I) = YR(I) + Q(I, J)
NEXT
NEXT
SUM = .
FOR J = 1 TO N
SUM = SUM + YR(J)
NEXT J
QY = SUM / N

```



```

SUM = .
FOR I = 1 TO N
SUM = SUM + (YR(I) - QY) ^ Y
NEXT I
ST = (SUM / (N - 1)) ^ .5
CV = ST / QY
SM = .
SM1 = .
SM2 = .
FOR I = 1 TO (N - 1)
SM = SM + (YR(I) - QY) * (YR(I + 1) - QY)
SM1 = SM1 + (YR(I) - QY) ^ Y
SM2 = SM2 + (YR(I) - QY) ^ Y
NEXT I
R = SM / (SM1 * SM2) ^ .5
SUM = .
FOR I = 1 TO N
SUM = SUM + (YR(I) - QY) ^ Y
NEXT I
A = N * SUM / ((N - Y) * (N - 1))
CS = A / (ST ^ Y)
PRINT #1, QY; ST; CV; CS; R
PRINT #1,
IF REF = 1 THEN GOTO 1.
IF REF = 2 THEN GOTO 2.
IF REF = 3 THEN GOTO 3.
IF REF = 4 THEN GOTO 4.
IF REF = 5 THEN GOTO 5.
IF REF = 6 THEN GOTO 6.
1. GOSUB 4. . .
N = N1
V = .
FOR I = 1 TO N
FOR J = 1 TO 12
V = V + 1
Q1(V) = Q(I, J)
NEXT
NEXT
GOTO 6.
2. GOSUB 5. . .
N = N1
V = .
FOR I = 1 TO N
FOR J = 1 TO 12
V = V + 1
Q1(V) = Q(I, J)
NEXT
NEXT
GOTO 6.
3. GOSUB 6. . .
N = N1
V = .
FOR I = 1 TO N
FOR J = 1 TO 12
V = V + 1
Q1(V) = Q(I, J)
NEXT
NEXT

```



```

GOTO 19
ξ. GOSUB 7000
N = N\
V = .
FOR I = 1 TO N
FOR J = 1 TO 12
V = V + 1
Q\ (V) = Q(I, J)
NEXT
NEXT
GOTO 19
ο. GOSUB 8000
N = N\
V = .
FOR I = 1 TO N
FOR J = 1 TO 12
V = V + 1
Q\ (V) = Q(I, J)
NEXT
NEXT
19 IF BG = 1 THEN 10 ELSE 70
10 ERASE Z
DIM DD(12000)
70 FDF = FDF + 1
FOR I = 1 TO 12 * NM
RED = NM\ / NM
N\ = N
Q\ (I) = Q\ ((FDF - 1) * 12 * NM + I)
NEXT
FOR I = 1 TO NM
FOR J = 1 TO 12
Q(I, J) = Q(NM * (FDF - 1) + I, J)
NEXT
NEXT
IF BG = 1 THEN GOTO 70
IF BG = 2 THEN GOTO 99
70 REM THIS PROGRAM FOR EVALUATION P.O.F BY BEHAVIOR METHOD
S = .
K\ = 12 * NM
FOR I = 1 TO K\
PRINT Q\ (I)
NEXT
Z\ (1) = C
M = K\ - 1
FOR I = 1 TO M
J = I + 1
GD = (J / 12 - INT(J / 12)) * 12
ET = REV(GD) * (-1.281906 + 36.6326 * Z\ (I) / 1000 + 86.06139 *
(Z\ (I) / 1000) ^ .2970310) * .001
Z\ (J) = Z\ (I) + Q\ (I) * MO(GD) * 3600 * 24 - DT * MO(GD) * 3600 *
24 - ET
IF Z\ (J) <= C AND Z\ (J) > . THEN GOTO 80
IF Z\ (J) > C THEN GOTO 80
S = S + 1
DD(S) = -1 * Z\ (J)
Z\ (J) = .
GOTO 80
80 Z\ (J) = C

```



```

Λο NEXT
FOR I = \ TO S
FOR J = I TO S
IF DD(I) >= DD(J) THEN Λ\ ELSE Λγ
Λ\ NEXT J
XX = DD(I)
GOTO ΛΛ
Λγ NEXT I
ΛΛ VUR = XX
ERASE DD
REDIM DD(Λγ····)
PP = \
FOR I = \ TO K\
IF Z\ (I) = · THEN Λϑ ELSE ϑγ
Λϑ DD(PP) = DD(PP) + \
GOTO ϑε
ϑγ PP = PP + \
ϑε NEXT
FOR I = \ TO PP

