DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

PERFORMANCE EVALUATION OF DAM RESERVOIRS: THE CASE OF KEMER DAM

by
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February, 2010
İZMİR

PERFORMANCE EVALUATION OF DAM RESERVOIRS: THE CASE OF KEMER DAM

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Ph.D. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **“PERFORMANCE EVALUATION OF DAM RESERVOIRS: THE CASE OF KEMER DAM”** completed by **H. YILDIRIM DALKILIÇ** under supervision of **PROF. DR. NİLGÜN HARMANCIOĞLU** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy.

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ABSTRACT

Risk based design of hydraulic structures requires that the performance of these structures in accomplishing their intended purpose is assessed and improved if seemed necessary. Such an approach is not very common in Turkey so that the operational performance of most structures is overlooked and is not described in tangible terms. The presented study is realized upon this deficiency in the Turkish engineering practices and is expected to be one of the first studies to assess the performance of water structures in computable figures.

In the presented study, methods for performance assessment of dam reservoirs are examined, and one of these methods based on the use of performance indicators is employed to evaluate reservoir performance in the case of Kemer Dam on Buyuk Menderes River.

General definitions of performance indicators are introduced first, and next, new definitions are developed by considering different operational objectives of Kemer Dam to account for the performance of the reservoir in flood control, energy production and irrigation.

The above indicators are computed under two conditions: first, they are assessed by taking into account the current practices of reservoir operation at Kemer; and second, the same indicators are computed again by considering different operational policies based on the coverage rate of irrigation demand, where specific operational rules are defined.

The recent concern over the impact of climatic changes on water resources also entails questions about the performance of existing hydraulic structures. This issue is covered in the present study so that potential changes in flows due to climatic variability are considered by utilizing a water budget model, and performance indicators are computed once again for different climate change scenarios based on projections of the years 2030 and 2050.

Changes in the performance of Kemer reservoir under the above different conditions are assessed on the basis of performance indicators computed for each condition. The results have shown that the identification of different indicators by themselves or by their combination in the form of figures of merit independently for each reservoir purpose (e.g., flood control, irrigation supply, power production, etc.) serves to properly assess the system particularly in the planning and decision making phase. Moreover, the use of independently computed indicators is helpful in identifying the shares of operational objectives (purposes) of the system. It is also possible to compute a single overall indicator (i.e. a figure of merit) for any system by multiplying the indicators by the weights determined through the percent shares of the operational objectives (purposes) defined for the reservoir system.

Keywords: Performance indicators, reservoir performance, climate change.

BARAJ HAZNELERİNİN PERFORMANSLARININ DEĞERLENDİRİLMESİ: KEMER BARAJI ÖRNEĞİ

ÖZ

Hidrolik yapıların risk temelli dizaynı, gerekli görüldüğü takdirde bu yapıların planlanan amaçlarını yerine getirmesi sırasındaki performanslarının da değerlendirilmesi ve geliştirilmesini gerektirmektedir. Bu yaklaşım Türkiye'de pek kullanılmayan bir yaklaşım olduğundan, birçok yapının işletme performansı göz ardı edilmekte ve somut ifadelerle tanımlanmamaktadır. Sunulan çalışma Türk mühendislik uygulamalarındaki bu eksikliğe bağlı olarak gerçekleştirilmiş ve bu çalışmanın su yapılarının performansının değerlendirilmesi anlamında ilk çalışmalardan biri olması beklenmektedir.

Sunulan çalışmada, baraj haznelerinin performansının değerlendirilmesi ile ilgili yöntemler ele alınmış ve Büyük Menderes nehri üzerindeki Kemer Barajının hazne performansını değerlendirmek için bu yöntemlerden biri olan performans indisleri yöntemi kullanılmıştır.

İlk olarak performans indislerinin genel tanımları sunulmuş ve daha sonra haznenin taşkın koruma, enerji üretimi ve sulama performansının hesaplanması için, Kemer Barajının farklı işletme amaçları dikkate alınarak yeni tanımlar geliştirilmiştir.

Yukarıdaki indisler iki koşul altında hesaplanmıştır: ilk olarak, bu indisler Kemer barajının mevcut hazne işletmesi ele alınarak değerlendirilmiş ve ikinci olarak, bu indisler özel işletme kurallarının tanımlandığı, sulama talebinin karşılanma yüzdesine göre oluşturulmuş farklı işletme politikalarına bağlı olarak tekrar hesaplanmıştır.

Son zamanlarda iklim değişikliğinin su kaynakları üzerindeki etkisinin yarattığı duyarlılık ta mevcut hidrolik yapıların performansıyla ilgili sorulara yol açmaktadır. Bu konu sunulan çalışmada ele alınmış böylece iklimsel çeşitliliğe bağlı, akımlardaki potansiyel değişiklikler su bütçesi modeli kullanılarak göz önüne alınmış ve performans indisleri 2030 ve 2050 yılları projeksiyonlarına bağlı farklı iklim senaryoları için bir kere daha hesaplanmıştır.

Yukarıdaki farklı koşullar altında Kemer Barajı haznesinin performansındaki değişimler her koşul için hesaplanan performans indislerine göre değerlendirilmiştir. Sonuçlar göstermiştir ki, farklı indislerin her bir amaca göre bağımsız olarak (taşkın koruma, enerji üretimi, sulama vb.) gerek kendi başlarına gerekse bu indislerin kombinasyonu olan bileşik indis formunda tanımlanmaları, özellikle planlama ve karar verme aşamasında sistemin tam anlamıyla değerlendirilmesine hizmet etmektedir. Bunun ötesinde, indislerin bağımsız olarak hesaplanmasının kullanımı işletme amaçlarının her birinin sistem içindeki paylarının ne kadar olduğunun tespit edilmesi açısından faydalıdır. Ayrıca, tanımlanan hazne sistemi için, her bir amaca göre ayrı ayrı hesaplanan bu indislerin, sistemin işletme amaçlarının ağırlık yüzdesiyle çarpılması sonucu elde edilen tek bir bileşik indis biçiminde hesaplanması da mümkündür.

Anahtar sözcükler: Performans indisleri, hazne performansı, iklim değişikliği.

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CHAPTER ONE
METHODS FOR RISK, RELIABILITY AND UNCERTAINTY ANALYSES IN WATER RESOURCES SYSTEMS

1.1 Introduction

The primary purpose of water resources systems is to provide safe water, in adequate amounts, to all users, at all times and at the lowest costs under economic and other constraints which exist any time.

Water resources system planners are faced with the problem of formulating control mechanisms over the input water and developing related operating policies in order to evaluate the consistency of proposed goals and various alternative systems while planning large water resources systems and multi purpose reservoirs. An important issue in the planning of water resources systems is the adoption of certain performance criteria to assess how the designed system acts. Many studies in this regard have indicated that some performance criteria can be defined and that some of these criteria may become more important than the others in system performance evaluation (Hashimoto 1982, Fiering 1982, Duckstein, Plate, Benedini 1985, Srdjevic, Obradovic 1995, McMahon, Adeloye, 2005).

In many developed countries, performance asessment of existing and new water resources systems has become increasingly important in time. In particular, the current trend for risk based design of water resources systems requires that the performance of these systems in accomplishing their intended purpose is assessed and improved if deemed necessary. Such an approach is not very common in Turkey so that the operational performance of most systems and hydraulic structures is overlooked and is not described in tangible terms. Risk and reliability analyses for most systems are either not performed at all or not realized properly. The presented study is realized upon this deficiency in the Turkish engineering practice and is expected to be one of the first studies to assess the performance of water structures in computable figures.

In particular, literature does not show any remarkable study related to the performance evaluation of dam reservoirs, based on scientific methods such as the use of performance indicators. This issue has provided the major impetus and focus towards the realization of this study.

1.2 Literatue Review

A classic and elegant solution for reservoir design was given by Moran (1954) in the form of a model that predicts the probability distribution of storages at the end of successive years for a given initial condition. This model uses the Markov chain and multiplies the probability distribution of storages at an initial time period by a transitional probability matrix to obtain the distibution for the next period. The assumptions of Moran's model are that annual inflows are independent and reservoir withdrawals are equal for each year.

Gould (1961) modified the derivation of Moran's transitional probability matrix to include seasonal flow variation by using monthly rather than annual flows. This model also accounted for evaporation and rainfall and foresaw monthly variation of withdrawals from storage.

Lloyd (1963) expanded Moran's model to include inflow autocorrelation and seasonality. In Lloyd's model, the representation of the state of the system is expanded to a pair of reservoir-inflow values, and the transitional probability matrix considers a bivariate transition from state to state.

Yen and Ang were the first to incorporate hydraulic uncertainty into the design process along with the inherent randomness of hydrologic events (Yen, Ang 1971). Later, the risk analysis procedure was merged with a dynamic programming framework for determining the optimal risk-based storm sewer systems.

Tang and Yen further developed the above methods for use in the design of hydraulic structures (Tang, Yen 1972) and applied them to the design of storm sewer networks (Yen, Tang 1976).

Ang and Tang defined risk and reliability in water resources systems as the probability of failure and probability of nonfailure of a system, respectively (Ang, Tang 1984).

Duckstein, Plate and Benedini provided a system framework for embedding criteria related to incidents and failure of reservoirs, dams and other hydrologic systems, including supply schemes. They compared the performance of alternative operation schemes or rules within a multiple criteria framework based on performance indices (Duckstien, Plate, Benedini 1985).

Ganoulis, Duckstein and Bogardi applied a unified approach to risk analysis in water quantity and quality problems, and this is done by overviewing the definitions and methodologies for risk and reliability analysis in water resources and environmental engineering, including the concepts of fuzzy sets (Ganoulis, Duckstein, Bogardi 1986).

Water resources operational problems were also examined on the basis of risk and reliability concepts by Simonovic and Marino (1980, 1981, 1982); Burges and Lettenmaier (1982); Simonovic and Orlob (1984) and Moy et al (1986).

Correia, Santos and Rodrigues also applied a similar methodology, which was very general and flexible, based on two different but complementary approaches to reliability analyses in regional drought studies in the case of Sado basin located in southern Portugal (Correia, Santos, Rodrigues 1986).

Duckstein, Shrestha and Stakhiv defined reliability in hydrologic design and operation within a general discrete state versus discrete time system framework. They presented three simple but realistic design examples which foresaw the development of schemes to cope with water supply problems under emerging drought conditions(Duckstein, Shrestha, Stakhiv 1986).

Tung (1987) stressed that the philosophy of risk-based and reliability-based design of hydraulic structures in water resources engineering had become widely accepted and applied in real-life design problems.

Vogel (1985) studied methods to obtain the average return period of reservoir failures, using a two-state Markov chain, where failure was understood as the inability of the reservoir to meet the total water demands.

Srdjevic and Obradovic discussed the reliability-risk concept with respect to the evaluation of reservoir performance within large scale water resources systems. They adopted the ‘demand priority matrix’ and applied it to determine the so-called acceptable and unacceptable system states, where system states refer to reservoir storage levels (Srdjevic, Obradovic 1995).

Tyagi investigated the important factors affecting the exactness of the First Order Approximation estimates and developed a simple correction procedure useful for practicing engineers to correct the First Order Approximation estimates for carrying out reliability and risk analysis (Tyagi 2000).

Bayazıt and Önöz (2000) developed a method to compute conditional distributions for reservoir capacity, firm yield or reliability given specific values of the other two variables by using simulated hydrologic time series.

Syed performed the reliability analysis of water distribution systems by focusing on the hydraulic failure of the water distribution system (Syed 2003).

Definitions and estimators of water resources system reliability (the probability that the system will remain in a non-failure state), resilience (the ability of the system to return to non-failure state after a failure has occurred) and vulnerability (the likely damage of a failure event) have been thoroughly investigated by Kjeldsen and Rosbjerg (2004).

McMahon, Adeloye and Zhou examined 10 reservoir performance metrics including time and volume based reliability, several measures of resilience and vulnerability, drought risk index and sustainability (McMahon, Adeloye, Zhou 2005).

Baroudy explored the utility of fuzzy set theory in the field of water resources systems reliability analysis through the development of a methodology that considers all aspects of system reliability in a fuzzy environment where subjectivity, human input and lack of previous records impede the decision making process (Baroudy 2006).

1.3 Definitions of Risk, Reliability and Uncertainty

In view of the lack of generally accepted rigorous definitions for uncertainty, risk and reliability; it will be helpful to define these three terms in a manner amenable to mathematical formulation for their quantitative evaluation for engineering systems. Frank Knight's pioneering book, *Risk, Uncertainty and Profit*, originally published in 1921, identified three basic situations that decision makers are faced with:

1. complete certainty,
2. risk and
3. uncertainty.

Complete certainty is defined as a situation where the decision maker knows each possible alternative available and its exact outcome or the "state of nature".

Many dictionaries give three main conditions of uncertainty as:

1. The condition of being uncertain,

2. Something uncertain and
3. The estimated amount or percentage by which an observed or calculated value may differ from the true value.

Uncertainty is defined by Knight to mean that probabilities cannot be assigned to the outcomes. A decision maker may know all the possible outcomes but have no way of assigning probabilities; or only some of the alternatives or their outcomes may be known. On the extreme side, decision makers may be faced with complete ignorance (Knight, 1921).

According to Chow, uncertainty can be defined in simple language as the occurence of events that are beyond human control (Chow, 1979).

Another definition of uncertainty is given by IWR as: "uncertainty is the indeterminancy, through absence of plausible information or otherwise, of some of the elements that characterize the sitiuation" (IWR, 1992).

"Uncertainty is a general concept that reflects our lack of sureness about something or someone, ranging from just short of complete sureness to an almost complete lack of conviction about an outcome" (NRC, 2000).

Rescher (1983) gave three basic modes of uncertainty:

1. Probability uncertainty arises when some of the relevant probabilities are undetermined or underdetermined;
2. Outcome uncertainty arises when some of the relevant outcomes are undetermined or underdetermined;
3. Result uncertainty arises when some of the relevant results of the above outcomes are undetermined or underdetermined.

Simonovic (1997) states that the two major sources of uncertainty are *randomness* and *lack of knowledge.* Randomness that he calls “variability for water resources systems” can be divided into three:

i. temporal,
ii. spatial and,
iii. individual heterogeneity.

Imprecision or ambiguity, sometimes called lack of knowledge, is the other type of uncertainty that stems from our inability to conceptualize the real world processes in a mathematical form, especially for complex systems. Ang and Tang (1984) referred to the model prediction error as the other type of uncertainty. They mentioned two types of model prediction errors:

i. systematic error
ii. random error

On the other hand, Singh et al (2007) give six types of uncertainty as:

1. Natural uncertainties are associated with random temporal and spatial fluctuations inherent in natural processes;
2. Model structure uncertainty reflects the inability of the simulation model or design technique to represent precisely the system’s true behavior or process. This inability is caused by wrong assumptions employed for constructing the model.
3. Model parameter uncertainties reflect the variability in determining the parameter to be used in a model or design.
4. Data uncertainties arise from;
    i. Measurement inaccuracy and errors,
    ii. İnadequacy of the data gauging network and,
    iii. Data handling and transcription errors.

5. Computational uncertainties arise from truncation and rounding off errors in performing the calculations.
6. Operational uncertainties are associated with construction, manufacturing, deterioration, maintanence and other human factors that are not accounted for in the modeling or design procedure.

Singh et al (2007) also emphasized, like Simonovic, that uncertainty may also be classified into two categories:

1. Inherent or intrinsic- caused by randomness in nature.
2. Epistemic-caused by the lack of knowledge of the system or paucity of data.

The unabridged Webster's Third New World International Dictionary(1986) gives the following four definitions of risk:

1. "the possibility of loss, injury, disadvantage, or destruction,

2. someone or something that creates or suggests a hazard or adverse chance: a dangerous element or factor;

3. a: (i) the chance of loss or the perils to the subject matter of insurance covered by a contract,

(ii) the degree of probability of such loss;

b: amount at risk;

c: a person or thing judged as a (specified) hazard to an insurer;

d: (insure...);

4. the product of the amount that may be lost and the probability of losing it [United Nations definitition]"

The unabridged Random House Dictionary lists the following definitions of risk:

1. "exposure to the chance of injury or loss;

2. insurance:

a) the hazard or chance of loss;

b) the degree of probability of such loss;

c) the amount that the insurance company may lose;

d) a person or thing with reference to the hazard involved in insuring him, her, or it;

e) the type of loss, such as life, fire, marine disaster, or earthquake, against which an insurance policy is drawn,

3. at risk;
4. take or run a risk

The Oxford English Dictionary defines risk as

1. a) hazard, danger; exposure to mischance or peril;
   b) to run a or the risk;
   c) a venturous course;
   d) at risk or high risk: in danger, subject to hazard;
   e) a person who is considered a liability or danger; one who is exposed to hazard;
2. the chance or hazard of commercial loss. Also, the chance that is accepted in economic enterprise and considered the source of (an entrepreneur's) profit.

With reference to the definition of the first two (American) dictionaries, risk is defined herein in general terms as the probability of failure to achieve an intended goal.

These definitions convey two distinguishing elements of the risk concept. The first suggests a probabilistic nature, variously expressed in terms of possibility, chance or probability. The second suggests an adverse consequence. The risk literature contains a great variety of alternate definitons, but in virtually all of them, risk implies a possible but not a deterministic outcome. In some context, risk has been used more or less as a synonym for probability, ignoring the adverse consequence dimension.

The U.S. Nuclear Regulatory Commission’s 1975 report, one of the best known in the risk field, expressed a technical definition of risk as follows:

i. risk = frequency & magnitude
ii. frequency / events / unit time
iii. Magnitude / conseqeunce / event
iv. Risk / consequence / unit time

Frequency is conceptually equivalent of probability, uncertainty, events of outcomes, and consequences to results. What makes a situation risky rather than uncertain is the availability of objective estimates of the probability distrubution. Mathematically, risk can be represented by a random variable described by a probability distrubution. Let X be a random variable assuming the value x to represent the events that describe the adverse conseqeunce or risk. Let P(x) be the probability denstiy function that represents the risk. Furthermore, let risk be a function of time so that we have X(t) and P(x(t)). Expected risk is now precisely defined as:

$$\int_0^\infty \int_{-\infty}^\infty x(t)P[x(t)]dxdt \tag{1.1}$$

Risk and uncertainty remain to be defined in an operational way for use in engineering analyses. Accordingly, some basic points can be summarized as: First, any situation that is not certain is, by definition, uncertain. Second, the lack of certainty stems from insufficient information; the information may be unknown or unknowable. Third, the nature of the uncertainty can be categorized by the type of information that is missing, but the resulting categories are not necessarily mutually exclusive. Risk is a special case of uncertainty in its general context (Fig.1.1).

Figure.1.1 Continuum of knowlegde

Reliability is defined mathematically as the complement of risk. In some disciplines, often the nonengineering ones, the word risk refers not just to the probability of failure but also to the consequence of that failure, such as the cost associated with the failure. Nevertheless, to avoid possible confusion, the mathematical analysis of risk and reliability is termed herein as “reliability analysis”.

Failure of an engineering system can be defined as a situation in which the load L (external forces or demands) on the system exceeds the resistance R (strength, capacity, or supply) of the system. The reliability P_s of an engineering system is defined as the probability of nonfailure in which the resistance of the system exceeds the load; that is,

$$P_s = P\,(L \leq R) \qquad (1.2)$$

in which P (·) denotes probability. Conversely, risk is the probability of failure when the load exceeds the resistance. Thus, the failure probability (risk) P_f can be expressed mathematically as

$$P_f = P\,(L > R) = 1 - p_s \qquad (1.3)$$

Failure of structures can be classified broadly into two types (Yen and Ang, 1971; Yen et al., 1986): structural failure and functional (performance) failure. Structural failure involves damage to or change of the structure or facility. On the other hand, performance failure does not necessarily involve structural damage. However, the performance limit of the structure is exceeded, and undesirable consequences occur. Generally, the two types of failure are related.

Equation 1.2. can be rewritten in terms of the performance function Z as;

$$P_f = P\,(Z < 0) \qquad (1.4)$$

Where Z is defined alternaively as;

$$Z = R - L \tag{1.5}$$

$$Z = \frac{R}{L} - 1 \tag{1.6}$$

$$Z = \ln\left[\frac{R}{L}\right] \tag{1.7}$$

Since R and L are random variables, the performance function Z is also random with the corresponding probability density function $f_z(Z)$ as shown in Figure.1.2;

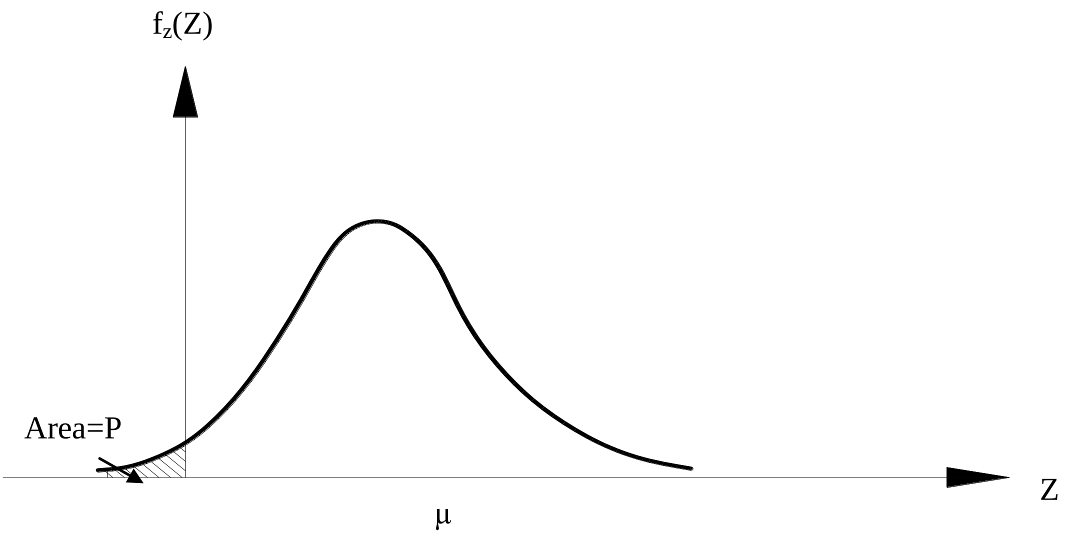


Figure 1.2 PDF of the performance function Z.