FOR J = I TO PP
IF DD(I) >= DD(J) THEN ϑ\ ELSE ϑγ
ϑ\ NEXT J
XXR = DD(I)
GOTO ϑΛ
ϑγ NEXT I
ϑΛ RESIL = XXR
PRINT "THE STORAGE AT THE END OF T-TH PERIOD IS THE FOLLOW:"
FOR I = \ TO K\
PRINT I; Z\ (I),
NEXT
P.O.F. = S / K\
SMM = P.O.F. + SMM
RTR = RTR + VUR
TRT = TRT + RESIL
IF FDF < RED THEN γ·
P.O.F. = SMM / RED
VUR = RTR / RED
RESIL = INT (TRT / RED)
PRINT "PROBABILITY OF FAILURE=", P.O.F.
RE = \ - P.O.F.
PRINT "RELIABILITY OF RESERVIOR=", RE
PRINT "VULNERABILITY OF RESERVIOR=", VUR
PRINT "RESILIENCE OF RESERVIOR=", RESIL
ERASE Z\
GOTO γο··
ϑϑ 'THIS PROGRAM FOR EVALUATION P.O.F BY GOULD METHOD
REDIM DV(Λ··), V(Λ··), Y(Λ··)
ERASE Z\
PRINT
P.O = ·
S = ·
FOR M = \ TO K
FOR I = \ TO K
DV(I) = ·
V(I) = ·
Y(I) = ·
A(I, M) = ·

```



```

S(M) = .
NEXT
NEXT
REDIM Z(1000, 12)
W = C / (K - 2)
ERASE Q
FOR M = 1 TO K
FOR I = 1 TO NM
IF M = K THEN GOTO 100
IF M = 1 THEN GOTO 150
CS = (2 * M - 3) * (W / 2)
GOTO 200
100 CS = (K - 2) * W
GOTO 200
150 CS = .
200 Z(I, 1) = CS
FOR J = 1 TO 12
ET = REV(J) * (-1.281906 + 26.6326 * Z(I, J) / 1000 + 86.0639 *
(Z(I, J) / 1000) ^ .3970310) * .001
Z(I, J + 1) = Z(I, J) + Q(I, J) * MO(J) * 2600 * 24 - DT * MO(J) *
2600 * 24 - ET
IF Z(I, J + 1) <= . THEN GOTO 200
IF Z(I, J + 1) >= C THEN GOTO 300
GOTO 500
200 Z(I, J + 1) = .
S(M) = S(M) + 1
GOTO 500
300 Z(I, J + 1) = C
500 NEXT J
IF Z(I, 12) <= . THEN GOTO 100
IF Z(I, 12) >= C THEN GOTO 200
F = INT(Z(I, 12) / W) + 2
GOTO 800
100 F = 1
GOTO 800
200 F = K
800 A(F, M) = A(F, M) + 1
NEXT I
NEXT M
ERASE Z
REDIM G(90, 90), Y(100), X(100), P(90, 90), L(90), T(90, 90)
PRINT #2, "transition matrix is:"
FOR F = 1 TO K
FOR M = 1 TO K
P(F, M) = A(F, M) / NM
P(F, M) = INT(10000 * P(F, M)) / 10000
PRINT #2, P(F, M);
NEXT
PRINT #2,
NEXT
PRINT #2, "the conditional probability of failure is:"
FOR M = 1 TO K
L(M) = S(M) / (12 * NM)
PRINT #2, M; L(M)
PRINT #2,
NEXT
PRINT #2, "number of failures matrix is:"
FOR F = 1 TO K

```