The reliability R_e of the system can be written as;

$$R_e = P(Z > 0) = 1 - P_f \tag{1.8}$$

In general, from (1.2), the risk can be expressed as;

$$P_f = \iint_{a\,c}^{b\,l} p_{R,L}(r,l)\,dr\,dl \tag{1.9}$$

where $p_{RJ},\{r,l)$ is the joint probability density function of R and L; c is the lower bound of R; and a and b are the lower and upper bounds of L respectively. The resistance, R, and load, L, are random variables given as;

$$R = g_1(\underline{V}) \tag{1.10}$$

$$L = g_2(\underline{U}) \tag{1.11}$$

where, U is the vector representing the input parameters of the model describing *R;* and V is the vector representing input parameters of the model defining *L*. In some problems, *L* may be a deterministic quantity representing a hydrologic/hydraulic/environmental target level. Alternatively, by using the performance variable Z defined in (1.3), (1.4), and (1.5), the risk can be written as;

$$P_f = P(Z < 0) = \int_{-\infty}^{0} pz\ (z) dZ \tag{1.12}$$

where $p_z\ (z)$ is the probability density function of Z. The probability distribution of Z is unknown, or difficult to obtain. In most cases, the exact distribution of Z may not be required as any of several distributions can be used to make a decision if correct information about the moments of p_z (z) is available (Bogardi and Kundzewicz 2002).

1.4 Methods for Risk, Reliability and Uncertainty Analyses

1.4.1 Method of Return Period

The return period (T) describes a time period in which the event X exceeds a prescribed resistance (R) (Tang, 1975). If the unit of return period is taken a year, the probability that the event, X is equal to or larger than the given resistance (capacity) per year, so;

$$P (X > R) = \frac{1}{T} \tag{1.13}$$

The method, which generally includes natural events such as floods and runoff, is used commonly in the design and analysis of hydraulic structures. The definitions must be made in terms of the nature of hydrologic events. X is generally continuous in hydrologic events, so it can be written as:

$$P\,(\,X = R\,) = 0 \tag{1.14}$$

Hydrologic risk is defined as the event X is larger than the resistance (capacity) every year and the reliability, therefore, can be identified as:

$$P\,(\,X \leq R\,) = 1 - \frac{1}{T} \tag{1.15}$$

Then, for a period of n years, risk becomes:

$$P\,(\,X > R\,) = 1 - (1 - \frac{1}{T})^{n} \tag{1.16}$$

or

$$P\,(\,X > R\,) = 1 - e^{(n/T)} \qquad \text{(for large T values)} \tag{1.17}$$

$$P\,(\,X > R\,) = \frac{n}{T} \qquad \text{(for T} >> \text{n)} \tag{1.18}$$

These equations are based on two basic assumptions:

i. Random events are independent from each other and,
ii. Hydrologic system is stationary

The return period method is often used to determine the risk imposed by natural inputs (e.g., inflows) to hydraulic structures. However, the disadvantage of the method is that some of the uncertainties are considered and some are neglected. To overcome this disadvantage, the return period method is usually used together with the safety factor method in some cases.

1.4.2 Safety Factor Method

Safety factor is an insurance against lack of information and uncertainties caused by randomness of natural events. If loads and resistance (capacity) are identified sufficiently, safety factor is then a measure of structural reliability.

In literature, there are various types of safety factor definitions which are given below (Yen, 1974);

i. Pre-determined safety factor
ii. Central value safety factor
iii. Predicted average safety factor
iv. Characteristics safety factor
v. Partial safety factor
vi. Reduced safety factor

The first definition is frequently used in engineering projects. In the design and analysis of hydraulic structures, extreme values of random variables are also used. If R and L denote supply and demand respectively, safety factor can be defined as:

$$\Theta = \frac{R}{L} \tag{1.19}$$

As R and L are random variables, Θ is also a random variable. Its density function as represented in Fig.1.3 may be derived from those of R and L. In this case, risk is defined as:

$$P_f = \int_0^1 f\Theta(\Theta)d\Theta \tag{1.20}$$

Equation 1.20 is the most suitable presentation of risk in the analysis of hydraulic structures. If the loads acting on structures and structural resistance capacity) are determined more accurately, the safety factor is achieved more reliably to define structural or system reliability (Yurdusev, 1990).

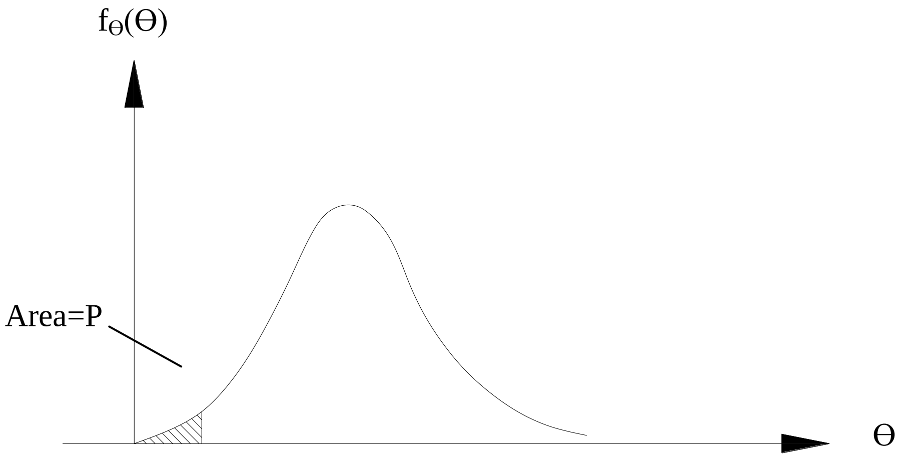


Figure 1.3 PDF of Safety Factor.

1.4.3 Direct Integration Method

Assuming that the necessary probability distributions of system capacity (supply) and demand are available, that is, when the probability density and cumulative distribution functions of load and resistance(capacity) are known, the risk (probability of failure) calculated from equation 1.3 for continuous R and L can be expressed as;

$$P_f = \int_0^\infty Fc(l) fl(l) dl \tag{1.21}$$

Where F_c is the cumulative distribution function and f_l is the pdf of random load and resistance(capacity). Alternatively reliability may be formulated as;

$$P_s = \int_0^\infty [1 - Fl(C)] fc(C) dc \tag{1.22}$$

Where F_c is the cumulative distribution function and f_l is the pdf of random load and resistance(capacity). Probability of failure may also be formulated in terms of performance function as;

$$P_f = \int_{-\infty}^{0} fz(Z)\,dz \qquad (1.23)$$

In Eq.1.21, loads and supply capacity must be statistically independent and the equation may be stated in terms of only the probability density functions as in Eq.1.9.

For the calculation of risk and reliability by the direct integration method as above, the probability density and cumulative distribution functions of loads and supply capacity must be determined clearly. In this regard, difficulties in determining the above distribution functions are essentially the largest disadvantages of the method. Particularly in complex systems such as dams, determination of these functions is very difficult because there are many factors affecting loads and capacity. Therefore, the direct integration method may be suitable for very simple systems or sub systems of large systems (Yurdusev, 1990).

1.4.4 Fisrt Order Approximation Method

The first order approximation (FOA) method can be used to estimate the amount of uncertainty, or scatter, of a dependent variable due to uncertainty about the independent variables included in a functional relationship. Cornell (1972) has described the first order approximation (FOA) technique in detail.

To present the general methodology of the first order approximation, consider an output random variable, Y, which is a function of n random variables. Mathematically, Y can be expressed as;

$$Y = g_1(\underline{X}) \qquad (1.24)$$

where $X = (Xi, X_2, \ldots\ldots\ldots, X_n)$, a vector containing n random variables. In FOA, a Taylor series expansion of the model output is truncated after the first-order term

$$Y = g_1(\underline{X}_e) + \sum_{i=1}^{n} (X_i - X_{ie}) \left[\frac{\partial g}{\partial Xi}\right]_{Xe} \qquad (1.25)$$

where $X_e = (X_{1e}, X_{2e}, \ldots\ldots, X_{ne})$, is a vector representing the expansion points. In FOA applications to water resources and environmental engineering, the expansion point is commonly the mean value of the basic variables. Thus, the expected value and variance of Y are;

$$E[Y] \approx g(\bar{X}) \tag{1.26}$$

$$Var(Y) = \sigma_Y^2 \approx \sum_{i=1}^{n} \sum_{j=1}^{n} \left[\frac{\partial g}{\partial Xi}\right]_{\overline{Xi}} \left[\frac{\partial g}{\partial Xj}\right]_{\overline{Xj}} E\left[(X_i - \bar{X}_i)(X_i - \bar{X}_j)\right] \tag{1.27}$$

where σ_Y is the standard deviation of Y; $\bar{X} = (\bar{X}_1, \bar{X}_2, \ldots.., \bar{X}_n)$ j, a vector of mean values of the basic input variables. If the basic variables are statistically independent, the expression for $Var(Y)$ becomes;

$$Var(Y) = \sigma_Y^2 \approx \sum_{i=1}^{n} \left[\left[\frac{\partial g}{\partial Xi}\right]_{\overline{Xi}} \sigma_{Xi}\right]^2 \tag{1.28}$$

To estimate the reliability of the system, R_e, it is typically assumed that the performance function (Z) is normally distributed. Assuming that $p_z(z)$ is a normal distribution with its parameters $E[Z]$ and σ_z determined by FOA, (1.3) and (1.7) are used to determine the risk and reliability of a given system.

An alternative method to define system reliability is the reliability index, β which is defined as the reciprocal of the coefficient of variation of Z, given as;

$$\beta = \frac{E[Z]}{\sigma_Z} \tag{1.29}$$

The great advantage of FOA is its simplicity, requiring knowledge of only the first two statistical moments of the basic variables and simple sensitivity calculations about selected central values. FOA is an approximate method that may suffice for many applications but the method does have several theoretical and/or conceptual shortcomings. The main weakness of the FOA method is that it is assumed that a single linearization of the system performance function at the central values of the basic variables is representative of the statistical properties of system performance over the complete range of basic input variables. In applying FOA in risk and reliability analyses, it is generally assumed that the performance function is normally distributed, which is seldom true. Any attempt to characterize the tails of the actual distribution based on an assumption of normality is likely to result in an inexact answer (Yurdusev 1990).

1.4.5 Response Surface Method

The response surface (SR) method is very similar to the FOA method. While the FOA method deals directly with the performance function, the RS approach involves approximating the original, complicated system performance function with by a simpler, more computationally tractable system model. This approximation typically takes the form of a first or second order polynomial where $G(x)$ is the approximate function representing the original function $g(X)$. Determination of the constants is accomplished through a linear regression about some nominal value, typically the mean. Given the new performance function, the analysis proceeds in exactly the same manner as the FOA method. This method has not been used much in the area of water resources and environmental engineering.

1.4.6 Monte Carlo Simulation

In Monte Carlo Simulation (MCS), probability distributions are assumed for the uncertain input variables for the system being studied. Random values of each of the uncertain variables are generated according to their respective probability distributions and the model describing the system is executed. By repeating the random generation of variable values and model execution steps many times, the statistics and an empirical probability distribution of the model output can be determined. The accuracy of the statistics and the probability distribution obtained from MCS is a function of the number of simulations performed and the adequacy of the assumed parameter distributions.

MCS is an art (Burges and Lettenmair, 1975). It requires judgement on the part of the modeler to create theoretical input sample distributions that are representative of the populations and to estimate the number of trials needed to generate the input and output density functions. There is no strictly defined answer to either of these questions.

A key problem in applying the MCS method is estimation of the necessary sample size. One empirical test to determine the adequacy of the sample size consists of iterating the sample program with increasingly greater sample sizes and estimating the convergence rate of the sample mean value towards the population mean (Burges and Lettenmair, 1975).

The error in the estimation of the population mean is inversely proportional to the square root of the number of trials. To improve the estimate by a factor of two, the sample size must increase by a factor of four. If the sample size is n, the standard deviation of the mean is $1/ n$ times the standard deviation of the population. This indicates that the sample size must be large (Siddall, 1983). As the sample size increases, the precision of the empirical percentrile estimates of a model output improves (Modarres, 1993).

The requirement of generating very large samples is a serious problem with MCS (Siddall, 1983). The method often entails sample sizes that are in the range of 5,000 to 20,000 members. Generally, the number of required samples increases with, the variances and the coefficient of skewness of the input distributions (Burges and Lettenmair, 1975).

MCS has been used to analyze uncertainty, risk, and reliability of many water resources and environmental engineering systems. Many of these applications of MCS were to provide a check of less computationally intensive methods.

On the other hand, The Monte Carlo Simulation method can be applied to large and complex systems. In practice due to following disadvantages, it is used only as a last resort, that is, when analytical or approximate methods are unavailable or inadequate.

i. The Monte Carlo Simulation method is basically a sampling technique, therefore, the results are subject to sampling errors and are also affected by probability distributions. Thus, Monte Carlo solutions from finite samples are not exact unless the sample size is infinitely large.

ii. A large repeating process requires extremely large computer capacity. Particularly for problems involving very rare events, its application to complex problems could be time consuming and costly.

Because of these two basic disadvantages, often, Monte Carlo Simulation maybe the only means for checking or validating an approximate method for probability calculations.

1.4.7 Second Order Approximation Method

In the second order approximation (SOA) method, a Taylor series expansion of a model is truncated after the second-order term. Consider a model represented by Eq.(1.25), the second order Taylor series expansion of *Y* is given as;

$$Y = g(\underline{X}_e) + \sum_{i=1}^{n} (X_i - X_{ie}) \left\{ \frac{\partial g}{\partial xi} \right\}_{X_e} + \frac{1}{2} \sum_{1=1}^{n} (X_i - X_{ie})^2 \left\{ \frac{\partial^2 g}{\partial Xi^2} \right\}_{X_e} \tag{1.19}$$

In SOA, the expansion point is commonly the mean value of the basic variables. Considering that all input variables are statistically independent and taking expectation of Eq.(1.24), the expected value *Y* is given as;

$$E[Y] \approx g\left(\underline{\bar{X}}\right) + \frac{1}{2} \sum_{i=1}^{n} \left(\frac{\partial^2 g}{\partial xi^2} \right) Var(X_i) \tag{1.20}$$

Bates and Townley (1984) and Tung and Hathhorn (1989) used SOA only for evaluating the mean of the model output. They preferred FOA to estimate variance of the model output due to involvement of complicated calculations in approximating the model output variance based on SOA.

1.4.8 First Order Reliability Method

The first order reliability (FORM) method is characterized by an iterative, linear approximation to the performance function. Fundamentally, this method can be considered as an extension of the FOA method and is also known as the advanced first order approximation (AFOA) method, which was developed to address technical difficulties of FOA. One of the major problems with the FOA technique was the lack of invariance of the solution relative to the formulation of the performance function. Simple algebraic changes in the problem formulation can lead to significant changes in assessment of the propagation of uncertainty. Hasofer and Lind (1974) presented a methodology which specifically addressed this issue by requiring expansion about a unique point in the feasible solution space. It should be mentioned that Fruedenthal (1956) also proposed a method suggesting similar restrictions on the expansion point.

Hasofer and Lind (1974) proposed taking the Taylor series expansion at a likely point on the failure surface of the performance function. Rackwitz (1976) implemented the ideas of Hasofer and Lind. The failure surface is defined by the equation Z = 0. The perpendicular drawn on the failure surface from the origin cuts the failure surface at a point called the failure point. The distance of the failure point from the origin is a measure of reliability. The expected value and the variance of Z can be obtained by first solving Z = 0 to find the failure point X*_ and then expanding Z about X*_ using a Taylor series expansion as;

$$E[Z] \approx \sum_{i=1}^{n} \left(\frac{\partial z}{\partial Xi}\right)_{X_i^*} (\bar{X}_i - X_i^*) \tag{1.21}$$

$$Var(Z) = \sigma_z^2 \approx \sum_{i=1}^{n} \sum_{j=1}^{n} \left(\frac{\partial z}{\partial Xi}\right)_{X_i^*} \left(\frac{\partial z}{\partial Xj}\right)_{X_j^*} E[(X_i - X_i^*)(X_i - X_j^*)] \tag{1.22}$$

where σ_z is the standard deviation of Z. For the case of statistically independent basic variables *Var(Z)* is rewritten as;

$$Var(Z) = \sigma_z^2 \approx \sum_{i=1}^{n} \left(\frac{\partial z}{\partial X_i}\right)_{X_i^*}^2 \sigma_{X_i}^2 \qquad (1.23)$$

FORM has been used quite successfully in a wide variety of fields for reliability and risk analyses. Some examples of using FORM in water quality uncertainty analyses include Melching and Anmangandla (1992).

1.4.9 Second Order Reliability Method

The second order reliability method (SORM) has been used extensively in structural reliability analyses. It has been established as an attempt to improve the accuracy of FORM. SORM is obtained by approximating the limit state surface function at the design point by a second order surface, and the failure probability is given as the probability content outside the second order surface. There are two kinds of second order reliability approximations: curvature-fitting SORM and point-fitting SORM (Zhao and Ono 1999). Both methods involve complex numerical algorithms and extensive computational efforts.

Hamed et al. (1996) compared risk assessments due to groundwater contamination based on FORM and SORM and reported that their results were in good agreement when the limit-state surface at the design point in the standard normal space is nearly flat. On the other hand, when the limit state function contains highly nonlinear terms, or when the input random variables have an accentuated non-normal character, SORM tends to produce more accurate results than FORM; yet the, computational requirements of SORM are much higher than FORM.

1.4.10 Point Estimation Method

The point estimation (PE) method was originally proposed by Rosenblueth (1975) to deal with symmetric, correlated, stochastic input parameters. The method was later extended to the case involving asymmetric random variables (Rosenblueth, 1981). The idea is to approximate the given PDF of an input random variable by discrete probability masses concentrated at two points in such a way that its first three moments are preserved.

Consider the model represented by (1-12) having *n* stochastic input parameters. Rosenblueth (1975, 1981) demonstrated that the r^{th}-order moment of output random variable *Y* about the origin could be approximated via a point-probability estimate of the first-order Taylor series expansion. This method requires 2^n model evaluations to estimate a single statistical moment of the model output. For a large model with a large number of parameters, Rosenblueth's PE method is computationally impractical. Further, a reliability analysis requires knowledge of higher order moments in order to approximate the distribution of the output random variable. This makes the method even more computationally extensive. Thus, while Rosenblueth's method is quite efficient for problems with a small number of uncertain basic variables, its computational requirements are similar to those of MCS for a model having a large number of parameters.

1.4.11 Transform Methods

Tung (1990) used the Mellin transform to calculate the higher-order moments of a model output. The application of the Mellin transform is not only cumbersome, but also it can not be universally applied. As pointed out by Tung, the Mellin transform may not be analytic under certain combinations of distribution and functional forms. In particular, problems may arise when a functional relationship consists of input variable(s) with negative exponents). When component functions of a given model have other forms than power functions, it can not be applied. Further, no formulation was suggested to obtain the moments of a model output having non-standard normally distributed input variable(s).

1.4.12 Conditional Reliability Modeling

The process of obtaining the reliability subject to an initial condition through several simulations is known as conditional reliability modelling (CRM). The main result of the CRM is the probability of meeting or exceeding different levels of the target amount for water supply diversions, environmental instream flow requirements, hydropower generation and reservoir storage given in a condition of storage levels, using specified premises regarding water management within a spesific time interval.

CRM allows managers to analyze the behavior of operational rules for a river/reservoir system under the occurrence of a specific condition and support their decisions (Tung, 2005).

CRM can be applied to support decisions regarding water management in the following months given current storage levels. The applications of the model can be summarized as follows:

a. Drought management: A CRM can support decisions regarding curtailment of water use and implementation of emergency water conversation measures. The model predicts the reliability of meeting demands over the next several months given conditions today and proposed drought contingency plans.

b. Operational planning: Reservoir operating rules may be developed based on the use of storage as a triggering mechanism for implementing predefined releases and water conversation plans. Water supply commitments for the next year or fort he irrigation season may be specified as a function of reservoir storage at the beginning of the year or season.

c. Water rights permits for reservoir storage: A CRM may be used to evaluate the probabilistic nature of the initial filling period, which may vary from a few weeks to several years, in preparing and evaluating plans for constructing new reservoir projects or reallaocating storage in existing reservoirs.

CHAPTER TWO

EVALUATION OF PERFORMANCE OF DAM RESERVOIRS WITH PERFORMANCE INDICATORS

2.1 General Approach

To model the reliability and other failure-related characteristics of hydrologic structures and water supply schemes, a general discrete system representation is employed (Duckstein et al., 1987). The system model comprises 5 elements:

(1) input set (controllable and noncontrollable inputs);
(2) state of the system;
(3) state transition function
(4) output;
(5) output function.

The latter two elements consist of performance indices (PIs) and combinations of indices or figures of merit (FMs). Examples of performance indices are grade of service, quality of service, and cost. Examples of figures of merit are engineering risk and reliability.

A discrete-time dynamic system Z, such as a water supply reservoir, has the system components **(T,S,X,Y,F,G),** which are defined respectively as follows:

T : a time scale (j = 1, 2, … , t, … , J)

S: this is a discrete state vector describing the system at time j. The elements of this vector belong to set S which may include storage volumes as well as physical characteristics of a dam such as resistance. The state set S also includes performance indices which measure how well the system performs.

X = (U,W): this is the input set composed of controllable elements U (e.g., height of dam) and noncontrollable elements W (e.g., the total net inflow into a reservoir).

Y: this is an output set that comprises physical variables such as water volume delivered. At every time j, the output usually includes an updated value of performance indices. The output also includes figures of merit, which are criterion functions defined over the components of the performance matrix. Figures of merit may be the mean values of performance indices, or their minimum or maximum components.

F: this is a state transition function which calculates the state of the system at time j+1 as a function of the previous states s(j) and the previous input x(j):

$$s(j + 1) = F(s(j), x(j)) \tag{2-1}$$

In case of reservoir operation, F is usually the mass balance equation:

$$v(j + 1) = v(j) - u(j) + w(j) \tag{2-2}$$

where:

v(j): water volume in storage at time j
u(j): controlled outflow including release
w(j): net random inflow.

G: this is an output function which represents an algorithm for calculating the present output y(j) as a function of the present state s(j):

$$y(j) = G(s(j)) \tag{2-3}$$

A simple example of output function is the transformation of a water shortage into an economic loss.

Table 2.1 represents the behavior of a reservoir system when an experiment c(t) is realized on the system (e.g. when the mass balance equation is applied).

2.2 Examples of Performance Indices

2.2.1 The Grade of Service

The grade of service is the relative frequency of providing a service, such as supplying water or reducing flood peak, when it is required, that is, when the demand arises or flood occurs. This performance indicator defines as the “ fraction of the demanded water which is supplied, computed over a specific period of time, such as a day, a month, a year”.

2.2.2 The Quality of Service

The quality of service or of response, measures for example the percentage of requirement satisfied.

2.2.3 The Speed of Response

The speed of response is the time elapsed between the occurence of the demand for a service and the delivery of that service.

2.2.4 The Reliability Performance Index

The reliability performance index, can be expressed in two types:

2.2.4.1 Time-based Reliability

Time based (Periodic) Reliability (R_p) is the percentage of periods that cover completely (%100) the diversion demand, hydropower generation, or instream flow requirement (Wurbs, 2001b, MacMahon et al, 2005). In a long term simulation, R_p can be calculated as;

$$R_p = \frac{n}{N} (\%100) \tag{2.4}$$

Where n= number of periods that the demand covered completely; and N= total number of periods.

The period reliability represents the likelihood of the deamnd being met in any month. In the conditional model developed in this research, the period reliability is equalto the probability of covering or exceeding the flow that would fully diversion or generation of the demand. In this case, it represents the likelihood that the demand would be totaly covered in the next period(s) of time given a condition of storage.

2.2.4.2 Volumetric Reliability

Volumetric Reliability (R_v) is the ratio of the water supplied(for any target) or energy generated (v) to the target amount (V) expressed as a percentage (Wurbs 2001b, McMahon et al, 2005). In a long term simulation, R_v can be calculated as;

$$R_v = \frac{v}{V} (\%100) \tag{2.5}$$

or

$$R_v = 1 - \frac{\sum_{i=1}^{N} Vi - vi}{\sum_{i=1}^{N} Vi} \tag{2.6}$$

2.2.5 Reliability Curve

Reliability Curve, is the relationship between a diversion/generation amount and the probability of equaling or exceeding that value. It is similar to the cumulative probability function of a random variable. Probability theory shows that the area under the cumulative probability function is equal to the expected value of the variable. Hence, the area under the reliability curve is equal to the expected value of the diversion/generation is expressed as a percentage of the target, the volume reliability is obtained.

2.2.6 Firm Yield

Firm Yield is the amount that could be diverted/generated without shortage during a lifetime. In reservoir, the firm yield is the amount that can be wihtdrawn continuously without causing the reservoir to be emptied(Klemes, 1981). The volumetric reliability is %100 when the target is less than or equal to the firm yield, or less than %100 otherwise. In the application of the conditional reliability model, the term “firm yield” is complemented by the time period of the analysis. For example, the firm annual yield is the maximum target that could be totally covered (without shortage) during th eyear following a storage condition. Firm yield, is also known as “safe dependent draft”.

2.2.7 The Incident Period

The incident period is the mean return period of failure state. It is also called the average recurrence time of shortages (Duckstein et al. 1987). It indicates how often a failure state happens in the system.

$$\text{Incident period} = \frac{\sum_{i=1}^{k} t_{m,i}}{k} \tag{2.7}$$

k: total mode number (surplus and deficit)
$t_{m,i}$: time between each sequence i.

2.2.8 The Mission Reliability

The mission reliability is an estimate of the probability that the system will not have an incident between the time that a non-null input requirement arrives and the corresponding service (water supply) is delivered. For a flood control problem, The mission reliability may count the proportion of floods mitigated by the reservoir to the total number of incoming floods.

2.2.9 The Availability

The availability is the probability that the system will not be in mode μ when the demand for a service occurs, for example, that the reservoir will not be above a critical control level when a flood arrives. The availability differs from the mission reliability in that a large flood may still result in substantial spillway overflow and damage downstream. the mission reliability and the availability are precise restatements of the grade of service.

2.2.10 The Resilience (The Repairability)

The resilience (the repairability) is the inverse of the average length of time that a system takes to return to a satisfactory state once a failure has occured (Duckstein et al. 1987). Another definiton of resilience is the ability to recover from a failure state (Hashimoto et al 1982). A large resilience indicates a quick return to normal state, while small value means that slow return to normal state from the failure state.

$$\Phi = \frac{fs}{fd}\ , \quad f_d \neq 0 \tag{2.8}$$

Where Φ is resilience, f_s is the number of individual continuous sequences of failure periods and f_d is total duration of all the failures, in other words, Φ is the inverse of the average failure duration.

Vogel and Bolognese (1995) described the use of a resilience parameter as a performance indicator for water supply systems and to classify reservoirs as within-year or over-year. Over-year reservoirs are not usually refilled annually, are more likely to reach a failure state, and have small resilience.

2.2.11 The Vulnerability

The vulnerability is likely magnitude of failure, if one occurs (Hashimoto et al, 1982). It expresses how severe the shortages will be. A system may have high reliability and high vulnerability at the same time, meaning that the probability of failure is low, but if the system is in failure mode, the damages will be enormous.

$$\acute{\eta} = \frac{\sum_{j=1}^{fs} \max(vj)}{fs} \tag{2.9}$$

where $\acute{\eta}$ is the vulnerability, v_j is the volumetric shortfall during jth continuous failure sequence and fs is the number of continuous failure sequences. A more useful expression of vulnerability is its dimensionless form given by:

$$\eta = \frac{\acute{\eta}}{Vf} \tag{2.10}$$

where η is the dimensionless vulnerability metric and V_f is the (constant) target demand during failure(McMahon et al. 2005).

2.2.12 The Sustainability Index

Recently, there have been a number of approaches defining sustainability of reservoir systems, e.g. fairness (Lence et al., 1997), reversibility (Fanai and Burn, 1997), consensus (Simonovic, 1998) and sustainability (Loucks, 1997). Of these the only quantitative measure is the sustainability metric of Loucks which combines the three measures reliability, resilience and vulnerability ratio to develop a sustainability index thus:

$$K = R_p.\ \Phi.(1 - \eta) \tag{2.11}$$

Where K is sustainability index, R_p is time-based reliability, Φ is resilience and η is dimensionless vulnerability.

2.2.13 The Economic Index

The economic index is a vector whose components may include expected costs, losses and benefits, rates of return, and cash flows (Duckstein, Bogardi 1981; Vogel 1986).

2.2.14 Figures of Merit

The performance indicators are usually calculated only at the end of each system experiment (different operation rules). They also be calculated at every time period if so desired. The Figures of Merit are then defined as a function of the performance indicators calculated over the ensemble of system experiments (different operation rules).

For a given initial state s(0), if system experiment c(t) is taken as the realization of a stochastic process with known distirubution $F_c(c)$, then a set of figures of merit (FM) may be defined by;

$$FM^k(\mu) = \int PI^k(c, \mu) dFc(c) \qquad \text{for k-1, …. K} \qquad (2.12)$$

where μ is mode surplus or mode deficit, k is the number of performance indicators.

An alternative definiton of figures of merit may also be given in terms of a percentile or another statistics; furthermore, a FM may consist of a combination of performance indicators;

$$FM = FM\ (PI^1, PI^2, \ldots, PI^k) \qquad (2.13)$$

where k is the number of performance indicators.

CHAPTER THREE
METHODOLOGY

In general, reservoir performance indicators are calculated in two modes: surplus and deficit. In this study, a new approach was developed for calculating the reservoir performance indicators. If reservoir is a multipurpose reservoir, performance indicators may also calculated for each purpose as a function of supply and demand.

In this study, definitions were given only calculable indicators for three purposes. At first, demands were determined for each purpose, then reservoir was operated for different rules with known supplies.

After that, the calcuable indicators were calculated with respect to their general definitons. In order to provide compatibility among the selected set of indicators, a further modification was performed for some of the indicators to generate a new set which varies between 0 and 1.

For determining the Figures of Merit, all calculated indicators were modified to show confident situation. For example, reliability shows confident situation so it can be used directly while calculation of FM; but vulnerability shows unconfident situation, so it can be taken into account as $(1-\eta)$. As an objective evaluation, it is assumed that these indicators which were calculated and modified have equal significance. If “n” indicators were calculated, their significance level was taken 1/n.

3.1 Definitions of Performance Indicators for Flood Control

3.1.1 The Grade of Service

The grade of service for flood control is defined as difference of the number of months which reservoir level is greater than the flood control curve level and the total obversation time.

3.1.2 Reliability

3.1.2.1 Time-based Reliability

Time-based reliability for flood control is defined as the ratio of the number of months which reservoir level is smaller than or equal to the flood control curve level and the total obversation time.

$$R_{p,flood} = \frac{n}{N}\,(\%100) \tag{2.14}$$

Where n is the number of months which reservoir level is smaller than or equal to the flood control curve level and N is the total observation time.

3.1.2.2 Volumetric Reliability

Volumetric reliability for flood control is defined as the ratio of the total volume covered for flood and total target demand. The total target demand for flood is total flood control volume of reservoir for defined obversation time.

$$R_{v,flood} = \frac{v}{V}\,(\%100) \tag{2.15}$$

Where v is the the total volume covered for flood and V is the total flood control volume of reservoir for defined obversation time.

3.1.3 Incident Period

As stated before the incident period is is the mean return period of failure state. Failure state for flood control is defined as the state where reservoir level is greater than the flood control curve level.

$$(\text{Incident period})_{flood} = \frac{\sum_{i=1}^{k} t_{m,i}}{k} \tag{2.16}$$

Where k is the total failure state number for flood control and $t_{m,i}$ is the time between each sequence i.

3.1.4 Resilience

Resilince for flood control is defined as the ratio of the number of state and the total duration time of state where reservoir level is greater than the flood control curve level.

$$\Phi_{\text{flood}} = \frac{fs}{fd} \;, \quad f_d \neq 0 \qquad (2.17)$$

Where f_s is the number of state and f_d is the total duration time of state where reservoir level is greater than the flood control curve level.

3.1.5 Vulnerability

Vulnerability for flood control is defined as the ratio of the total of the maximum volume differences for each state and the number of state where reservoir level is greater than the flood control curve level.

$$\acute{\eta}_{flood} = \frac{\sum_{j=1}^{fs} \max(vj)}{fs} \qquad (2.18)$$

Where v_j is the volumetric difference where reservoir level is greater than the flood control curve level (or volume of water spilled) and f_s is the number of continuous failure sequences.

3.2 Definitions of Performance Indicators for Energy Production

3.2.1 The Grade of Service

The grade of service for energy production is defined as difference of the number of months which requried amount of water for energy production is allocated and the total obversation time.

3.2.2 Reliability

3.2.2.1 Time-based Reliability

Time-based reliability for energy production is defined as the ratio of the number of months which requried amount of water for energy production is allocated and the total obversation time.

$$R_{p,energy} = \frac{n}{N} (\%100) \tag{2.19}$$

Where n is the number of months which requried amount of water for energy production is allocated and N is the total obversation time.

3.2.2.2 Volumetric Reliability

Volumetric reliability for energy production is defined as the ratio of the total volume covered for energy production and total target demand. The total target demand for energy production is total volume of water which requried to produce of defined energy production of reservoir.

$$R_{v,energy} = \frac{v}{V} (\%100) \tag{2.20}$$

Where v is the the total volume covered for energy produvtion and V is the total volume of water which requried to produce of defined energy production of reservoir.

3.2.3 Incident Period

As stated before the incident period is is the mean return period of failure state. Failure state for energy production is defined as the state where required amount of water for energy production is not allocated.

$$\text{(Incident period)}_{\text{energy}} = \frac{\sum_{i=1}^{k} t_{m,i}}{k} \qquad (2.21)$$

Where k is the total failure state number for energy production and $t_{m,i}$ is the time between each sequence i.

3.2.4 Resilience

Resilince for energy production is defined as the ratio of the number of state and the total duration time of state where required amount of water for energy production is not allocated.

$$\Phi_{\text{energy}} = \frac{fs}{fd} \;, \quad f_d \neq 0 \qquad (2.22)$$

Where f_s is the number of state and f_d is the total duration time of state where required amount of water for energy production is not allocated.

3.2.5 Vulnerability

Vulnerability for energy production is defined as the ratio of the total of the maximum volume differences for each state and the number of state where required amount of water for energy production is not allocated.

$$\acute{\eta}_{energy} = \frac{\sum_{j=1}^{fs} \max{(vj)}}{fs} \qquad (2.23)$$

Where v_j is the volumetric difference where required amount of water for energy production is not allocated and f_s is the number of continuous failure sequences.

3.3 Definitions of Performance Indicators for Irrigation

3.3.1 The Grade of Service

The grade of service for irrigation is defined as difference of the number of months which requried amount of irrigation water is allocated and the total obversation time.

3.3.2 Reliability

3.3.2.1 Time-based Reliability

Time-based reliability for irrigation is defined as the ratio of the number of months which requried amount of irrigation water is allocated and the total obversation time.

$$R_{p,irrigation} = \frac{n}{N} (\%100) \qquad (2.24)$$

Where n is the number of months which requried amount of water for irrigation is allocated and N is the total obversation time.

3.3.2.2 Volumetric Reliability

Volumetric reliability for irrigation is defined as the ratio of the total volume covered for irrigation and total target demand. The total target demand for irrigation is total volume of requried amount of water which is allocated.

$$R_{v,energy} = \frac{v}{V} (\%100) \qquad (2.25)$$

Where v is the the total volume covered for irrigation and V is the total target demand which total volume of requried amount of water for irrigation which is allocated.

3.3.3 *Incident Period*

As stated before the incident period is is the mean return period of failure state. Failure state for irrigation is defined as the state where required amount of water for irrigation is not allocated.

$$(\text{Incident period})_{\text{irrigation}} = \frac{\sum_{i=1}^{k} t_{m,i}}{k} \qquad (2.26)$$

Where k is the total failure state number for irrigation and $t_{m,i}$ is the time between each sequence i.

3.3.4 *Resilience*

Resilince for irrigation is defined as the ratio of the number of state and the total duration time of state where required amount of water for irrigation is not allocated.

$$\Phi_{\text{irrigation}} = \frac{fs}{fd} \;, \quad f_d \neq 0 \qquad (2.27)$$

Where f_s is the number of state and f_d is the total duration time of state where required amount of water for irrigation is not allocated.

3.3.5 *Vulnerability*

Vulnerability for irrigation is defined as the ratio of the total of the maximum volume differences for each state and the number of state where required amount of water for irrigation is not allocated.

$$\acute{\eta}_{irrigation} = \frac{\sum_{j=1}^{fs} \max(vj)}{fs} \tag{2.28}$$

Where v_j is the volumetric difference where required amount of water for irrigation is not allocated and f_s is the number of continuous failure sequences.

CHAPTER FOUR
EVALUATION OF PERFORMANCE OF DAM RESERVOIRS IN THE CASE OF KEMER DAM

4.1 Kemer Dam Characteristics and Study Area

Kemer Dam is located on the Büyük Menderes, which is the longest river in the Aegean region. It meanders for 584 km through western Turkey before reaching the Aegean Sea with a large delta, consisting of several lagoons, extensive salt steppes and mudflats (the biggest in Turkey). The Büyük Menderes Delta is an important wetland with an area of 9800 ha; like Gediz Delta, it is recognized as a RAMSAR site. Büyük Menderes has a total drainage area of 24976 km^2, and the annual runoff is in the order of 3 km^3, which accounts for 1.6% of Turkey’s water potential.

The basin is engineered into extensive water resources systems, including 13 dams and a large number of irrigation schemes. The total irrigated area in the basin is more than 88000 ha. The region is rich not only in terms of agriculture but also in industry, the major one being the textile industry, and tourism. These activities indicate significant demand and competition for water (SUMER, 2006).

Kemer Dam is on the Akçay river which drains the largest tributary of the Büyük Menderes basin. Kemer Dam is located about 46 km south of the town of Nazilli, in a relatively narrow gorge, 620 m downstream from the old Kemer bridge whose name was given to the project. Figure 4.1. shows the location and Table 4.1. shows the characteristics of Kemer Dam.

The dam and the reservoir are located on a metamorphic system composed of highly folded and foulted series of rocks consisting of mica-schists, slates, quratzites, phillites, marble and schistos limestones. The Dam axis is situated in fairly abutment step and consists of medium to masievly bedded marble and schistos limestone. The left abutment has more gentle slope and is composed of alternating beds of schistose limestone and micaschist (Ural & Ungan 1967).

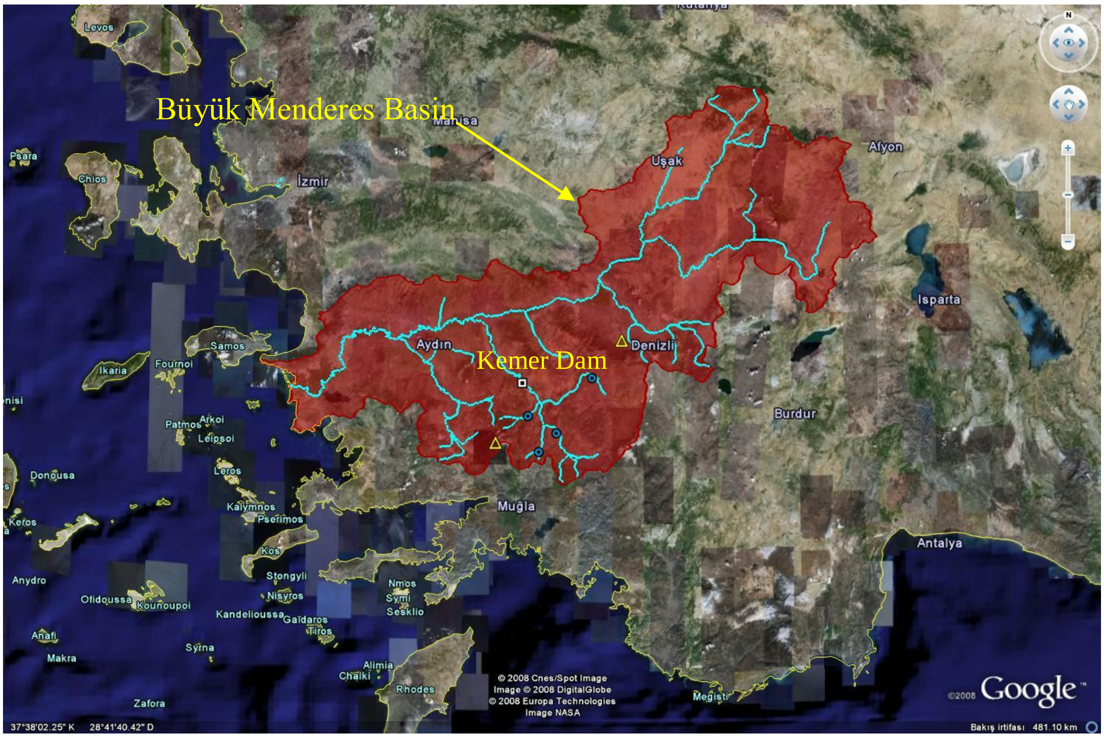


Figure 4.1 The location of Büyük Menderes Basin and Kemer Dam

Table 4.1 The major characteristics of Kemer Dam (DSI 2007).