```

FOR M = 1 TO K
S = S + A(F, M)
PRINT #2, A(F, M);
NEXT
PRINT #2,
NEXT
PRINT #2, "the sumation of failures is:"; S
FOR F = 1 TO K
G(F, X) = 1
NEXT
FOR F = 1 TO K
FOR M = 1 TO K
G(F, M) = P(F, M)
NEXT
NEXT
FOR F = 1 TO K
G(F, F) = P(F, F) - 1
NEXT
FOR M = 1 TO K
G(X, M) = 1
NEXT
FOR I = 1 TO K
Y(I) = 1
NEXT
Y(X) = 1
FOR I = 1 TO K
FOR J = 1 TO K
PRINT #2, G(I, J);
NEXT: PRINT #2, : NEXT
2180 REM **SOLVER SUBROUTINE BY GAUSS EIEMINATION AND DETERMIND
THE DETERMINENT**
2190 REM *DETERMINED THE UPPER TRIANGULAR*
2200 FOR I = 1 TO K
2210 FOR J = I TO K
2220 R = G(J, I - 1) / G(I - 1, I - 1)
2230 Y(J) = Y(J) - R * Y(I - 1)
2240 FOR M = I TO K
2250 G(J, M) = G(J, M) - R * G(I - 1, M)
2260 NEXT M, J, I
2270 REM *DETERMINED THE GLOBAL RELATIVE DISPLACEMENT*
2280 DV(K) = Y(K) / G(K, K)
2290 FOR I = K - 1 TO 1 STEP -1
2300 DV(I) = Y(I)
2310 FOR J = I + 1 TO K
2320 DV(I) = DV(I) - G(I, J) * DV(J)
2330 NEXT J
2340 DV(I) = DV(I) / G(I, I)
2350 NEXT I
2360 FOR I = 1 TO K
2370 V(I) = DV(I) + V(I)
2380 NEXT I
PRINT #2, "STEADY STATE PROBABILITY OF B. IN Z. IS:"
FOR I = 1 TO K
PRINT #2, V(I);
NEXT
FOR I = 1 TO K
X(I) = V(I) * L(I)
NEXT

```



```

PRINT #2,
PRINT #2,
PRINT #2, "OVER ALL P.O.F IS:"
FOR I = 1 TO K
PRINT #2, X(I);
NEXT
FOR I = 1 TO K
P.O = P.O + X(I)
NEXT
SMM = P.O + SMM
IF FDF < RED THEN Y.
P.O.F. = SMM / RED
PRINT "PROBABILITY OF FAILURE=", P.O.F.
RE = 1 - P.O.F.
PRINT "RELIABILITY OF RESERVIOR=", RE
PRINT #2,
Y000 PRINT #2, "P.O.F. IS: "; P.O.F.
PRINT #2, "RELIABILITY IS: "; RE
END
'%%%%%%%%%%
%THE FOLLOWING FOR GENERATE DATA IN N\ YEARS BY T.F.M WITH LN%
'%%%%%%%%%%
KA = 0 ^ 0
KB = Y ^ 0
NA = Y ^ Y0 - Y1
NB = Y ^ Y1 - 1
XA = 1 / (Y * NA)
XB = 1 / (Y * NB)
LA = 100001Y
LB = Y20Y2Y2
LA = (KA * LA)
FOR I = 1 TO 12 * N\ STEP Y
LA = ((KA * LA) / NA - FIX(KA * LA / NA)) * NA
Q(I) = (LA / NA) + XA
LB = ((KB * LB) / NB - FIX(KB * LB / NB)) * NB
Q(I + 1) = LB / NB + XB
NEXT
NYN = 12 * N\ - 1
AN = A * ATN(1)
FOR I = Y TO NYN STEP Y
AA = (-Y * LOG(Q(I))) ^ .0
SQI = Q(I + 1)
Q(I) = AA * COS(AN * SQI)
Q(I + 1) = AA * SIN(AN * SQI)
NEXT
FOR I = 1 TO 12 * N\
PRINT Q(I)
NEXT
SM = .
FOR I = 1 TO 12 * N\
SM = SM + Q(I)
NEXT
MU = SM / (12 * N\ )
SM = .
FOR I = 1 TO 12 * N\
SM = SM + (MU - Q(I)) ^ Y
NEXT
VAR = (SM / (12 * N\ - 1))

```