Characteristics	**Unit**	**Value**
Drainage area	km^2	3100
Average flow	m^3/sec	28.4
Recorded maximum flow	m^3	943
Maximum operation elevation	m	287.45
Maximum operation volume	hm^3	
Minimum operation elevation	m	248.65
Minimum operation volume	hm^3	57.6
Flood Control Volume	hm^3	120
Crest elevation	m	289.45
Crest length	m	309.79
Installed capacity	MW	3x16
Annual energy production (planned)	GWh	143
Annual energy production (revised)	GWh	60
Energy tunnel elevation	m	239.30
Critical energy elevation	m	243.95
Dipsavak eksen kotu	m	211.15

4.2 Hydrologic and Meteorological Data

The hydrologic data which were used in the study, were collected from the records of two different institutes: XXI. Regional Directorate of State Hydraulic Works and Operational Directorate of Kemer Dam Power Plant which is a part of the Electrical Works Authority. The collected data were examined and 1981-2000 period was selected for the study (DSI 2007, EUAS 2007).

The meteorological data were collected from the records of the Turkish State Meteorological Service. At first, three meteorological stations which are outside the drainage area of Kemer were selected; these are 17237 – Denizli, 17292 – Muğla and 17860 Nazilli (DMI 2007). Since there are no meteorological stations within the drainage area of Kemer Dam, these stations were selected because they are more close to the area than others. To investigate how well these stations do represent the drainage area of the dam, Thiessen poligon was formed, which showed that 17860 Nazilli station does not reflect the area sufficiently and that each of the other two stations approximately represent the area at a percentage of 50% .

4.3 Determination of Inflows Under Climate Change Effects

4.3.1 Climate Change Effects

Climate change effects in spatially averaged temperature and precipitation Buyuk Menderes River Basin were assessed using a new version of the MAGICC/SCENGEN model, developed by NCAR-CRU using over a dozen recent GCMs by SUMER (SUMER, 2006).

MAGICC/SCENGEN is a coupled gas-cycle/climate model (MAGICC) that drives a spatial climate change scenario generator (SCENGEN). MAGICC is a Simple Climate Model that computes the mean global surface air temperature and sea-level rise for particular emissions scenarios for greenhouse gases and sulphur dioxide (Raper et al., 1996).

The 49 emission scenarios involved in MAGICC model are investigated in the project; and the ASF model of A2 and MESSAGE model of B2 storylines, which represent the marker scenarios of IPCC SRES, were selected to evaluate climate change effects in the case basin (SUMER, 2006).

The above global change scenarios are downscaled to the regional scale by using SCENGEN. In the regional analysis, the changes in the temperature and precipitation are examined on annual, seasonal (four seasons) and monthly (12 months) basis. The procedure was repeated for both emission scenarios, i.e., A2-ASF and B2-MESSAGE and for three projection years of 2030, 2050 and 2100 (SUMER, 2006).

The IPCC SRES B2 scenario assumes a world of moderate population growth and intermediate level of economic development and technological change. SCENGEN estimates a global mean temperature increase of 0.85 °C by 2030, 1.33 °C by 2050, and 2.48 °C by 2100 for the B2 scenario.

The IPCC SRES A2 scenario assumes a world of high population growth and intermediate level of economic development and technological change. SCENGEN estimates a global mean temperature increase of 0.67 °C by 2030, 1.29 °C by 2050, and 3.47 °C by 2100 for the A2 scenario.

In this study only 2030 and 2050 scenarios were selected and the estimated changes in temperature and precipitation are summarized in Tables 4.2. through 4.5.

Table 4.2 Generated Changes in Temperature under the IPCC B2-MES Scenario.

Period	Baseline			2030		2050		2100	
	Observed	Modeled							
	Mean	Mean	Std.	Change	Ch. in Var.	Change	Ch. in Var.	Change	Ch. in Var.
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
	^{0}C	^{0}C	^{0}C	^{0}C	%	^{0}C	%	^{0}C	%
Annual	16.3	16.4	0.4	**1.2**	5.1	**1.8**	7.9	**3.2**	14.7
DJF	9.4	9.4	0.8	**1.0**	-2.5	**1.5**	-3.9	**2.6**	-7.2
MAM	14.4	14.4	0.6	**1.1**	2.7	**1.7**	4.1	**2.9**	7.7
JJA	23.4	23.5	0.6	**1.6**	3.8	**2.4**	5.9	**4.1**	10.9
SON	17.8	17.8	0.8	**1.4**	-2.0	**2.0**	-3.1	**3.6**	-5.7
January	8.7	9.0	1.4	**0.9**	1.1	**1.4**	1.7	**2.5**	3.1
February	9.2	9.3	1.2	**0.9**	5.6	**1.3**	8.8	**2.4**	16.4
March	10.9	10.9	1.0	**0.8**	-4.6	**1.2**	-7.2	**2.1**	-13.4
April	14.2	14.3	0.8	**1.1**	0.6	**1.6**	0.9	**2.7**	1.8
May	18.0	17.9	0.9	**1.4**	7.1	**2.1**	11	**3.7**	20.5
June	21.8	21.9	1.1	**1.6**	5.1	**2.3**	7.9	**4.1**	14.8
July	24.1	23.9	0.8	**1.6**	-0.5	**2.3**	-0.7	**4.1**	-1.3
August	24.4	24.4	0.8	**1.7**	-1.1	**2.6**	-1.6	**4.5**	-3.1
September	21.7	21.6	0.8	**1.5**	1.5	**2.2**	2.3	**3.8**	4.3
October	17.8	17.8	1.1	**1.4**	2.5	**2.1**	3.9	**3.7**	7.3
November	14.0	13.8	1.1	**1.1**	0.4	**1.6**	0.6	**2.7**	1.1
December	10.4	10.5	1.3	**1.0**	-3.2	**1.5**	-4.9	**2.6**	-9.2

Table 4.3 Generated Changes in Temperature under the IPCC A2-ASF Scenario.

Period	Baseline			2030		2050		2100	
	Observed	Modeled							
	Mean	Mean	Std.	Change	Ch. in Var.	Change	Ch. in Var.	Change	Ch. in Var.
	1	2	3	4	5	6	7	8	9
	^{0}C	^{0}C	^{0}C	^{0}C	%	^{0}C	%	^{0}C	%
Annual	16.3	16.4	0.4	**1.2**	4.0	**2.0**	7.7	**4.4**	20.6
DJF	9.4	9.4	0.8	**1.0**	-2.0	**1.6**	-3.8	**3.5**	-10.1
MAM	14.4	14.4	0.6	**1.2**	2.1	**1.9**	4.0	**4.1**	10.8
JJA	23.4	23.5	0.6	**1.5**	3.0	**2.5**	5.7	**5.5**	15.3
SON	17.8	17.8	0.8	**1.2**	-1.6	**2.0**	-3.0	**4.7**	-8.0
January	8.7	9.0	1.4	**1.0**	0.8	**1.6**	1.6	**3.6**	4.3
February	9.2	9.3	1.2	**0.7**	4.4	**1.2**	8.6	**3.1**	22.9
March	10.9	10.9	1.0	**1.0**	-3.6	**1.6**	-7.0	**3.1**	-18.8
April	14.2	14.3	0.8	**1.2**	0.5	**1.9**	0.9	**3.7**	2.5
May	18.0	17.9	0.9	**1.3**	5.6	**2.2**	10.7	**5.0**	28.7
June	21.8	21.9	1.1	**1.5**	4.0	**2.5**	7.7	**5.5**	20.7
July	24.1	23.9	0.8	**1.5**	-0.4	**2.4**	-0.7	**5.4**	-1.9
August	24.4	24.4	0.8	**1.6**	-0.8	**2.7**	-1.6	**6.0**	-4.3
September	21.7	21.6	0.8	**1.2**	1.2	**2.1**	2.3	**5.1**	6.1
October	17.8	17.8	1.1	**1.3**	2.0	**2.1**	3.8	**4.9**	10.2
November	14.0	13.8	1.1	**0.9**	0.3	**1.5**	0.6	**3.5**	1.5
December	10.4	10.5	1.3	**1.2**	-2.5	**1.9**	-4.8	**3.5**	-12.9

Table 4.4 Generated Changes in Precipitation under the IPCC B2-MES Scenario.

Period	Baseline			2030		2050		2100	
	Observed	Modeled							
	Mean	Mean	Std.	Change	Ch. in Var.	Change	Ch. in Var.	Change	Ch. in Var.
	1	2	3	4	5	6	7	8	9
	mm/day	mm/day	mm/day	%	%	%	%	%	%
Annual	1.7	1.7	0.2	**-5.0**	5.6	**-8.0**	8.7	**-15.4**	16.2
DJF	3.3	3.1	0.7	**-2.7**	-2.6	**-4.7**	-4.0	**-10.2**	-7.5
MAM	1.7	1.6	0.4	**-5.1**	-1.9	**-7.9**	-3.0	**-14.4**	-5.6
JJA	0.3	0.3	0.1	**-26.1**	-5.5	**-36.8**	-8.5	**-59.9**	-15.9
SON	1.5	1.5	0.4	**-9.0**	-1.6	**-14.5**	-2.5	**-28.1**	-4.6
January	3.2	3.2	1.1	**-3.3**	8.9	**-5.5**	13.8	**-11.6**	25.8
February	2.9	2.7	1.1	**-0.7**	-14.2	**-2.6**	-22.0	**-7.9**	-41.1
March	2.4	2.2	0.9	**-0.2**	-3.2	**-0.1**	-4.9	**-0.6**	-9.2
April	1.5	1.5	0.5	**-5.9**	13.6	**-9.3**	21.1	**-16.2**	39.5
May	1.0	1.0	0.4	**-12.4**	-10.0	**-18.7**	-15.6	**-31.6**	-29.2
June	0.5	0.5	0.3	**-24.9**	-0.6	**-35.9**	-1.0	**-59.3**	-1.8
July	0.3	0.3	0.2	**-35.2**	-9.3	**-47.6**	-14.5	**-73.0**	-27.0
August	0.2	0.2	0.1	**-13.5**	-16.1	**-20.4**	-25.1	**-37.2**	-46.8
September	0.4	0.4	0.3	**-9.9**	-6.8	**-15.7**	-10.6	**-30.1**	-19.8
October	1.3	1.3	0.8	**-17.1**	-10.5	**-26.5**	-16.3	**-48.5**	-30.4
November	2.9	2.8	1.0	**-6.2**	1.2	**-10.5**	1.9	**-21.6**	3.5
December	3.8	3.5	1.2	**-4.4**	3.2	**-6.5**	5.0	**-12.1**	9.3

Table 4.5 Generated Changes in Precipitation under the IPCC A2-ASF Scenario.

Period	Baseline			2030		2050		2100	
	Observed	Modeled							
	Mean	Mean	Std.	Change	Ch. in Var.	Change	Ch. in Var.	Change	Ch. in Var.
	1	2	3	4	5	6	7	8	9
	mm/day	mm/day	mm/day	%	%	%	%	%	%
Annual	1.7	1.7	0.2	**-5.8**	4.4	**-10.2**	8.5	**-23.8**	22.7
DJF	3.3	3.1	0.7	**-5.6**	-2.0	**-9.2**	-3.9	**-19.0**	-10.5
MAM	1.7	1.6	0.4	**-7.4**	-1.5	**-11.5**	-2.9	**-21.9**	-7.8
JJA	0.3	0.3	0.1	**-15.5**	-4.3	**-26.4**	-8.3	**-66.3**	-22.3
SON	1.5	1.5	0.4	**-4.8**	-1.3	**-11.9**	-2.4	**-39.6**	-6.5
January	3.2	3.2	1.1	**-7.8**	7.0	**-11.9**	13.5	**-22.0**	36.1
February	2.9	2.7	1.1	**-1.2**	-11.2	**-4.5**	-21.5	**-16.3**	-57.6
March	2.4	2.2	0.9	**-9.9**	-2.5	**-11.6**	-4.8	**-8.4**	-12.8
April	1.5	1.5	0.5	**0.3**	10.7	**-3.1**	20.6	**-17.4**	55.2
May	1.0	1.0	0.4	**0.0**	-7.9	**-5.9**	-15.3	**-32.0**	-40.8
June	0.5	0.5	0.3	**-1.1**	-0.5	**-10.4**	-1.0	**-57.5**	-2.6
July	0.3	0.3	0.2	**-3.7**	-7.3	**-11.5**	-14.1	**-59.7**	-37.8
August	0.2	0.2	0.1	**-19.2**	-12.7	**-29.5**	-24.5	**-56.8**	-65.5
September	0.4	0.4	0.3	**-6.9**	-5.4	**-14.5**	-10.3	**-42.9**	-27.7
October	1.3	1.3	0.8	**-1.8**	-8.2	**-11.7**	-15.9	**-58.1**	-42.6
November	2.9	2.8	1.0	**-6.1**	1.0	**-12.6**	1.8	**-34.5**	4.9
December	3.8	3.5	1.2	**-7.2**	2.5	**-10.6**	4.9	**-19.3**	13.0

4.3.2 Water Budget Model

4.3.2.1 Model Structure

Water Budget Model is a model which calculates surface flow, subsurface flow and groundwater flow components and estimates the monthly flow by using monthly precipitation and evapotranspiration values.

When the model types are considered, WBM is conceptual, deterministic, lumped and continuous model. The process details of the model is shown in Figure 4.2.

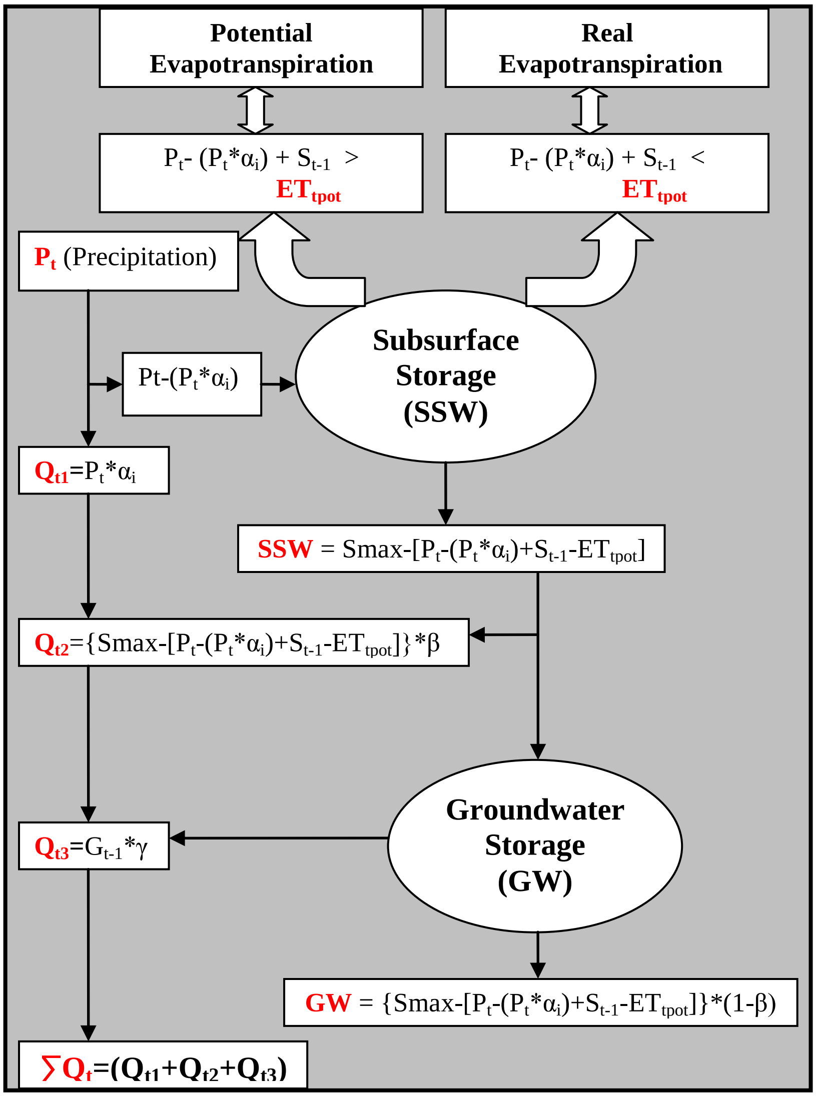


Figure 4.2 Flow chart of the model.

In flow chart;

P_t **:** Monthly total precipitation(mm/month).

ET_{tpot} **:** Monthly total potential evapotranspiration(mm/month).

ET_{tref} **:** Monthly total reference potential evapotranspiration (mm/month).

θ_i **:** The plant coefficient which converts Monthly total reference potential evapotranspiration to monthly total potential evapotranspiration

α_i **:** Surface flow parameter which shows how much monthly precipitation does pass directly to surface flow.

β **:** Subsurface flow parameter which shows how much monthly precipitation does pass directly to subsurface flow.

γ **:** Groundwater flow parameter which shows how much monthly precipitation does pass directly to groundwater flow.

Smax **:** Soil parameter which shows the max. subsurface store of the soil (mm)

S_{t-1} **:** Subsurface storage value of previous month. (mm)

G_{t-1} **:** Groundwater storage value of previous month (mm)

α, **β**, **γ and Smax** are the parameters which need to be determined and calibrated within WBM; they change with respect to basin properties. **β**, **γ** ve **Smax** depend on soil porperties of the basin, and **α** parameter ve **θ** coefficient relate to land cover type (Fıstıkoğlu and Harmancıoğlu 2001, Okkan 2007).

4.3.2.2 The Model Process

Water Bugdet Model firstly guides **α_i*P_t** part of the monthly total precipitation to surface flow depending on monthly **α_i** coefficient. After that, the monthly potential evapotranspiration value, which is determined depending on the **θ_i** coefficient of that month, is compared with the difference (**ET_{tpot}** = **ET_{tref}*θ_i**), **P_t -(α_i *P_t);** if there is sufficient residual precipitation, **ET_{tpot}** is covered by residual precipitation and the other residual part passes through subsurface storage. So **ET_{tref}*θ_i** value which is obtained gives the potential evapotranspiration value of that month.

If $\mathbf{ET_{tref}*\theta_i}$ value is higher than residual precipitation, the difference is covered by soil moisture of the previous month, namely by subsurface storage. In such a case, it is checked whether the need of total potential evapotranspiration of that month is covered or not. If there is not sufficient soil moisture, the value of real total potential evapotranspiration is considered. If the Smax value, which is the maximum value of subsurface storage, is excessive, some part of the exceeding amount feeds the surface flow depending on **β** coeefficient, while **(1-β) part** passes into subsurface storage. On the other hand, the part of surface flow which is fed by groundwater is obtained from groundwater storage of the previous month, depending on **γ** coefficient**.** So surface flow of any month i can be expressed as follows;

$$Q_t = \alpha_i * P_t + \beta * SSW_t + \gamma * GW_{t-1} \tag{4.1}$$

In this equation;

$\boldsymbol{\alpha_i}$: Monthly surface flow coefficient (i=1,2,3,..)

$\mathbf{P_t}$ **:** Precipitation in month t (mm/month) (t=1,2,3,..)

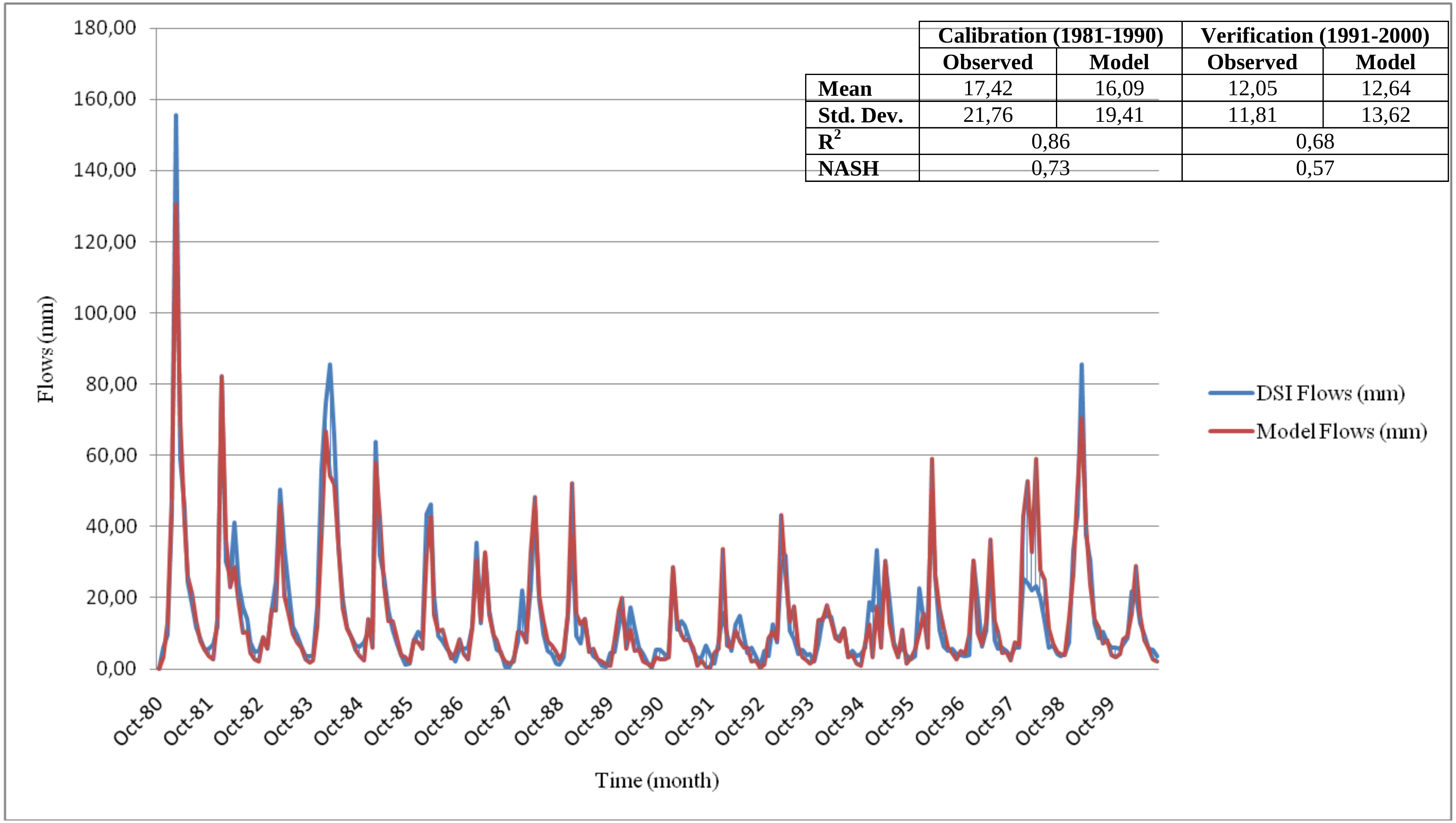
β : Subsurface flow ceofficient

$\mathbf{SSW_t}$ **:** The part which exceed the subsurface storage in month t (mm/month)

γ : Groundwater flow coefficient

$\mathbf{GW_{t-1}}$: Subsurface storage in month t-1 (mm/month)

The model was run many times and the calibration was done manually. The model use the exponential relation between evaporation and temperature. The results of the model flow for A2-2030, A2-2050, B2-2030, B2-2050 and the statistics of observed and model data are presented in Appendix. The variation of the DSI records and the modeled flows and their statistics are also given in Figure 4.3.



	Calibration (1981-1990)		**Verification (1991-2000)**	
	Observed	**Model**	**Observed**	**Model**
Mean	17,42	16,09	12,05	12,64
Std. Dev.	21,76	19,41	11,81	13,62
R^2	0,86		0,68	
NASH	0,73		0,57	

Figure 4.3 DSI records and model outputs

4.4 Calculation of Performance Indices

Before the system is operated using DSI records, at first the demands for irrigation and energy are defined on the basis of DSI operating programs. It is assumed here that these programs were defined by DSI, depending on demands of irrigation associations. Therefore the demand values which are used in simulations are considered as the average demand value of these programs. It is assumed that %79.5 of the energy demand is covered in the irrigation season. These values are presented in Table 4.6.

Table 4.6 Average values of energy and irrigation demands

Months	Energy demands	Irrigation demands
October	0,000	0
November	0,000	0
December	0,000	0
January	0,100	0
February	0,100	0
March	0,005	0
April	0,000	0
May	0,095	0,095
June	0,120	0,12
July	0,240	0,372
August	0,240	0,312
September	0,100	0,101

The irrigation area fed by Kemer Dam was around 40,000 ha in 1980 and 58,000 ha in 2000 (DSI, 2007). It is assumed that crop water demand is around 10.000 m^3/ha with all losses (Acatay, 2002). So, the total irrigation demand volume is calculated as 400.10^6 m^3/year in 1980 and 580.10^6 m^3/year in 2000. It is also assumed that the irrigation system developed in area at a rate of around 7.5% every four years and energy demand was constant for every year. The energy demand volume is calculated depending on the average unit energy production factor. The average water for unit energy production of Kemer Dam is 4.9 m^3/kWh. The annual energy production demand is 62.10^6 GWh/year (EUAS, 2008). So the energy demand volume is calculated as;

Energy Demand Volume = E * e_{ave} (4.2.)

Energy Demand Volume = 62,000,000 kWh/year * 4,9 m^3/kWh

Energy Demand Volume = 303,800,000 m^3/year

The system is operated with known supplies in records and demands defined above depending on two different volume-area-elevation relations which were determined by DSI in 1979 and 1989.

4.4.1 Calculation of Performance Indices of Existing DSI Operation

Depending on the definitions and explanations given above, the system was operated and the changes of reservoir volume in observation time was given in Figure 4.4. The blue line shows the changes of reservoir volume, the green line shows the minimum operating elevation and red line shows flood control curve. Calculated parameters were also given from Table 4.7 to 4.9.

Table 4.7 Parameters using the calculation of performance indices for flood control - DSI

Total duration of all failures (month)	41
Total number of failures	14
Total time between failure modes (month)	206
Total volume of flood control demand (hm^3)	$28.8.10^9$
Total volume of all failures	$1.956.10^9$
Total of max volume of each failure	$0.848.10^9$
Average volume of demands where failures were occured	$0.12.10^9$

Level of Service: 240 – 41 = 199 months

Reliability:

Time-based Reliability: $R_t = 1 - 41/240 = 0.829$

Volumetric Reliability: $R_v = 1 - 1.956 / 28.8 = 0.932$

Incident Period: IP = 206/13 = 15.85 months

Resilience: φ = 14/41 = 0.342 months or φ = 41/14 = 2.93 months

Vulnerability: $\acute{\eta}$ = 848 / 14 = 60,57 hm^3

$\eta = \acute{\eta}$ / 120 hm^3 = 0.505

$FM_{flood,DSI} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1-\eta)=0.5328$

Table 4.8 Parameters using the calculation of performance indices for energy – DSI

Total duration of all failures (month)	72
Total number of failures	40
Total time between failure modes (month)	223
Total volume of energy demand (hm^3)	$6.076.10^9$
Total volume of all failures	$2.216.10^9$
Total of max volume of each failure	$0.839.10^9$
Average volume of demands where max. failures were occured	$0.033.10^9$

Level of Service: 240 – 72 = 168 months

Reliability:

Time-based Reliability: R_t = 1 – 72/240 = 0.7

Volumetric Reliability: R_v = 1 – 2.216 / 6.076 = 0.635

Incident Period: IP = 223/39 = 5.72 months

Resilience: φ = 40/72 = 0.555 months or φ = 72/40 = 1.8 months

Vulnerability: $\acute{\eta}$ = 839 / 40 = 20,98 hm^3

$$\eta = \acute{\eta} / 33 \text{ hm}^3 = 0.636$$

$$FM_{energy,DSI} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1-\eta)=0.4556$$

Table 4.9 Parameters using the calculation of performance indices for irrigation – DSI

Total duration of all failures (month)	83
Total number of failures	21
Total time between failure modes (month)	226
Total volume of irrigation demand (hm^3)	$9.8.10^9$
Total volume of all failures	$3.026.10^9$
Total of max volume of each failure	$1.24.10^9$
Average volume of demands where max. failures were occured	$0.168.10^9$

Level of Service: 240 – 83 = 157 months

Reliability:

Time-based Reliability: $R_t = 1 - 83/240 = 0.654$

Volumetric Reliability: $R_v = 1 - 3.026 / 9.8 = 0.691$

Incident Period: IP = 226/20 = 11.3 months

Resilience: $\varphi = 21/83 = 0.253$ months or $\varphi = 83/21 = 3.95$ months

Vulnerability: $\acute{\eta} = 1240 / 21 = 59{,}05 \text{ hm}^3$

$$\eta = \acute{\eta} / 168 \text{ hm}^3 = 0.352$$

$$FM_{irrigation,DSI} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1-\eta)=0.4586$$

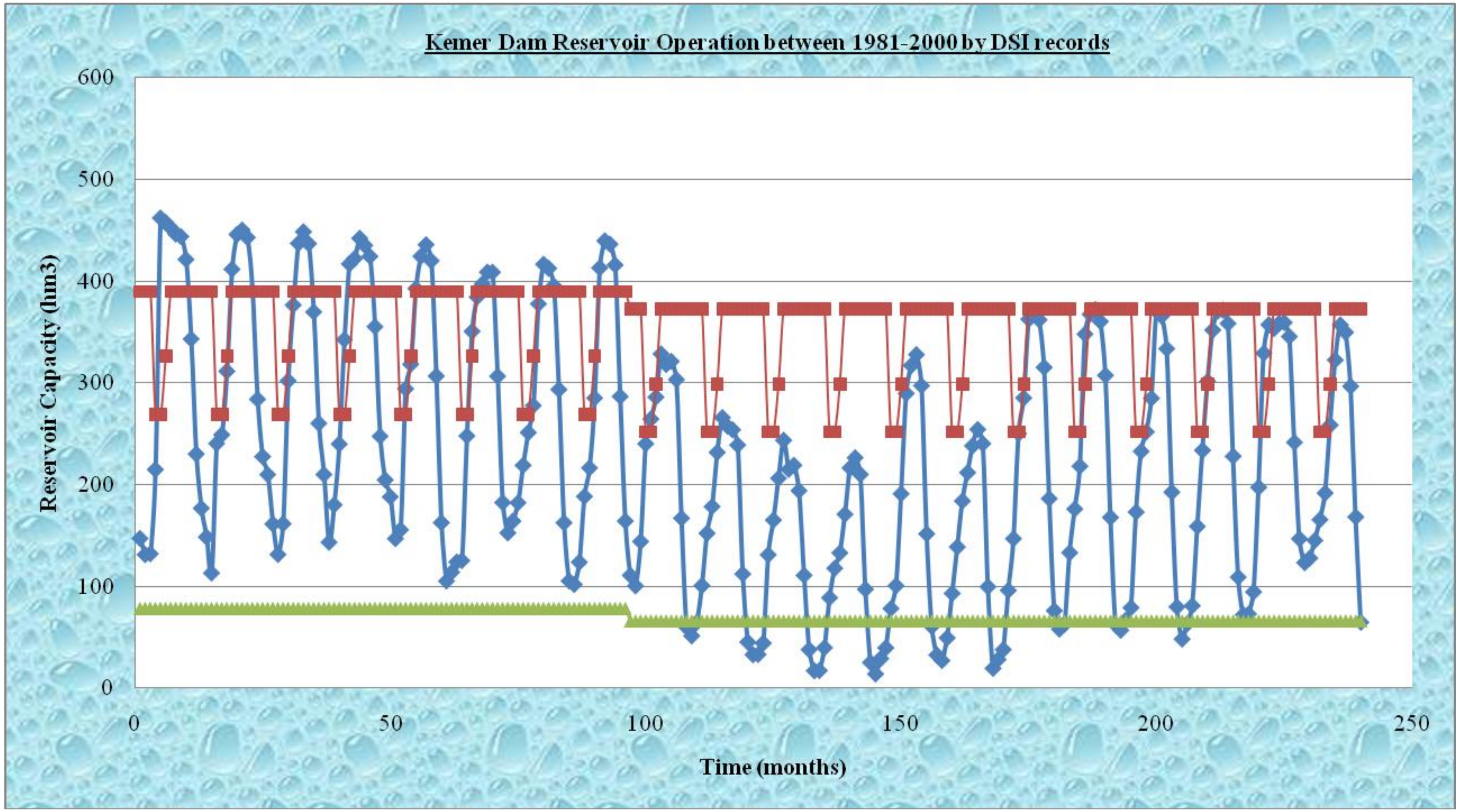


Figure 4.4 Kemer Dam reservoir operation between 1981-2000 when inputs recorded by DSI are used.

4.4.2 Calculation of Performance Indices With Respect to the New Operation Rule

4.4.2.1 Definiton of the New Operation Rule and Scenarios

The new operation rule was defined for purposes of this study as an alternative to DSI’s operating rule. The properties of new operation rule are as follows;

- Demands ratios are constant as defined in Table 4.6,
- It is assumed that all demands will be covered completely (%100 of energy demand and %100 of irrigation demand) month by month if the reservoir has enough water.
- The most significant limitation of the new rule is that “the reservoir will never be in a deficit situation”.
- If reservoir does not have enough water to cover the demand completely, it will allocate only amount of water: “current reservoir volume - min. operation volume”.

Next, scenarios are defined as follows;

- Scenario-1: The reservoir will be accepted as successful if it will cover %100 of energy demand and %100 of irrigation demand (demand ratios are constant).
- Scenario-2: The reservoir will be accepted as successful if it will cover %100 of energy demand and %90 of irrigation demand (demand ratios are constant).
- Scenario-3: The reservoir will be accepted as successful if it will cover %100 of energy demand and %80 of irrigation demand (demand ratios are constant).
- Scenario-4: The reservoir will be accepted as successful if it will cover %100 of energy demand and %70 of irrigation demand (demand ratios are constant).

4.4.2.2 Calculation of Performance Indices With Respect to Scenario-1

Depending on the definitions and explanations given above for Scenario-1, the system was operated and the changes in reservoir volumes within the observation period were obtained as in Figure 4.5. The blue line shows the changes in reservoir volumes, the green line shows the minimum operating elevation and red line shows flood control curve. Calculated parameters are given in Tables 4.10 to 4.12.

Table 4.10 Parameters using the calculation of performance indices for flood control – Scenario-I

Total duration of all failures (month)	58
Total number of failures	13
Total time between failure modes (month)	218
Total volume of flood control demand (hm^3)	$28.8.10^9$
Total volume of all failures	$4.054.10^9$
Total of max volume of each failure	$1.214.10^9$
Average volume of demands where failures were occured	$0.12.10^9$

Level of Service: 240 – 58 = 182 months

Reliability:

Time-based Reliability: $R_t = 1 - 58/240 = 0.758$

Volumetric Reliability: $R_v = 1 - 4.054 / 28.8 = 0.859$

Incident Period: IP = 218/12 = 18.17 months

Resilience: $\varphi = 13/58 = 0.224$ months or $\varphi = 58/13 = 4.46$ months

Vulnerability: $\acute{\eta} = 1214 / 13 = 93{,}38\ hm^3$

$\eta = \acute{\eta} / 120\ hm^3 = 0.778$

$FM_{flood,Sc\text{-}I}$ = (1/5).R_t+(1/5).R_v+(1/5) (IP/N_{obs})+ (1/5)φ+(1/5) (1 – η)=0.4277

Table 4.11 Parameters using the calculation of performance indices for energy – Scenario-I

Total duration of all failures (month)	23
Total number of failures	14
Total time between failure modes (month)	155
Total volume of energy demand (hm^3)	$6.076.10^9$
Total volume of all failures	$0.783.10^9$
Total of max volume of each failure	$0.630.10^9$
Average volume of demands where max. failures were occured	$0.055.10^9$

Level of Service: 240 – 23 = 217 months

Reliability:

Time-based Reliability: R_t = 1 – 23/240 = 0.904

Volumetric Reliability: R_v = 1 – 0.783 / 6.076 = 0.871

Incident Period: IP = 155/13 = 11.92 months

Resilience: φ = 14/23 = 0.609 months or φ = 23/14 = 1.64 months

Vulnerability: ή = 630 / 14 = 45 hm^3

η = ή / 55 hm^3 = 0.818

$FM_{energy,Sc\text{-}I}$ = (1/5).R_t+(1/5).R_v+(1/5) (IP/N_{obs})+ (1/5)φ+(1/5) (1 – η)=0.5231

Table 4.12 Parameters using the calculation of performance indices for irrigation – Scenario-I

Total duration of all failures (month)	36
Total number of failures	14
Total time between failure modes (month)	155
Total volume of irrigation demand (hm^3)	$9.8.10^9$
Total volume of all failures	$2.72.10^9$
Total of max volume of each failure	$1.622.10^9$
Average volume of demands where max. failures were occured	$0.149.10^9$

Level of Service: 240 – 36 = 204 months

Reliability:

Time-based Reliability: $R_t = 1 – 36/240 = 0.850$

Volumetric Reliability: $R_v = 1 – 2.72 / 9.8 = 0.722$

Incident Period: IP = 155/13 = 11.92 months

Resilience: φ = 14/36 = 0.389 months or φ = 36/14 = 2.57 months

Vulnerability: $\acute{\eta} = 1622 / 14 = 115,85\ hm^3$

$\eta = \acute{\eta} / 149\ hm^3 = 0.778$

$FM_{irrigation,Sc\text{-}I} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 – \eta)=0.4465$

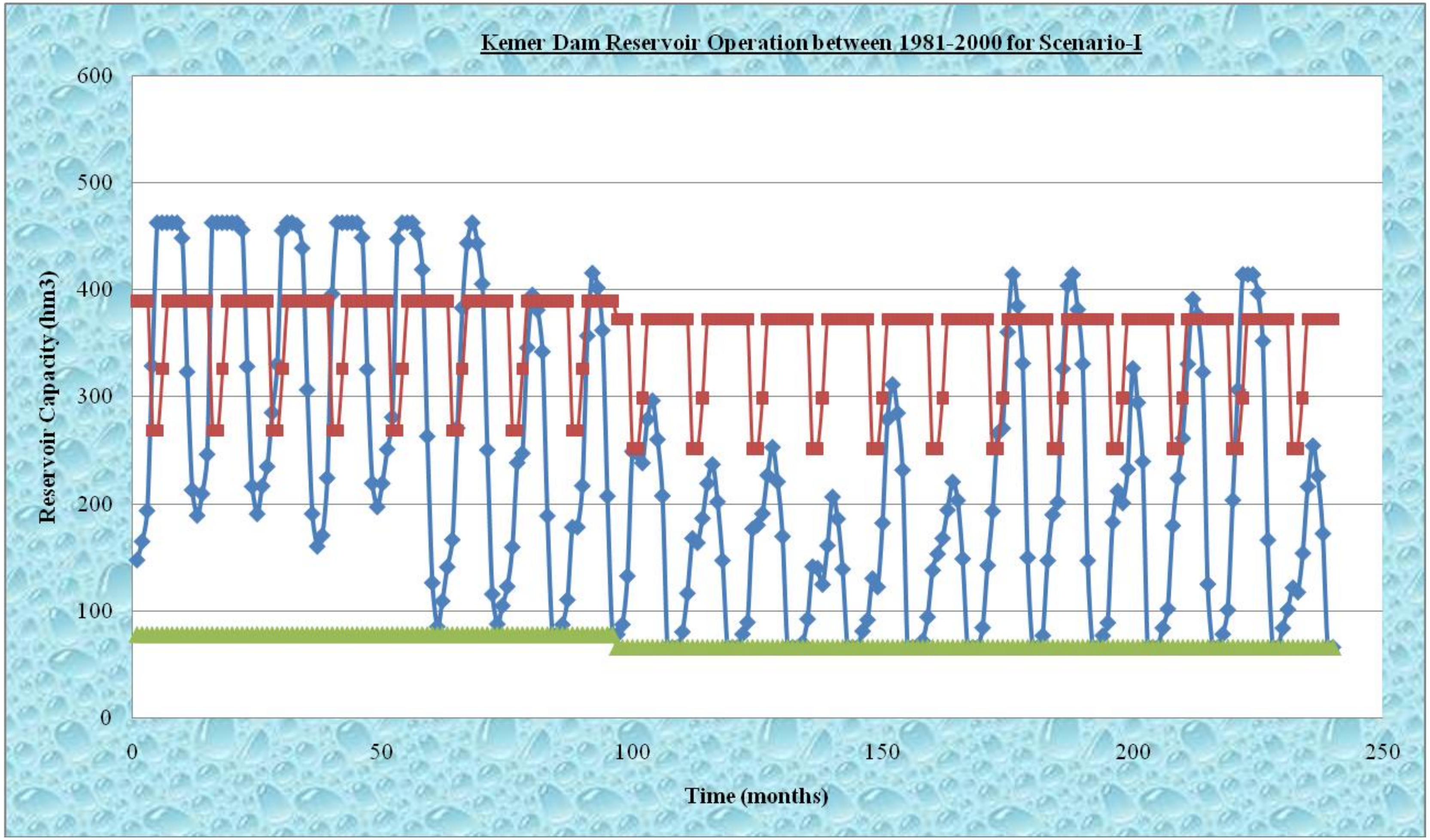


Figure 4.5 Kemer Dam reservoir operation between 1981-2000 for Scenario-1

4.4.2.3 Calculation of Performance Indices With Respect to Scenario-2

Depending on the definitions and explanations given above for Scenario-2, the system was operated and the changes in reservoir volumes within the observation period were obtained as in Figure 4.6. The blue line shows the changes in reservoir volumes, the green line shows the minimum operating elevation and red line shows flood control curve. Calculated parameters are given in Tables 4.13 to 4.15.