```

PRINT #1, " VAR OF UN. RND IS:"; VAR; " MEAN OF RND IS:"; MU
Q1(I) = Q2(I) + ST(I) * Q3(I)
FOR I = 1 TO 12 * N1 - 1
J = (I / 12 - FIX(I / 12)) * 12
IF Q1(I) > . THEN 110 ELSE 100
110 IF J = 1 THEN 100
100 Q1(I + 1) = Q2(J + 1) + B(J) * (Q1(I) - Q2(J)) + Q3(I) * ST(J
+ 1) * (1 - R(J) ^ 2) ^ .5
GOTO 100
100 Q1(I + 1) = Q2(1) + B(12) * (Q1(I) - Q2(12)) + Q3(I) * ST(1)
* (1 - R(12) ^ 2) ^ .5
GOTO 100
100 Q1(I) = .
IF J = 12 GOTO 100
Q1(I + 1) = Q2(J + 1) + ST(J + 1) * Q3(I)
GOTO 100
100 Q1(I + 1) = Q2(1) + ST(1) * Q3(I)
100 NEXT I
FOR I = 1 TO N1
FOR J = 1 TO 12
III = III + 1
Q(I, J) = EXP(Q1(III)) - .001
NEXT J
NEXT I
ERASE Q1
RETURN
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
.000 'TWO-TIER MODEL WITH(MONTHLY LN DISTR,ANNUAL NOR DISTR%%%%%%%%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%
DIM Q1(1200)
KA = . ^ .
KB = 1 ^ .
NA = 2 ^ 20 - 31
NB = 2 ^ 31 - 1
XA = 1 / (2 * NA)
XB = 1 / (2 * NB)
LA = 1000017
LB = 2207223
LA = (KA * LA)
FOR I = 1 TO N1 STEP 2
LA = ((KA * LA) / NA - FIX(KA * LA / NA)) * NA
Q1(I) = (LA / NA) + XA
LB = ((KB * LB) / NB - FIX(KB * LB / NB)) * NB
Q1(I + 1) = LB / NB + XB
NEXT
NYY = N1 - 1
AN = 1 * ATN(1)
FOR I = 2 TO NYY STEP 2
AA = (-2 * LOG(Q1(I))) ^ .5
SQI = Q1(I + 1)
Q1(I) = AA * COS(AN * SQI)
Q1(I + 1) = AA * SIN(AN * SQI)
NEXT
YR(1) = Q2
FOR I = 1 TO N1 - 1
YR(I + 1) = Q2 + R * (YR(I) - Q2) + Q1(I) * ST * (1 - R ^ 2) ^ .5
IF YR(I + 1) <= . THEN YR(I + 1) = Q2

```



```

NEXT
FOR I = 1 TO N1
PRINT YR(I)
NEXT
KA = 0 ^ 0
KB = 1 ^ 0
NA = 2 ^ 20 - 31
NB = 2 ^ 31 - 1
XA = 1 / (2 * NA)
XB = 1 / (2 * NB)
LA = 1000017
LB = 2207222
LA = (KA * LA)
FOR I = 1 TO 12 * N1 STEP 2
LA = ((KA * LA) / NA - FIX(KA * LA / NA)) * NA
Q(I) = (LA / NA) + XA
LB = ((KB * LB) / NB - FIX(KB * LB / NB)) * NB
Q(I + 1) = LB / NB + XB
NEXT
NYI = 12 * N1 - 1
AN = 1 * ATN(1)
FOR I = 2 TO NYI STEP 2
AA = (-2 * LOG(Q(I))) ^ .0
SQI = Q(I + 1)
Q(I) = AA * COS(AN * SQI)
Q(I + 1) = AA * SIN(AN * SQI)
NEXT
SM = .
FOR I = 1 TO 12 * N1
SM = SM + Q(I)
NEXT
MU = SM / (12 * N1)
SM = .
FOR I = 1 TO 12 * N1
SM = SM + (MU - Q(I)) ^ 2
NEXT
VAR = (SM / (12 * N1 - 1))
Q2(1) = Q2(1) + ST(1) * Q(1)
FOR I = 2 TO 12 * N1 - 1
J = (I / 12 - FIX(I / 12)) * 12
IF Q2(I) > . THEN 0180 ELSE 0800
0180 IF J = 1 THEN 0800
0700 Q2(I + 1) = Q2(J + 1) + B(J) * (Q2(I) - Q2(J)) + Q(I) * ST(J
+ 1) * (1 - R(J) ^ 2) ^ .0
GOTO 0900
0800 Q2(I + 1) = Q2(1) + B(12) * (Q2(I) - Q2(12)) + Q(I) * ST(1)
* (1 - R(12) ^ 2) ^ .0
GOTO 0900
0800 Q2(I) = .
Q2(I + 1) = Q2(J + 1) + ST(J + 1) * Q(I)
0900 NEXT I
III = .
FOR I = 1 TO N1
FOR J = 1 TO 12
III = III + 1
Q(I, J) = EXP(Q2(III)) - .001
NEXT J
NEXT I

```