Table 4.13 Parameters using the calculation of performance indices for flood control – Scenario-II

Total duration of all failures (month)	64
Total number of failures	15
Total time between failure modes (month)	217
Total volume of flood control demand (hm^3)	$28.8.10^9$
Total volume of all failures	$4.57.10^9$
Total of max volume of each failure	$1.31.10^9$
Average volume of demands where max. failures were occured	$0.12.10^9$

Level of Service: 240 – 64 = 176 months

Reliability:

Time-based Reliability: $R_t = 1 - 64/240 = 0.733$

Volumetric Reliability: $R_v = 1 - 4.57 / 28.8 = 0.841$

Incident Period: IP = 217/14 = 15.50 months

Resilience: $\varphi = 15/64 = 0.234$ months or $\varphi = 64/15 = 4.27$ months

Vulnerability: $\acute{\eta} = 1310 / 15 = 87{,}33\ hm^3$

$\eta = \acute{\eta} / 120\ hm^3 = 0.727$

$FM_{flood,Sc\text{-}II} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 - \eta)=0.4291$

Table 4.14 Parameters using the calculation of performance indices for energy – Scenario-II

Total duration of all failures (month)	20
Total number of failures	12
Total time between failure modes (month)	132
Total volume of energy demand (hm^3)	$6.076.10^9$
Total volume of all failures	$0.701.10^9$
Total of max volume of each failure	$0.550.10^9$
Average volume of demands where max. failures were occured	$0.059.10^9$

Level of Service: 240 – 20 = 220 months

Reliability:

Time-based Reliability: $R_t = 1 – 20/240 = 0.917$

Volumetric Reliability: $R_v = 1 – 0.701 / 6.076 = 0.885$

Incident Period: IP = 132/11 = 12 months

Resilience: $\varphi = 12/20 = 0.6$ months or $\varphi = 20/12 = 1.67$ months

Vulnerability: $\acute{\eta} = 550 / 12 = 45.83\ hm^3$

$\eta = \acute{\eta} / 59\ hm^3 = 0.777$

$FM_{energy,Sc\text{-}II} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 – \eta)=0.5350$

Table 4.15 Parameters using the calculation of performance indices for irrigation – Scenario-II

Total duration of all failures (month)	29
Total number of failures	12
Total time between failure modes (month)	131
Total volume of irrigation demand (hm^3)	$8.82.10^9$
Total volume of all failures	$1.94.10^9$
Total of max volume of each failure	$1.24.10^9$
Average volume of demands where max. failures were occured	$0.124.10^9$

Level of Service: 240 – 29 = 211 months

Reliability:

Time-based Reliability: $R_t = 1 - 29/240 = 0.879$

Volumetric Reliability: $R_v = 1 - 1.94 / 8.82 = 0.780$

Incident Period: IP = 131/11 = 11.91 months

Resilience: $\varphi = 12/29 = 0.412$ months or $\varphi = 29/12 = 2.42$ months

Vulnerability: $\acute{\eta} = 1240 / 12 = 103,33\ hm^3$

$\eta = \acute{\eta} / 124\ hm^3 = 0.833$

$FM_{irrigation,Sc\text{-}II} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1-\eta)=0.4575$

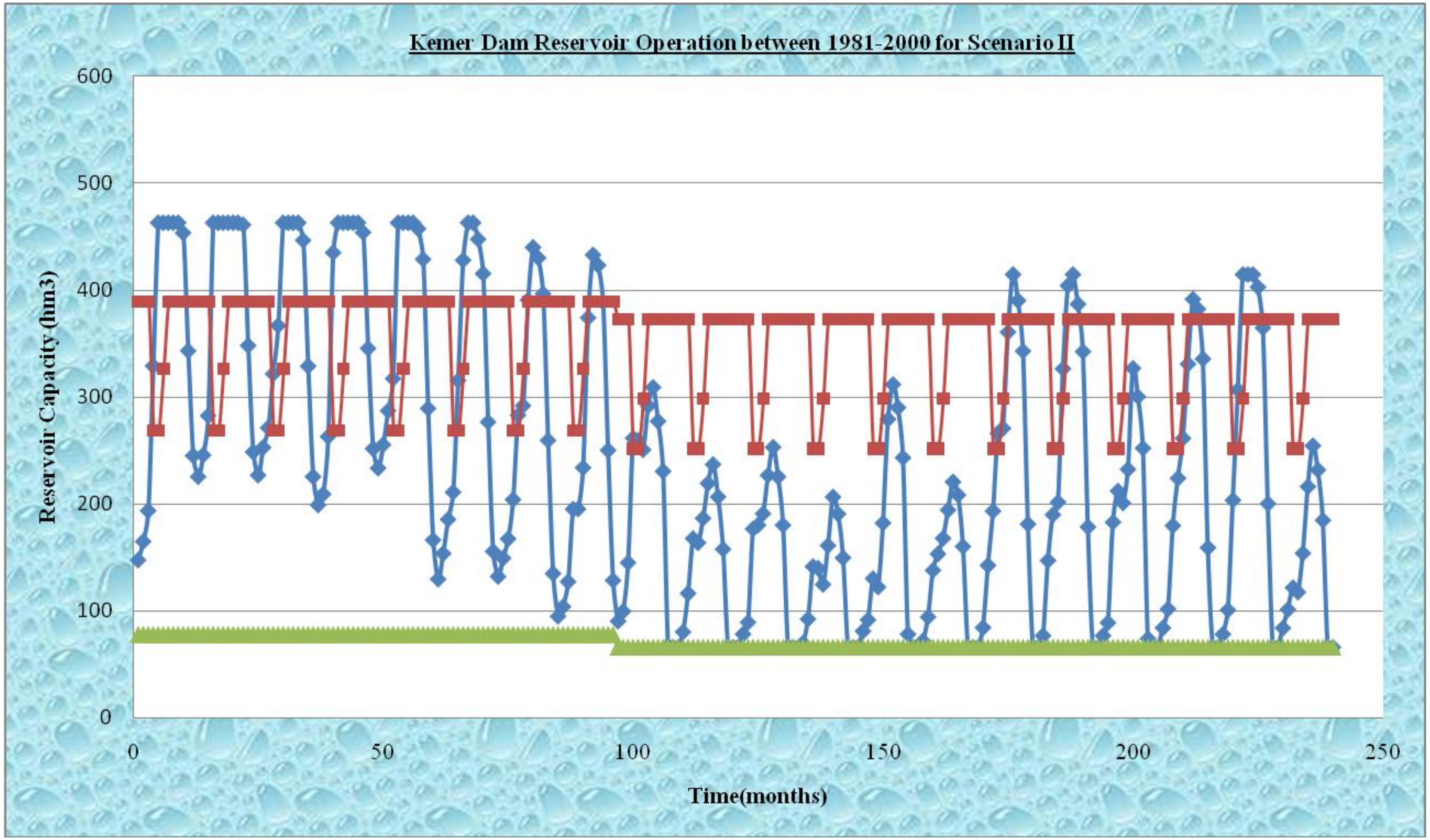


Figure 4.6 Kemer Dam reservoir operation between 1981-2000 for Scenario-2

4.4.2.4 Calculation of Performance Indices With Respect to Scenario-3

Depending on the definitions and explanations given above for Scenario-3, the system was operated and the changes in reservoir volumes within the observation period were obtained as in Figure 4.7. The blue line shows the changes in reservoir volumes, the green line shows the minimum operating elevation and red line shows flood control curve. Calculated parameters are given in Tables 4.16 to 4.18.

Table 4.16 Parameters using the calculation of performance indices for flood control – Scenario-III

Total duration of all failures (month)	69
Total number of failures	15
Total time between failure modes (month)	219
Total volume of flood control demand (hm^3)	$28.8.10^9$
Total volume of all failures	$5.276.10^9$
Total of max volume of each failure	$1.453.10^9$
Average volume of demands where max. failures were occured	$0.12.10^9$

Level of Service: 240 – 69 = 171 months

Reliability:

Time-based Reliability: $R_t = 1 - 69/240 = 0.713$

Volumetric Reliability: $R_v = 1 - 5.276 / 28.8 = 0.817$

Incident Period: IP = 219/14 = 15.64 months

Resilience: $\varphi = 15/69 = 0.217$ months or $\varphi = 69/15 = 4.60$ months

Vulnerability: $\acute{\eta} = 1453 / 15 = 96.87\ hm^3$

$\eta = \acute{\eta} / 120\ hm^3 = 0.807$

$FM_{flood,Sc\text{-}III} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 - \eta)=0.4010$

Table 4.17 Parameters using the calculation of performance indices for energy – Scenario-III

Total duration of all failures (month)	18
Total number of failures	11
Total time between failure modes (month)	131
Total volume of energy demand (hm^3)	$6.076.10^9$
Total volume of all failures	$0.562.10^9$
Total of max volume of each failure	$0.429.10^9$
Average volume of demands where max. failures were occured	$0.058.10^9$

Level of Service: 240 – 18 = 222 months

Reliability:

Time-based Reliability: $R_t = 1 - 18/240 = 0.925$

Volumetric Reliability: $R_v = 1 - 0.562 / 6.076 = 0.908$

Incident Period: IP = 131/10 = 13.1 months

Resilience: $\varphi = 11/18 = 0.611$ months or $\varphi = 18/11 = 1.64$ months

Vulnerability: $\acute{\eta} = 429 / 11 = 39\ hm^3$

$\eta = \acute{\eta} / 58\ hm^3 = 0.672$

$FM_{energy,Sc\text{-}III} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 - \eta)=0.5653$

Table 4.18 Parameters using the calculation of performance indices for irrigation – Scenario-III

Total duration of all failures (month)	26
Total number of failures	12
Total time between failure modes (month)	131
Total volume of irrigation demand (hm^3)	$8.1.10^9$
Total volume of all failures	$1.436.10^9$
Total of max volume of each failure	$0.949.10^9$
Average volume of demands where max. failures were occured	$0.106.10^9$

Level of Service: 240 – 26 = 214 months

Reliability:

Time-based Reliability: $R_t = 1 – 26/240 = 0.892$

Volumetric Reliability: $R_v = 1 – 1.436 / 8.1 = 0.823$

Incident Period: IP = 131/11 = 11.91 months

Resilience: $\varphi = 12/26 = 0.462$ months or $\varphi = 26/12 = 2.17$ months

Vulnerability: $\acute{\eta} = 949 / 12 = 79.08\ hm^3$

$\eta = \acute{\eta} / 106\ hm^3 = 0.746$

$FM_{irrigation,Sc-III} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1 – \eta)=0.4961$

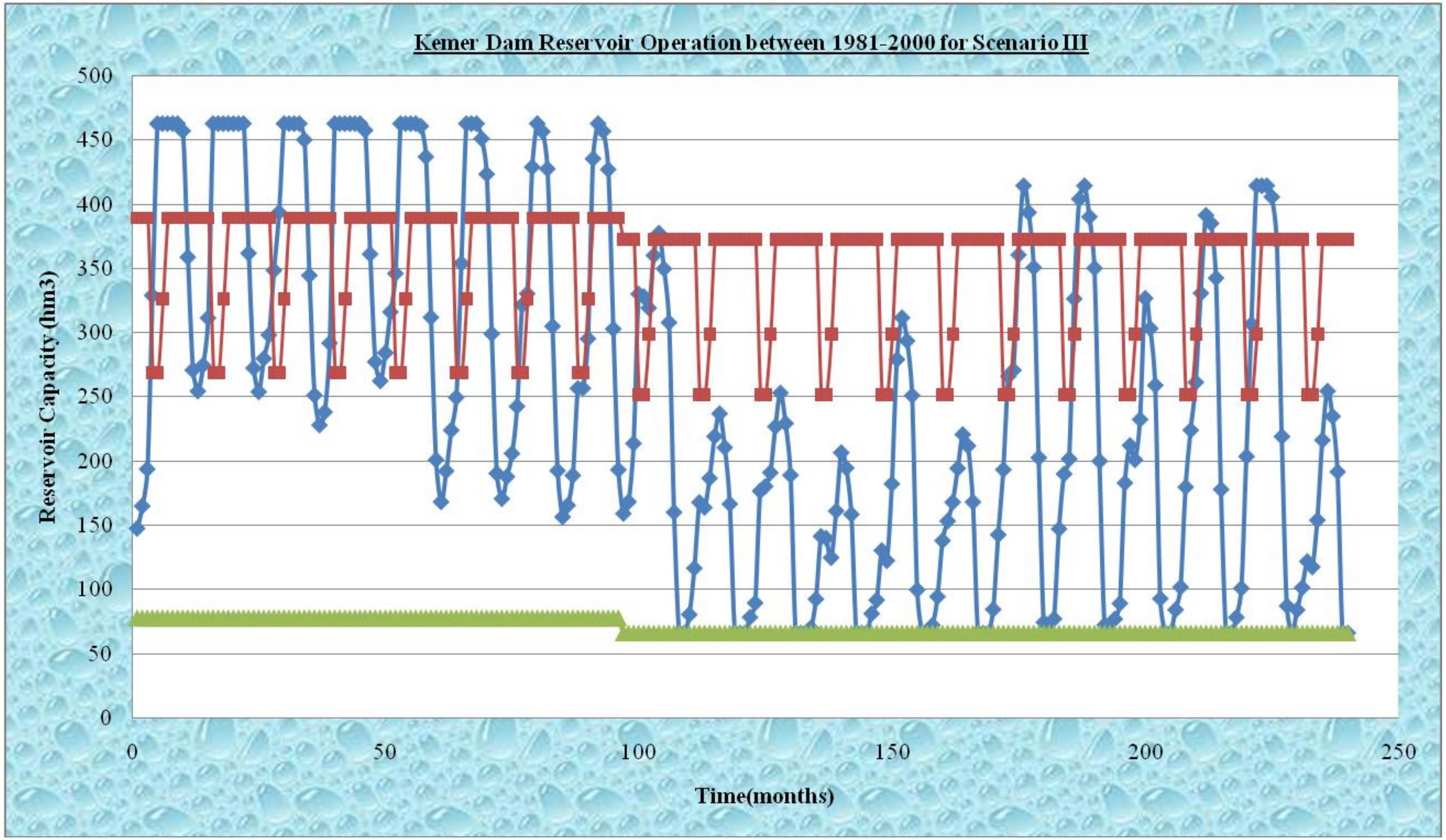


Figure 4.7 Kemer Dam reservoir operation between 1981-2000 for Scenario-3

4.4.2.5 Calculation of Performance Indices With Respect to Scenario-4

Depending on the definitions and explanations given above for Scenario-4, the system was operated and the changes in reservoir volumes within the observation period were obtained as in Figure 4.8. The blue line shows the changes in reservoir volumes, the green line shows the minimum operating elevation and red line shows flood control curve. Calculated parameters are given in Tables 4.19 to 4.21.

Table 4.19 Parameters using the calculation of performance indices for flood control – Scenario-IV

Total duration of all failures (month)	77
Total number of failures	14
Total time between failure modes (month)	217
Total volume of flood control demand (hm^3)	$28.8.10^9$
Total volume of all failures	$6.155.10^9$
Total of max volume of each failure	$1.528.10^9$
Average volume of demands where max. failures were occured	$0.12.10^9$

Level of Service: 240 – 77 = 163 months

Reliability:

Time-based Reliability: $R_t = 1 - 77/240 = 0.679$

Volumetric Reliability: $R_v = 1 - 6.155 / 28.8 = 0.786$

Incident Period: IP = 217/13 = 16.69 months

Resilience: $\varphi = 14/77 = 0.182$ months or $\varphi = 77/14 = 5.50$ months

Vulnerability: $\acute{\eta} = 1528 / 14 = 109.14\ hm^3$

$\eta = \acute{\eta} / 120\ hm^3 = 0.909$

$FM_{flood,Sc\text{-}IV} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1 - \eta)=0.3615$

Table 4.20 Parameters using the calculation of performance indices for energy – Scenario-IV

Total duration of all failures (month)	11
Total number of failures	7
Total time between failure modes (month)	121
Total volume of energy demand (hm^3)	$6.076.10^9$
Total volume of all failures	$0.329.10^9$
Total of max volume of each failure	$0.248.10^9$
Average volume of demands where max. failures were occured	$0.055.10^9$

Level of Service: 240 – 11 = 229 months

Reliability:

Time-based Reliability: $R_t = 1 – 11/240 = 0.954$

Volumetric Reliability: $R_v = 1 – 0.329 / 6.076 = 0.946$

Incident Period: IP = 121/6 = 20.17 months

Resilience: $\varphi = 7/11 = 0.636$ months or $\varphi = 11/7 = 1.57$ months

Vulnerability: $\acute{\eta} = 248 / 7 = 35.43\ hm^3$

$\eta = \acute{\eta} / 55\ hm^3 = 0.644$

$FM_{energy,Sc\text{-}IV} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1 – \eta)=0.5952$

Table 4.21 Parameters using the calculation of performance indices for irrigation – Scenario-IV

Total duration of all failures (month)	15
Total number of failures	7
Total time between failure modes (month)	120
Total volume of irrigation demand (hm^3)	$6.86.10^9$
Total volume of all failures	$0.609.10^9$
Total of max volume of each failure	$0.441.10^9$
Average volume of demands where max. failures were occured	$0.103.10^9$

Level of Service: 240 – 15 = 225 months

Reliability:

Time-based Reliability: $R_t = 1 - 15/240 = 0.938$

Volumetric Reliability: $R_v = 1 - 0.609 / 6.86 = 0.911$

Incident Period: IP = 120/6 = 20 months

Resilience: $\varphi = 7/15 = 0.467$ months or $\varphi = 15/7 = 2.14$ months

Vulnerability: $\acute{\eta} = 441 / 7 = 63\ hm^3$

$\eta = \acute{\eta} / 103\ hm^3 = 0.612$

$FM_{irrigation,Sc\text{-}IV} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1 - \eta) =0.5575$

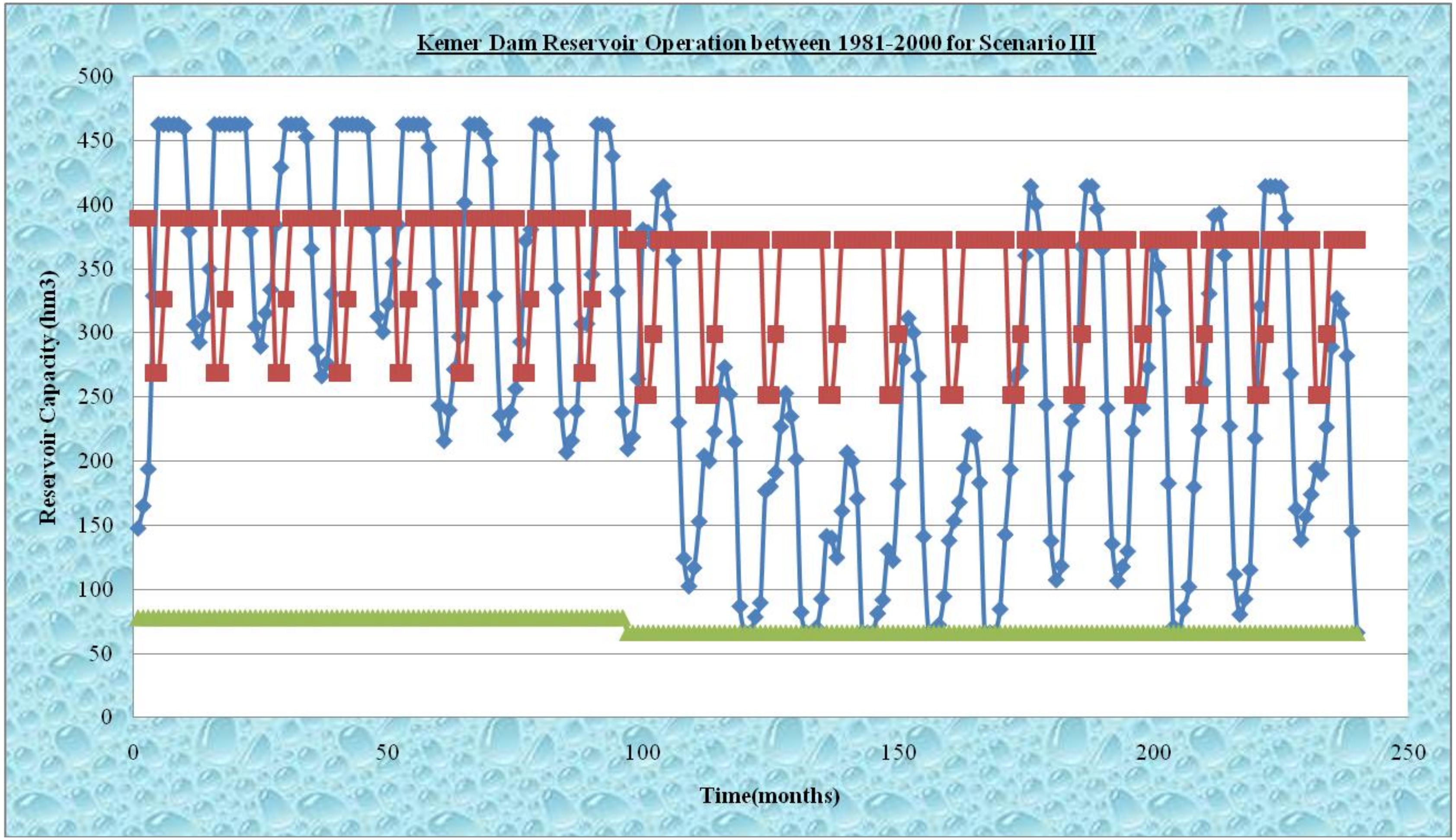


Figure 4.8 Kemer Dam reservoir operation between 1981-2000 for Scenario-4

4.4.3 Calculation of Performance Indices With Respect to The Climate Change

4.4.3.1 Calculation of Performance Indices of A2-2030

Depending on the definitions and explanations given in chapter 4.3.1 for A2-2030, the system was operated and the changes in reservoir volumes within the observation period were obtained as in Figure 4.9. The blue line shows the changes of reservoir volume, the green line shows the minimum operating elevation and red line shows flood control curve. Calculated parameters are given in Tables 4.22 to 4.24.

Table 4.22 Parameters using the calculation of performance indices for flood control – A2-2030

Total duration of all failures (month)	37
Total number of failures	7
Total time between failure modes (month)	217
Total volume of flood control demand (hm^3)	$28.8.10^9$
Total volume of all failures	$2.799.10^9$
Total of max volume of each failure	$0.826.10^9$
Average volume of demands where max. failures were occured	$0.12.10^9$

Level of Service: 240 – 37 = 203 months

Reliability:

Time-based Reliability: $R_t = 1 - 37/240 = 0.846$

Volumetric Reliability: $R_v = 1 - 2.799 / 28.8 = 0.903$

Incident Period: IP = 217/6 = 36.17 months

Resilience: $\varphi = 7/37 = 0.189$ months or $\varphi = 37/7 = 5.29$ months

Vulnerability: $\acute{\eta} = 826 / 7 = 118\ hm^3$

$\eta = \acute{\eta} / 120\ hm^3 = 0.983$

$FM_{flood,A2\text{-}2030}$ = (1/5).R_t+(1/5).R_v+(1/5) (IP/N_{obs})+ (1/5)φ+(1/5) (1 – η) =0.4211

Table 4.23 Parameters using the calculation of performance indices for energy - A2-2030

Total duration of all failures (month)	34
Total number of failures	16
Total time between failure modes (month)	202
Total volume of energy demand (hm^3)	$6.076.10^9$
Total volume of all failures	$1.41.10^9$
Total of max volume of each failure	$0.839.10^9$
Average volume of demands where max. failures were occured	$0.06.10^9$

Level of Service: 240 – 34 = 206 months

Reliability:

Time-based Reliability: R_t = 1 – 34/240 = 0.858

Volumetric Reliability: R_v = 1 – 1.410 / 6.076 = 0.768

Incident Period: IP = 202/15 = 13.46 months

Resilience: φ = 16/34 = 0.471 months or φ = 34/16 = 2.13 months

Vulnerability: ή = 839 / 16 = 52.44 hm^3

η = ή / 60 hm^3 = 0.874

$FM_{energy,A2\text{-}2030}$ = (1/5).R_t+(1/5).R_v+(1/5) (IP/N_{obs})+ (1/5)φ+(1/5) (1 – η) =0.4558

Table 4.24 Parameters using the calculation of performance indices for irrigation – A2-2030

Total duration of all failures (month)	41
Total number of failures	16
Total time between failure modes (month)	189
Total volume of irrigation demand (hm^3)	$9.8.10^9$
Total volume of all failures	$3.902.10^9$
Total of max volume of each failure	$2.095.10^9$
Average volume of demands where max. failures were occured	$0.159.10^9$

Level of Service: 240 – 41 = 199 months

Reliability:

Time-based Reliability: $R_t = 1 - 41/240 = 0.829$

Volumetric Reliability: $R_v = 1 - 3.902 / 9.8 = 0.602$

Incident Period: IP = 189/15 = 12.6 months

Resilience: $\varphi = 16/41 = 0.39$ months or $\varphi = 41/16 = 2.56$ months

Vulnerability: $ή = 2095 / 16 = 130.94\ hm^3$

$\eta = ή / 159\ hm^3 = 0.824$

$FM_{irrigation,A2\text{-}2030} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 - \eta) =0.4099$

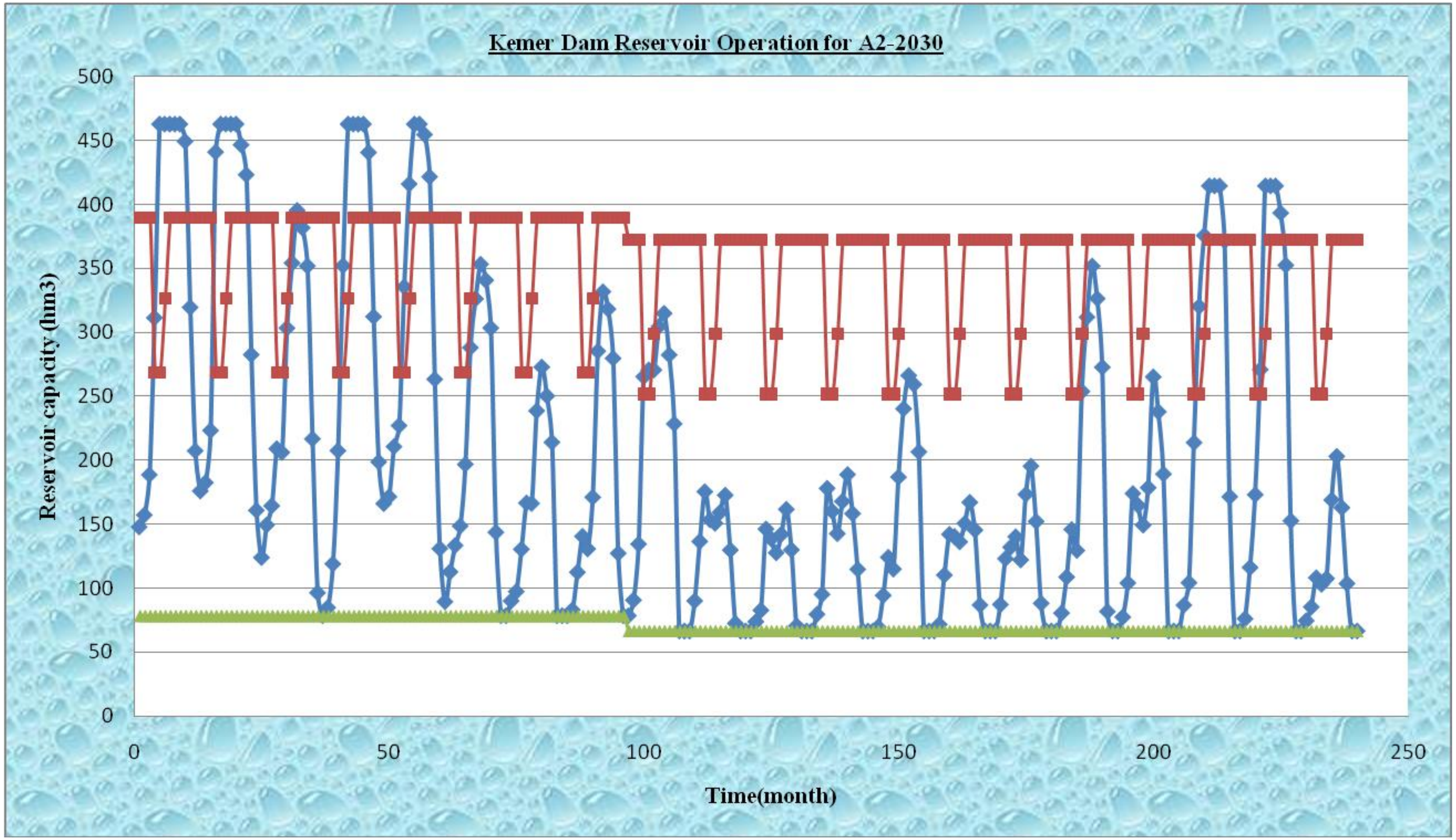


Figure 4.9 Kemer Dam reservoir operation for A2-2030

4.4.3.2 Calculation of Performance Indices of A2-2050

Depending on the definitions and explanations given in chapter 4.3.1 for A2-2050, the system was operated and the changes in reservoir volumes within the observation period were obtained as in Figure 4.10. The blue line shows the changes of reservoir volume, the green line shows the minimum operating elevation and red line shows flood control curve. Calculated parameters are given in Tables 4.25 to 4.27.

Table 4.25 Parameters using the calculation of performance indices for flood control – A2-2050

Total duration of all failures (month)	33
Total number of failures	6
Total time between failure modes (month)	217
Total volume of flood control demand (hm^3)	$28.8.10^9$
Total volume of all failures	$2.2.10^9$
Total of max volume of each failure	$0.639.10^9$
Average volume of demands where max. failures were occured	$0.12.10^9$

Level of Service: 240 – 33 = 207 months

Reliability:

Time-based Reliability: $R_t = 1 - 33/240 = 0.863$

Volumetric Reliability: $R_v = 1 - 2.2 / 28.8 = 0.924$

Incident Period: IP = 217/5 = 43.4 months

Resilience: $\varphi = 6/33 = 0.182$ months or $\varphi = 33/6 = 5.5$ months

Vulnerability: $\acute{\eta} = 639 / 6 = 106.5\ hm^3$

$\eta = \acute{\eta} / 120\ hm^3 = 0.888$

$FM_{flood,A2\text{-}2050}$ = (1/5).R_t+(1/5).R_v+(1/5) (IP/N_{obs})+ (1/5)φ+(1/5) (1 – η) =0.4524

Table 4.26 Parameters using the calculation of performance indices for energy – A2-2050

Total duration of all failures (month)	38
Total number of failures	17
Total time between failure modes (month)	202
Total volume of energy demand (hm^3)	$6.076.10^9$
Total volume of all failures	$1.62.10^9$
Total of max volume of each failure	1.10^9
Average volume of demands where max. failures were occured	$0.063.10^9$

Level of Service: 240 – 38 = 202 months

Reliability:

Time-based Reliability: R_t = 1 – 38/240 = 0.842

Volumetric Reliability: R_v = 1 – 1.620 / 6.076 = 0.733

Incident Period: IP = 202/16 = 12.63 months

Resilience: φ = 17/38 = 0.447 months or φ = 38/17 = 2.24 months

Vulnerability: ή = 1000 / 17 = 58.82 hm^3

η = ή / 63 hm^3 = 0.934

$FM_{energy,A2\text{-}2050}$ = (1/5).R_t+(1/5).R_v+(1/5) (IP/N_{obs})+ (1/5)φ+(1/5) (1 – η) =0.4281

Table 4.27 Parameters using the calculation of performance indices for irrigation – A2-2050

Total duration of all failures (month)	49
Total number of failures	17
Total time between failure modes (month)	201
Total volume of irrigation demand (hm^3)	$9.8.10^9$
Total volume of all failures	$4.625.10^9$
Total of max volume of each failure	$2.394.10^9$
Average volume of demands where max. failures were occured	$0.163.10^9$

Level of Service: 240 – 49 = 191 months

Reliability:

Time-based Reliability: $R_t = 1 - 49/240 = 0.796$

Volumetric Reliability: $R_v = 1 - 4.625 / 9.8 = 0.472$

Incident Period: IP = 201/16 = 12.56 months

Resilience: $\varphi = 17/49 = 0.347$ months or $\varphi = 49/17 = 2.88$ months

Vulnerability: $\acute{\eta} = 2394 / 17 = 140.82\ hm^3$

$\eta = \acute{\eta} / 163\ hm^3 = 0.864$

$FM_{irrigation,A2\text{-}2050} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+(1/5)\varphi+(1/5)\ (1-\eta) = 0.3607$

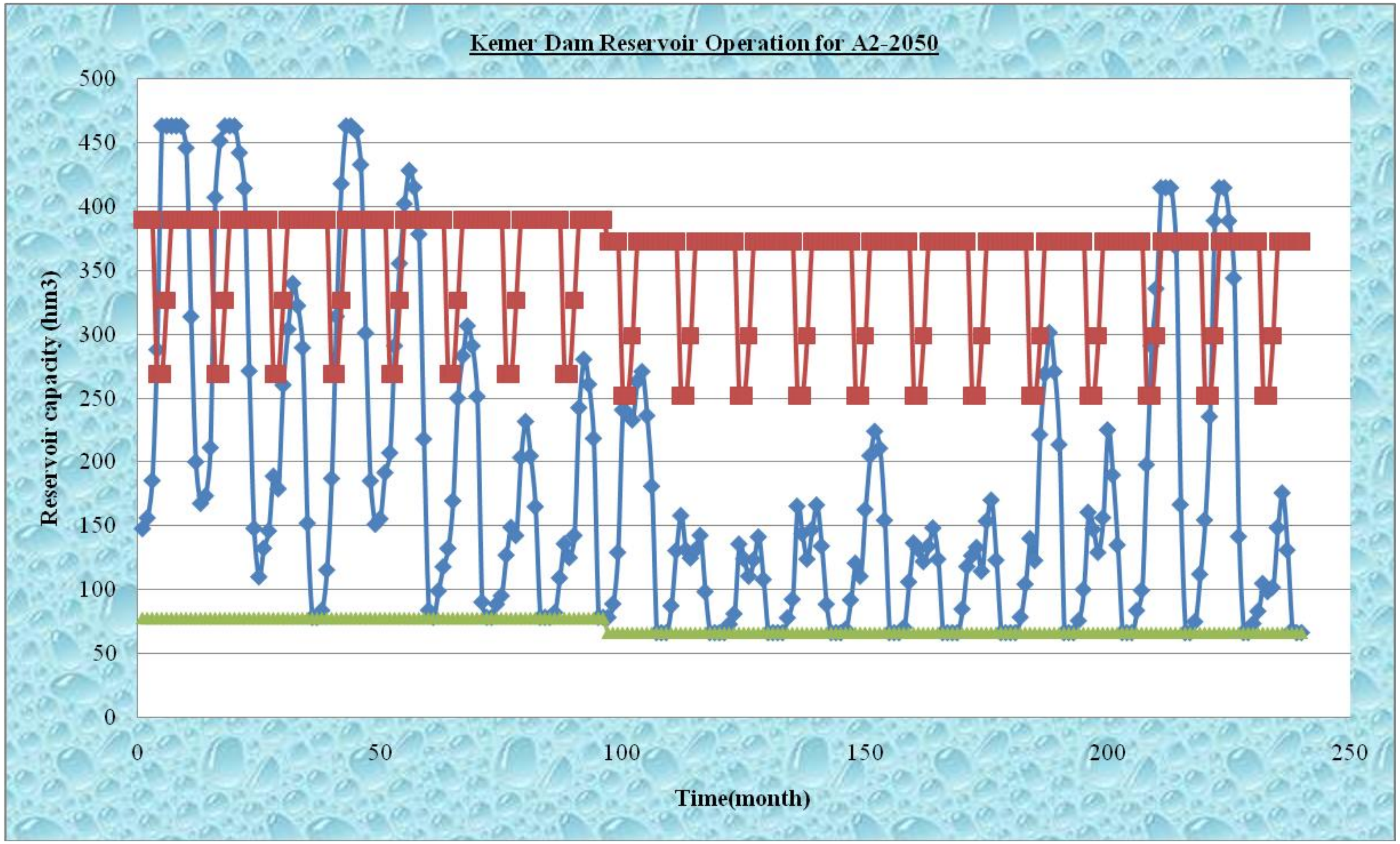


Figure 4.10 Kemer Dam reservoir operation for A2-2050

4.4.3.3 Calculation of Performance Indices of B2-2030

Depending on the definitions and explanations given in chapter 4.3.1 for B2-2030, the system was operated and the changes in reservoir volumes within the observation period were obtained as in Figure 4.11. The blue line shows the changes of reservoir volume, the green line shows the minimum operating elevation and red line shows flood control curve. Calculated parameters are given in Tables 4.28 to 4.30.

Table 4.28 Parameters using the calculation of performance indices for flood control – B2-2030

Total duration of all failures (month)	41
Total number of failures	8
Total time between failure modes (month)	217
Total volume of flood control demand (hm^3)	$28.8.10^9$
Total volume of all failures	$3.02.10^9$
Total of max volume of each failure	$0.903.10^9$
Average volume of demands where max. failures were occured	$0.12.10^9$

Level of Service: 240 – 41 = 199 months

Reliability:

Time-based Reliability: $R_t = 1 – 41/240 = 0.829$

Volumetric Reliability: $R_v = 1 – 3.02 / 28.8 = 0.895$

Incident Period: IP = 217/7 = 31 months

Resilience: $\varphi = 8/41 = 0.195$ months or $\varphi = 41/8 = 5.13$ months

Vulnerability: $\acute{\eta} = 903 / 8 = 112.9\ hm^3$

$\eta = \acute{\eta} / 120\ hm^3 = 0.941$

$FM_{flood,B2-2030} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 – \eta) =0.4214$

Table 4.29 Parameters using the calculation of performance indices for energy – B2-2030

Total duration of all failures (month)	31
Total number of failures	15
Total time between failure modes (month)	166
Total volume of energy demand (hm^3)	$6.076.10^9$
Total volume of all failures	$1.24.10^9$
Total of max volume of each failure	$0.775.10^9$
Average volume of demands where max. failures were occured	$0.062.10^9$

Level of Service: 240 – 31 = 209 months

Reliability:

Time-based Reliability: $R_t = 1 - 31/240 = 0.871$

Volumetric Reliability: $R_v = 1 - 1.24 / 6.076 = 0.796$

Incident Period: IP = 166/14 = 11.85 months

Resilience: $\varphi = 15/31 = 0.484$ months or $\varphi = 31/15 = 2.07$ months

Vulnerability: $\acute{\eta} = 775 / 15 = 51.67\ hm^3$

$\eta = \acute{\eta} / 62\ hm^3 = 0.833$

$FM_{energy,B2\text{-}2030} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 - \eta) =0.4735$

Table 4.30 Parameters using the calculation of performance indices for irrigation – B2-2030

Total duration of all failures (month)	40
Total number of failures	16
Total time between failure modes (month)	202
Total volume of irrigation demand (hm^3)	$9.8.10^9$
Total volume of all failures	$3.584.10^9$
Total of max volume of each failure	$1.937.10^9$
Average volume of demands where max. failures were occured	$0.152.10^9$

Level of Service: 240 – 40 = 200 months

Reliability:

Time-based Reliability: $R_t = 1 - 40/240 = 0.833$

Volumetric Reliability: $R_v = 1 - 3.584 / 9.8 = 0.634$

Incident Period: IP = 202/15 = 13.46 months

Resilience: $\varphi = 16/40 = 0.4$ months or $\varphi = 40/16 = 2.5$ months

Vulnerability: $\acute{\eta} = 1937 / 16 = 121.06\ hm^3$

$\eta = \acute{\eta} / 152\ hm^3 = 0.796$

$FM_{irrigation,B2-2030} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 - \eta) =0.4254$

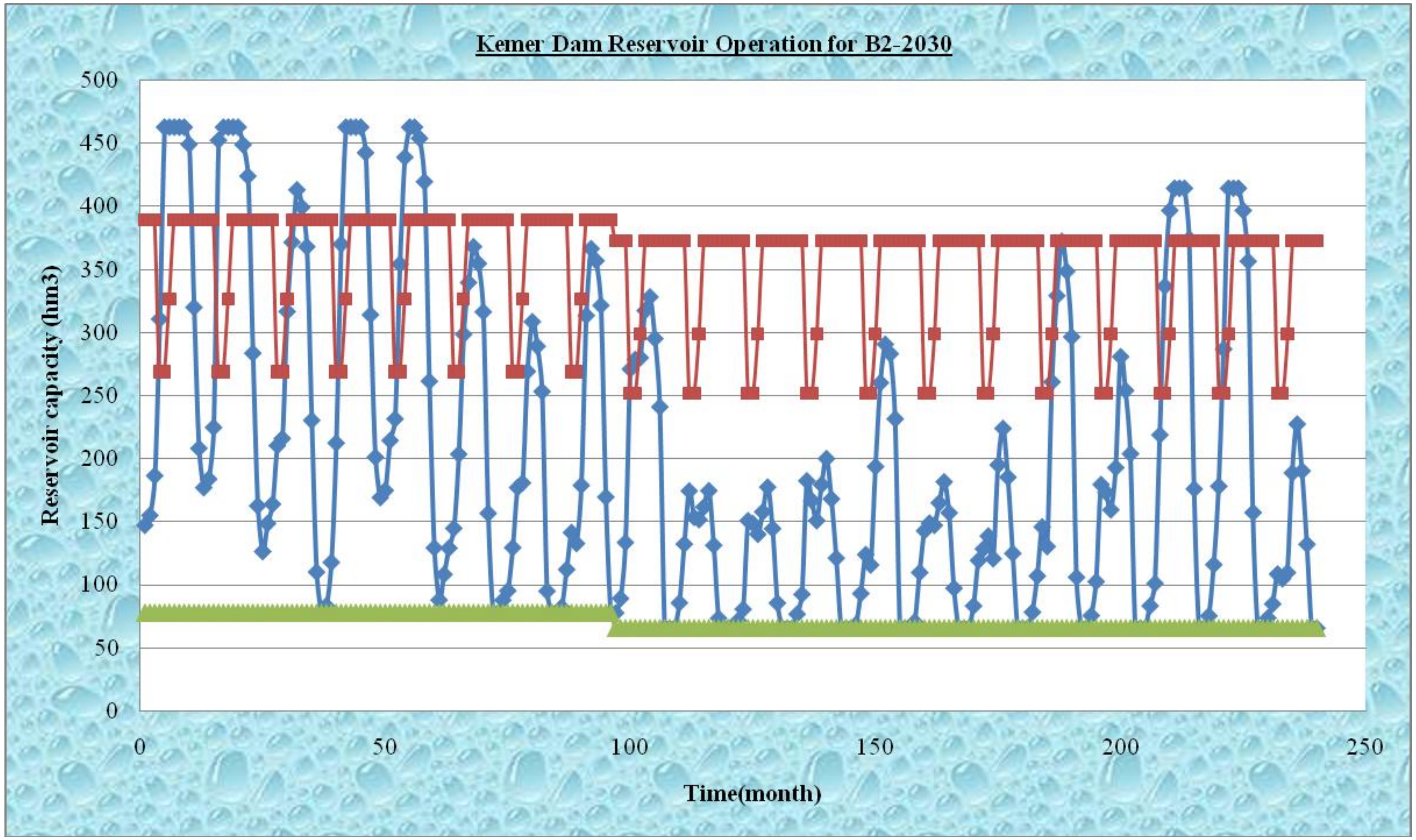


Figure 4.11 Kemer Dam reservoir operation for B2-2030

4.4.3.4 Calculation of Performance Indices of B2-2050

Depending on the definitions and explanations given in chapter 4.3.1 for B2-2050, the system was operated and the changes in reservoir volumes within the observation period were obtained as in Figure 4.12. The blue line shows the changes of reservoir volume, the green line shows the minimum operating elevation and red line shows flood control curve. Calculated parameters are given in Tables 4.31 to 4.33.