```

FOR I = 1 TO N1
Q1(I) = .
FOR J = 1 TO 12
Q1(I) = Q1(I) + Q(I, J)
NEXT
NEXT
FOR I = 1 TO N1
FOR J = 1 TO 12
Q(I, J) = Q(I, J) * YR(I) / Q1(I)
NEXT
NEXT
ERASE Q11
RETURN
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
1... 'MODIFIED TWO-TIER MODEL WITH (MONTHLY LN DISTR, ANNUAL NOR D%%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
DIM Q11(1200)
KA = 0 ^ 0
KB = 7 ^ 0
NA = 2 ^ 20 - 31
NB = 2 ^ 21 - 1
XA = 1 / (2 * NA)
XB = 1 / (2 * NB)
LA = 1000017
LB = 2207223
LA = (KA * LA)
FOR I = 1 TO N1 STEP 2
LA = ((KA * LA) / NA - FIX(KA * LA / NA)) * NA
Q11(I) = (LA / NA) + XA
LB = ((KB * LB) / NB - FIX(KB * LB / NB)) * NB
Q11(I + 1) = LB / NB + XB
NEXT
NY1 = N1 - 1
AN = 1 * ATN(1)
FOR I = 2 TO NY1 STEP 2
AA = (-2 * LOG(Q11(I))) ^ .0
SQI = Q11(I + 1)
Q11(I) = AA * COS(AN * SQI)
Q11(I + 1) = AA * SIN(AN * SQI)
NEXT
YR(1) = Q2
FOR I = 1 TO N1 - 1
YR(I + 1) = Q2 + R * (YR(I) - Q2) + Q11(I) * ST * (1 - R ^ 2) ^ .0
IF YR(I + 1) <= . THEN YR(I + 1) = Q2
NEXT
KA = 0 ^ 0
KB = 7 ^ 0
NA = 2 ^ 20 - 31
NB = 2 ^ 21 - 1
XA = 1 / (2 * NA)
XB = 1 / (2 * NB)
LA = 1000017
LB = 2207223
LA = (KA * LA)
FOR I = 1 TO 12 * N1 STEP 2
LA = ((KA * LA) / NA - FIX(KA * LA / NA)) * NA
Q1(I) = (LA / NA) + XA
LB = ((KB * LB) / NB - FIX(KB * LB / NB)) * NB

```



```

Q\ (I + 1) = LB / NB + XB
NEXT
NYY = 12 * N1 - 1
AN = A * ATN(1)
FOR I = 2 TO NYY STEP 2
AA = (-2 * LOG(Q\ (I))) ^ .5
SQI = Q\ (I + 1)
Q\ (I) = AA * COS(AN * SQI)
Q\ (I + 1) = AA * SIN(AN * SQI)
NEXT
SM = .
FOR I = 1 TO 12 * N1
SM = SM + Q\ (I)
NEXT
MU = SM / (12 * N1)
SM = .
FOR I = 1 TO 12 * N1
SM = SM + (MU - Q\ (I)) ^ 2
NEXT
VAR = (SM / (12 * N1 - 1))
Q\x(1) = Q2(1) + ST(1) * Q\ (1)
FOR I = 2 TO 12 * N1 - 1
J = (I / 12 - FIX(I / 12)) * 12
IF Q\x(I) > . THEN 168. ELSE 185.
168. IF J = 1 THEN 180.
170. Q\x(I + 1) = Q2(J + 1) + B(J) * (Q\x(I) - Q2(J)) + Q\ (I) * ST(J
+ 1) * (1 - R(J) ^ 2) ^ .5
GOTO 190.
180. Q\x(I + 1) = Q2(1) + B(12) * (Q\x(I) - Q2(12)) + Q\ (I) * ST(1)
* (1 - R(12) ^ 2) ^ .5
GOTO 190.
185. Q\x(I) = .
Q\x(I + 1) = Q2(J + 1) + ST(J + 1) * Q\ (I)
190. NEXT I
III = .
FOR I = 1 TO N1
FOR J = 1 TO 12
III = III + 1
Q(I, J) = EXP(Q\x(III)) - .001
NEXT J
NEXT I
FOR I = 1 TO N1
Q\x(I) = .
FOR J = 1 TO 12
Q\x(I) = Q\x(I) + Q(I, J)
NEXT: NEXT
ERASE Q\1
DIM YRD(1200)
FOR I = 1 TO N1
YRD(I) = YR(I)
NEXT I
FOR J = 1 TO N1 - 1
XX = YRD(1)

FOR I = 1 TO N1 - 1
IF XX >= YRD(I + 1) THEN 192. ELSE 192.5
192. XX = YRD(I + 1)
YRD(I + 1) = YRD(I)

```



```

YRD(I) = XX
1920 XX = YRD(I + 1)
NEXT I: NEXT J
FOR J = 1 TO N1 - 1
XX = Q1(1)
FOR I = 1 TO N1 - 1
IF XX >= Q1(I + 1) THEN 1940 ELSE 1945
1940 XX = Q1(I + 1)
Q1(I + 1) = Q1(I)
Q1(I) = XX
1945 XX = Q1(I + 1)
NEXT I: NEXT J
FOR I = 1 TO N1
FOR J = 1 TO 12
Q(I, J) = Q(I, J) * YRD(I) / Q1(I)
NEXT J
NEXT I
FOR I = 1 TO N1
FOR S = 1 TO N1
IF YRD(I) = YR(S) THEN 1960 ELSE 1970
1960 FOR J = 1 TO 12
Q(S, J) = Q(I, J)
NEXT J
GOTO 1990
1970 NEXT S
1990 YRD(I) = .
NEXT I
RETURN
'%%%%%%%%%%
Y... 'FRAGMENT MODEL WITH MARCOV MODEL FOR ANNUAL INFLOW%%%%%%%%
'%%%%%%%%%%
ERASE Z, Z1
DIM YRD(120), QF(1000, 12), NUM(100), FRG(100)
FOR I = 1 TO N
YRD(I) = YR(I)
NEXT I
FOR I = 1 TO N
FOR J = 1 TO 12
QF(I, J) = Q(I, J) / YR(I)
NEXT J
NEXT I
FOR J = 1 TO N - 1
XX = YRD(1)
FOR I = 1 TO N - 1
IF XX >= YRD(I + 1) THEN 1992 ELSE 1995
1992 XX = YRD(I + 1)
YRD(I + 1) = YRD(I)
YRD(I) = XX
1995 XX = YRD(I + 1)
NEXT
NEXT
FOR I = 1 TO N
PRINT YRD(I)
NEXT
FOR I = 1 TO N
FOR Y = 1 TO N
IF YRD(I) = YR(Y) THEN 1998 ELSE 1995
1998 FOR J = 1 TO 12

```



```

QF(I, J) = QF(Y, J)
NEXT J
YR(Y) = .
Y940 NEXT Y
NEXT I
FRG(1) = .
NUM(1) = 1
NUM(N) = N
FOR I = 2 TO N - 1
NUM(I) = I
FRG(I) = (YRD(I) + YRD(I - 1)) / 2
NEXT I
DIM Q(1)(1200)
KA = 0 ^ 0
KB = 1 ^ 0
NA = 2 ^ 20 - 31
NB = 2 ^ 21 - 1
XA = 1 / (2 * NA)
XB = 1 / (2 * NB)
LA = 1000014
LB = 2207222
LA = (KA * LA)
FOR I = 1 TO N1 STEP 2
LA = ((KA * LA) / NA - FIX(KA * LA / NA)) * NA
Q(1)(I) = (LA / NA) + XA
LB = ((KB * LB) / NB - FIX(KB * LB / NB)) * NB
Q(1)(I + 1) = LB / NB + XB
NEXT
NYN = N1 - 1
AN = 1 * ATN(1)
FOR I = 2 TO NYN STEP 2
AA = (-2 * LOG(Q(1)(I))) ^ .0
SQI = Q(1)(I + 1)
Q(1)(I) = AA * COS(AN * SQI)
Q(1)(I + 1) = AA * SIN(AN * SQI)
NEXT
YR(1) = Q2
FOR I = 1 TO N1 - 1
YR(I + 1) = Q2 + R * (YR(I) - Q2) + Q(1)(I) * ST * (1 - R ^ 2) ^ .0
IF YR(I + 1) <= . THEN YR(I + 1) = Q2
NEXT
FOR I = 1 TO N1
PRINT YR(I)
NEXT
FOR I = 1 TO N1
FOR JT = 2 TO N
IF YR(I) = FRG(1) THEN Y910
IF YR(I) >= FRG(N) THEN Y914
IF YR(I) <= FRG(JT) AND YR(I) >= FRG(JT - 1) THEN Y900 ELSE Y916
Y900 FOR J = 1 TO 12
Q(I, J) = YR(I) * QF(JT - 1, J)
NEXT J
Y916 NEXT JT
Y910 FOR J = 1 TO 12
Q(I, J) = YR(I) * QF(1, J)
NEXT J
GOTO Y940
Y914 FOR J = 1 TO 12

```



```

Q(I, J) = YR(I) * QF(N, J)
NEXT J
Y9Y. NEXT I
ERASE QF, FRG, NUM
REDIM Z(1000, 12), Z(12000)
Y999 RETURN
'%%%%%%%%%%
8000 'T.F MODEL WITH BOX-COX TRANSFORMATION
'%%%%%%%%%%
ERASE Z, Z\
DIM YT(1000)
li = -1.6
8002 li = li + .2
li = INT(li * 10) / 10
L = L + 1

FF(L) = li
FOR I = 1 TO 12 * N
IF li = . THEN 8010 ELSE 8020
8010 YT(I) = LOG(Q\ (I) + .000001)
GOTO 8021
8020 YT(I) = ((Q\ (I) + .000001) ^ li) - 1) / li
8021 NEXT I
FOR J = 1 TO 12 * N - 1
XX = YT(1)
FOR I = 1 TO 12 * N - 1
IF XX >= YT(I + 1) THEN 8022 ELSE 8020
8022 XX = YT(I + 1)
YT(I + 1) = YT(I)
YT(I) = XX
8020 XX = YT(I + 1)
NEXT I
NEXT J
YYY = 12 * N / 2 - INT(12 * N / 2)
IF YYY = . THEN 8060 ELSE 8070
8060 MED = YT(12 * N / 2 + .5)
GOTO 8080
8070 MED = (YT((12 * N / 2) + 1) + YT(12 * N / 2)) / 2
8080 SUM = .
FOR R = 1 TO 12 * N
SUM = SUM + YT(R)
NEXT R
MEAN = SUM / (12 * N)
SUM = .
FOR R = 1 TO 12 * N
SUM = SUM + (MEAN - YT(R)) ^ 2
NEXT R
ST2 = (SUM / (12 * N - 1)) ^ .5
IF ST2 = . THEN 8082
DLIM(L) = (MEAN - MED) / ST2
GOTO 8082
8082 DLIM(L) = 1000000
8083 PRINT
PRINT FF(L), DLIM(L)
IF li < 1.6 THEN 8002
FOR I = 1 TO 12
FOR J = I TO 12
IF ABS(DLIM(I)) <= ABS(DLIM(J)) THEN 8080 ELSE 8090

```



```

A.80 NEXT J
XX = ABS(DLIM(I))
GOTO A100
A.90 NEXT I
A100 FOR I = 1 TO 17
IF XX = ABS(DLIM(I)) THEN A110 ELSE A120
A110 MY = FF(I)
PRINT MY
A120 NEXT I
'THE VALUE OF MY DOWN IS COMING FROM INTERPOLATION OF
FF(I),DLIM(I) TO FIND
'THE VALUE OF DLIM APPROACHES TO ZERO(OUTSIDE THE PROGRAM);THE
USER CAN
'EITHER USES THE SAME PROCEDURE OR DELETES THE LINE A130 AND
DEPENDS ON THE VALUE
'OF MY WHICH RESULTS FROM THE PROGRAM IN LINE A110
A130 MY = -.2360
IF MY = 0 THEN A140 ELSE A150
A140 PRINT "SOORY"
END
A150 FOR I = 1 TO N
FOR J = 1 TO 12
Q(I, J) = ((Q(I, J) + .....1) ^ MY - 1) / MY
NEXT J
NEXT I
PRINT MY
FOR J = 1 TO 12
SUM = 0
FOR I = 1 TO N
SUM = SUM + Q(I, J)
NEXT I
Q2(J) = SUM / N
NEXT J

FOR J = 1 TO 12
SUM = 0
FOR I = 1 TO N
SUM = SUM + (Q(I, J) - Q2(J)) ^ 2
NEXT I
ST(J) = (SUM / (N - 1)) ^ .5
NEXT J

FOR J = 1 TO 12
CV(J) = ST(J) / Q2(J)
NEXT J

FOR J = 1 TO 12
SM = 0
SM1 = 0
SM2 = 0
FOR I = 1 TO N - 1
Q(I, 12) = Q(I + 1, 1)
Q2(12) = Q2(1)
SM = SM + (Q(I, J) - Q2(J)) * (Q(I, J + 1) - Q2(J + 1))

SM1 = SM1 + (Q(I, J) - Q2(J)) ^ 2
SM2 = SM2 + (Q(I, J + 1) - Q2(J + 1)) ^ 2
NEXT I

```



```

R(J) = SM / (SM\ * SM\)^ .o
NEXT J

FOR J = \ TO \\
B(J) = (R(J) * ST(J + \) / ST(J))
NEXT J
B(\\ ) = R(\\ ) * ST(\) / ST(\\ )

FOR J = \ TO \\
SUM = .
FOR I = \ TO N
SUM = SUM + (Q(I, J) - Q\ (J)) ^ \
NEXT I
A = N * SUM / (N - \) * (N - \)
CS(J) = A / (ST(J) ^ \)
NEXT J
FOR J = \ TO \\
PRINT #\, Q\ (J); ST(J); CV(J); CS(J); R(J); B(J)
PRINT #\,
NEXT
KA = o ^ o
KB = \ ^ o
NA = \ ^ \o - \
NB = \ ^ \ - \
XA = \ / (\ * NA)
XB = \ / (\ * NB)
LA = \o\o\
LB = \o\o\
LA = (KA * LA)
FOR I = \ TO \\ * N\ STEP \
LA = ((KA * LA) / NA - FIX(KA * LA / NA)) * NA
Q\ (I) = (LA / NA) + XA
LB = ((KB * LB) / NB - FIX(KB * LB / NB)) * NB
Q\ (I + \) = LB / NB + XB
NEXT
NYY = \\ * N\ - \
AN = \ * ATN(\)
FOR I = \ TO NYY STEP \
AA = (-\ * LOG(Q\ (I))) ^ .o
SQI = Q\ (I + \)
Q\ (I) = AA * COS(AN * SQI)
Q\ (I + \) = AA * SIN(AN * SQI)
NEXT
SM = .
FOR I = \ TO \\ * N\
SM = SM + Q\ (I)
NEXT
MU = SM / (\\ * N\ )
SM = .
FOR I = \ TO \\ * N\
SM = SM + (MU - Q\ (I)) ^ \
NEXT
VAR = (SM / (\\ * N\ - \))
PRINT #\, " VAR OF UN. RND IS:"; VAR; " MEAN OF RND IS:"; MU
Q\ (\) = Q\ (\) + ST(\) * Q\ (\)
FOR I = \ TO \\ * N\ - \
J = (I / \ - FIX(I / \)) * \
IF Q\ (I) > . THEN \ \ ELSE \ \ .

```



```

^1^1. IF J = 1 THEN ^1^1.
^1^2. Q^1(I + 1) = Q^2(J + 1) + B(J) * (Q^1(I) - Q^2(J)) + Q^1(I) * ST(J
+ 1) * (1 - R(J) ^ 2) ^ .5
GOTO ^1^3.
^1^4. Q^1(I + 1) = Q^2(1) + B(1^2) * (Q^1(I) - Q^2(1^2)) + Q^1(I) * ST(1)
* (1 - R(1^2) ^ 2) ^ .5
GOTO ^1^5.
^1^6. Q^1(I) = .
IF J = 1^2 GOTO ^1^7.
Q^1(I + 1) = Q^2(J + 1) + ST(J + 1) * Q^1(I)
GOTO ^1^5.
^1^8. Q^1(I + 1) = Q^2(1) + ST(1) * Q^1(I)
^1^9. NEXT I
FOR I = 1 TO N1
FOR J = 1 TO 1^2
III = III + 1
HHH = Q^1(III) * M^2 + 1
IF HHH <= . THEN ^1^10.
^1^10. Q(I, J) = (HHH) ^ (1 / M^2)
GOTO ^1^11.
^1^11. Q(I, J) = .
^1^12. NEXT J
NEXT I
ERASE Q^1
ERASE Y^1
REDIM Z(1^3, 1^4), Z^1(1^5)
PRINT #1, "M^2="; M^2
^1^13. RETURN

```

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