Table 4.31 Parameters using the calculation of performance indices for flood control B2-2050

Total duration of all failures (month)	39
Total number of failures	7
Total time between failure modes (month)	217
Total volume of flood control demand (hm^3)	$28.8.10^9$
Total volume of all failures	$2.715.10^9$
Total of max volume of each failure	$0.718.10^9$
Average volume of demands where max. failures were occured	$0.12.10^9$

Level of Service: 240 – 39 = 201 months

Reliability:

Time-based Reliability: $R_t = 1 - 39/240 = 0.838$

Volumetric Reliability: $R_v = 1 - 2.715 / 28.8 = 0.906$

Incident Period: IP = 217/6 = 36.17 months

Resilience: $\varphi = 7/39 = 0.179$ months or $\varphi = 39/7 = 5.57$ months

Vulnerability: $\acute{\eta} = 718 / 7 = 102.57\ hm^3$

$\eta = \acute{\eta} / 120\ hm^3 = 0.855$

$FM_{flood,B2-2050} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1 - \eta) = 0.4437$

Table 4.32 Parameters using the calculation of performance indices for energy – B2-2050

Total duration of all failures (month)	35
Total number of failures	16
Total time between failure modes (month)	202
Total volume of energy demand (hm^3)	$6.076.10^9$
Total volume of all failures	$1.517.10^9$
Total of max volume of each failure	$0.891.10^9$
Average volume of demands where max. failures were occured	$0.062.10^9$

Level of Service: 240 – 35 = 205 months

Reliability:

Time-based Reliability: $R_t = 1 - 35/240 = 0.854$

Volumetric Reliability: $R_v = 1 - 1.517 / 6.076 = 0.75$

Incident Period: IP = 202/15 = 13.47 months

Resilience: $\varphi = 16/35 = 0.457$ months or $\varphi = 35/16 = 2.19$ months

Vulnerability: $\acute{\eta} = 891 / 16 = 55.68\ hm^3$

$\eta = \acute{\eta} / 62\ hm^3 = 0.898$

$FM_{energy,B2\text{-}2050} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+\ (1/5)\varphi+(1/5)\ (1-\eta) =0.4438$

Table 4.33 Parameters using the calculation of performance indices for irrigation – B2-2050

Total duration of all failures (month)	46
Total number of failures	16
Total time between failure modes (month)	203
Total volume of irrigation demand (hm^3)	$9.8.10^9$
Total volume of all failures	$4.093.10^9$
Total of max volume of each failure	$2.183.10^9$
Average volume of demands where max. failures were occured	$0.159.10^9$

Level of Service: 240 – 46 = 194 months

Reliability:

Time-based Reliability: $R_t = 1 - 46/240 = 0.808$

Volumetric Reliability: $R_v = 1 - 4.093 / 9.8 = 0.582$

Incident Period: IP = 203/15 = 13.53 months

Resilience: $\varphi = 16/46 = 0.348$ months or $\varphi = 46/16 = 2.88$ months

Vulnerability: $\acute{\eta} = 2183 / 16 = 136.44 \text{ hm}^3$

$\eta = \acute{\eta} / 159 \text{ hm}^3 = 0.858$

$FM_{irrigation,B2\text{-}2050} = (1/5).R_t+(1/5).R_v+(1/5)\ (IP/N_{obs})+ (1/5)\varphi+(1/5)\ (1 - \eta) =0.3873$

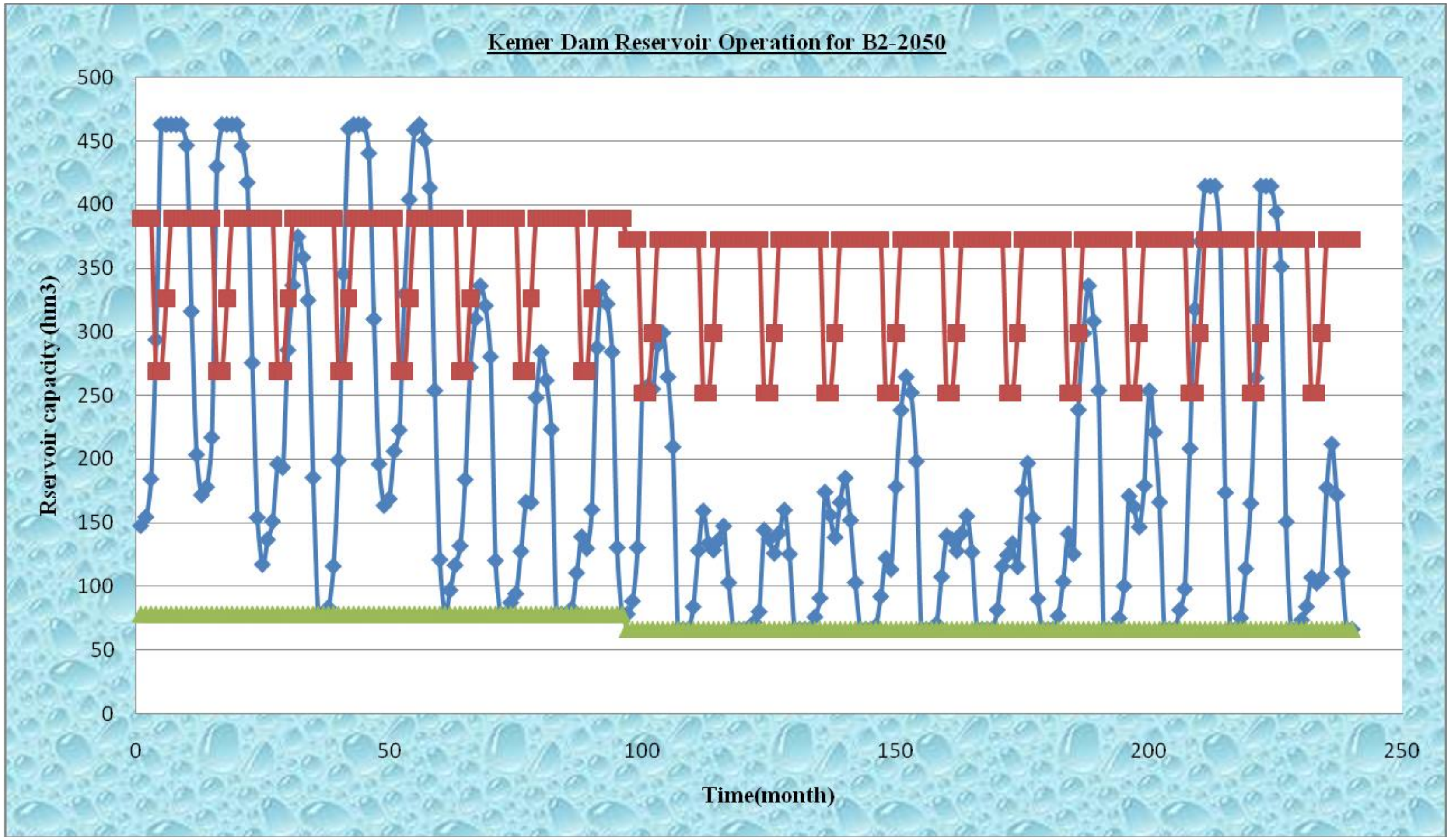


Figure 4.12 Kemer Dam reservoir operation for B2-2050

CHAPTER FIVE
CONCLUSION AND DISCUSSION

The performance indicators, which were calculated in chapter 4, are identified with respect to different reservoir operation rules and climate change scenarios as in Tables 5.1 and 5.2. The results show that the figures of merit for the existing operation for flood control is higher than the figures of merit for the new operation rule for flood control. In contrast to this, the figures of merit for energy produciton have increased while the figures of merit for irrigation remained nearly the same. The existing DSI operation foresees the production of secondary energy when any flood occurs even if the target energy demand is covered. Furthermore, during the irrigation season, DSI also prefers to cover the irrigation demand at a maximum level by forcing the reservoir level to below the minimum operation level if needed.

On the other hand, the new operation rule defined foresees to ensure maximum operation level at the beginning of the irrigation season and never adopts to be on the minimum operation level. In the new operation rule, since production of secondary energy is disregarded, water is allowed to spill, and a considerable amount of the energy demand is covered by the water allocated in irrigation season. This situation has led to a decrease in the figures of merit for flood control, an increase in those for energy production and a slight decrease in the figures of merit for irrigation. The new operation rule is not allowed to be in a deficit mode, and this is an important detail for operation. Whether deficit is allowed and needed is another subject to be discussed.

When the other scenarios are examined, it is observed that there is a decrease in the figures of merit for flood control and an increase in the figures of merit for energy and irrigation. Depending on the reasons explained above, this situation is reasonable since the percentage coverage of the irrigation demand decreases. Becasue the reservoir storage never covers the irrigation demand at %100, the current DSI operation can be considered as a successful operation except that it allows the reservoir to be in the deficit mode.

Another detail is that the vulnerability indicator is quite high in terms of flood both in the operational scenarios and the climate change scenarios. When we consider this situation in terms of deficit, even if the reservoir becomes less vulnerable and often allows a failure situation, it is also acceptable for DSI to allow a deficit mode in order to obtain secondary energy.

When the results are examined, it is clearly observed that the system gets more vulnerable in terms of all defined operational objectives. Decreases in flows do not suggest decreases in flood vulnerability or in the figures of merit; this can be explained by the characteristics of the observation period which contains a substantial wet period. Yet, the increases in the vulnerabilities that correspond to all the operational objectives obviously suggest that decreasing flows would have bigger detrimental impacts than would the operational policies.

In general, the results of the study have shown that the identification of different performance indicators by themselves or by their combination in the form of figures of merit independently for each reservoir purpose (e.g., flood control, irrigation supply, power production, etc.) serves to properly assess the system particularly in the planning and decision making phase. Moreover, the use of independently computed indicators is helpful in identifying the shares of operational objectives (purposes) of the system. It is also possible to compute a single overall indicator (i.e. a figure of merit) for any system by multiplying the indicators by the weights determined through the percent shares of the operational objectives (purposes) defined for the reservoir system.

The approach used in this study is not very common in Turkey so that the operational performance of most systems and hydraulic structures is overlooked and is not described in tangible terms. Risk and reliability analyses for most systems are either not performed at all or not realized properly. The presented study is realized upon this deficiency in the Turkish engineering practice and is expected to be one of the first studies to assess the performance of water structures in computable figures.

Table 5.1 Performance Indicators and Figures of Merit with respect to DSI operation and other operation

		DSI Existing Operation			Scenario-I			Scenario-II			Scenario-III			Scenario-IV		
		Flood Control	Energy Prod.	Irrig.	Flood Control	Energy Prod.	Irrig.	Flood Control	Energy Prod.	Irrig.	Flood Control	Energy Prod.	Irrig.	Flood Control	Energy Prod.	Irrig.
Performance Indicators	Time-based reliability	0,829	0,7	0,654	0,758	0,904	0,85	0,733	0,917	0,879	0,713	0,925	0,892	0,679	0,954	0,938
	Volumetric reliability	0,932	0,635	0,691	0,859	0,871	0,722	0,841	0,885	0,78	0,817	0,908	0,823	0,786	0,946	0,911
	Incident period	15,85	5,72	11,3	18,17	11,92	11,92	15,5	12	11,91	15,64	13,1	11,91	16,69	20,17	20
	Resilience	0,342	0,555	0,253	0,224	0,609	0,389	0,234	0,6	0,412	0,217	0,611	0,462	0,182	0,636	0,467
	Vulnerability	0,505	0,636	0,352	0,778	0,818	0,778	0,727	0,777	0,833	0,807	0,672	0,746	0,909	0,644	0,612
	Figures of Merit	0,5328	0,4556	0,4586	0,4277	0,5231	0,4465	0,4291	0,5350	0,4575	0,4010	0,5653	0,4961	0,3615	0,5952	0,5575

Table 5.2 Performance Indicators and Figures of Merit under climate change effects

		A2-2030			B2-2030			A2-2050			B2-2050		
		Flood Control	Energy Prod.	Irrig.	Flood Control	Energy Prod.	Irrig.	Flood Control	Energy Prod.	Irrig.	Flood Control	Energy Prod.	Irrig.
Performance Indicators	Time-based reliability	0,846	0,858	0,829	0,829	0,871	0,833	0,863	0,842	0,796	0,838	0,854	0,808
	Volumetric reliability	0,903	0,768	0,602	0,895	0,796	0,634	0,924	0,733	0,472	0,906	0,75	0,582
	Incident period	36,17	13,46	12,6	31	11,85	13,46	43,4	12,63	12,56	36,17	13,47	13,53
	Resilience	0,189	0,471	0,39	0,195	0,484	0,4	0,182	0,447	0,347	0,179	0,457	0,348
	Vulnerability	0,983	0,874	0,824	0,941	0,833	0,796	0,888	0,934	0,864	0,855	0,898	0,858
	Figures of Merit	0,4211	0,4558	0,4099	0,4214	0,4735	0,4254	0,4524	0,4281	0,3607	0,4437	0,4438	0,3873

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APPENDIX

	DSI Flows (mm)	Model Flows (mm)	A2-2030 (mm)	B2-2030 (mm)	A2-2050 (mm)	B2-2050 (mm)
1	5,82	3,31	3,25	2,74	2,92	2,43
2	9,43	13,15	10,28	10,27	9,57	9,80
3	43,79	47,84	39,79	40,19	33,22	35,46
4	155,55	130,43	115,77	121,79	107,12	116,45
5	58,88	69,35	62,14	64,01	56,50	60,37
6	45,27	41,57	36,50	38,28	33,19	36,19
7	24,35	25,96	22,86	23,64	20,63	22,17
8	18,08	21,20	19,09	19,13	17,34	17,89
9	11,60	13,32	11,86	11,82	10,66	10,96
10	8,44	7,84	6,86	7,13	6,16	6,68
11	5,29	5,41	4,73	4,91	4,24	4,60
12	5,75	3,70	3,24	3,37	2,91	3,15
13	6,78	2,69	2,37	2,43	2,13	2,27
14	12,00	14,26	13,28	13,33	12,31	12,69
15	81,46	82,40	70,49	73,55	63,40	68,90
16	30,12	36,34	28,70	31,12	24,22	28,21
17	26,21	22,91	18,76	19,92	16,14	18,20
18	41,24	28,73	20,42	24,60	16,55	22,42
19	23,88	18,50	14,65	15,80	12,38	14,33
20	17,39	10,24	7,59	8,37	6,07	7,38
21	14,08	10,59	8,72	8,20	7,29	7,05
22	7,56	4,59	3,32	3,52	2,60	3,01
23	4,89	2,54	1,68	2,04	1,24	1,76
24	5,19	2,19	1,58	1,80	1,25	1,59
25	8,71	9,09	8,56	7,50	7,57	6,63
26	6,04	5,53	4,97	5,08	4,52	4,79
27	16,38	16,83	14,58	15,08	13,96	14,70
28	24,51	16,42	8,97	11,73	6,71	9,03
29	50,30	46,12	41,36	42,43	36,20	39,76
30	33,91	20,48	17,13	18,41	14,80	17,11
31	22,63	15,55	13,68	13,81	11,97	12,72
32	12,02	9,70	8,42	8,37	7,20	7,58
33	9,42	7,55	6,64	6,16	5,66	5,42
34	6,13	5,91	5,21	4,49	4,51	3,86
35	3,64	2,62	2,12	2,25	1,74	2,02
36	3,72	1,89	1,58	1,64	1,33	1,48
37	3,52	2,51	2,30	2,11	1,99	1,88
38	17,48	11,99	11,17	11,19	10,33	10,65
39	55,68	37,50	28,76	30,69	23,30	27,06
40	74,51	66,86	56,72	60,81	50,94	57,24
41	85,44	54,12	48,32	49,89	43,54	46,87

	DSI Flows (mm)	Model Flows (mm)	A2-2030 (mm)	B2-2030 (mm)	A2-2050 (mm)	B2-2050 (mm)
42	65,16	51,76	42,60	48,39	38,73	46,45
43	34,85	34,16	28,99	29,28	25,13	27,25
44	19,54	17,02	13,70	14,56	11,58	13,48
45	11,77	11,34	9,07	9,69	7,64	8,97
46	9,05	8,93	7,34	7,39	6,27	6,75
47	6,64	5,36	4,29	4,58	3,61	4,24
48	6,32	3,67	2,95	3,14	2,49	2,91
49	7,32	2,46	1,96	2,10	1,65	1,94
50	10,41	13,89	12,81	12,89	11,81	12,26
51	9,77	5,98	5,41	5,61	5,10	5,43
52	63,78	58,10	45,04	49,54	36,99	44,47
53	32,04	42,45	35,95	37,31	30,83	34,01
54	25,74	23,24	18,70	20,20	15,78	18,37
55	16,50	13,48	10,78	11,32	8,80	10,02
56	11,02	13,40	11,55	11,34	9,93	10,15
57	7,05	8,60	7,31	6,88	6,13	5,96
58	3,88	3,94	3,07	3,23	2,44	2,81
59	1,25	3,39	2,65	2,83	2,15	2,51
60	1,56	1,81	1,40	1,50	1,12	1,31
61	7,95	8,14	7,74	6,74	6,86	5,97
62	10,41	7,40	6,81	6,85	6,25	6,48
63	8,36	5,52	5,04	5,20	4,78	5,04
64	43,65	32,27	25,55	28,91	21,96	26,80
65	46,26	43,07	39,45	40,60	35,93	38,44
66	20,23	15,26	13,03	13,94	11,40	12,95
67	9,24	10,52	9,12	9,54	7,98	8,82
68	7,83	11,08	10,13	9,87	9,09	9,11
69	5,81	6,53	5,85	5,55	5,13	4,99
70	4,10	3,05	2,60	2,72	2,24	2,49
71	1,95	4,43	3,66	3,91	3,17	3,59
72	5,79	8,35	7,66	7,53	6,97	7,02
73	5,78	4,17	3,97	3,52	3,54	3,15
74	5,96	2,74	2,51	2,54	2,30	2,41
75	12,00	11,71	10,83	11,17	10,40	10,91
76	35,45	30,61	21,68	25,33	17,02	22,42
77	12,82	13,42	9,84	11,16	7,87	9,92
78	32,53	32,66	24,08	29,20	20,41	27,28
79	16,36	15,29	11,50	13,13	9,53	11,94
80	9,68	9,51	6,91	7,93	5,54	7,08
81	5,38	8,09	6,28	6,40	5,14	5,56
82	4,68	4,06	2,82	3,19	2,19	2,77

	DSI Flows (mm)	**Model Flows (mm)**	**A2-2030 (mm)**	**B2-2030 (mm)**	**A2-2050 (mm)**	**B2-2050 (mm)**
83	0,73	2,23	1,41	1,83	1,02	1,61
84	0,46	1,53	0,96	1,25	0,70	1,10
85	3,11	2,06	1,66	1,70	1,37	1,50
86	7,63	10,47	9,62	9,74	8,86	9,25
87	22,03	10,07	9,20	9,56	8,79	9,31
88	9,98	7,46	6,78	7,16	6,43	6,97
89	22,41	32,59	23,02	24,79	15,55	19,82
90	45,94	48,41	37,61	44,13	33,02	41,76
91	19,37	20,43	15,43	17,51	12,66	15,82
92	9,78	13,28	9,86	11,17	7,93	9,98
93	5,16	7,89	5,55	6,55	4,29	5,79
94	4,15	6,58	4,94	5,22	3,99	4,55
95	1,60	4,74	3,41	3,99	2,72	3,57
96	1,09	2,55	1,79	2,14	1,39	1,90
97	3,16	4,71	4,15	3,91	3,58	3,47
98	14,78	15,49	14,27	14,42	13,15	13,69
99	37,73	52,19	42,41	44,47	36,16	40,31
100	9,34	15,48	11,71	12,44	9,22	10,78
101	7,11	12,48	9,94	10,42	8,18	9,25
102	13,89	14,14	11,69	12,73	10,42	11,97
103	5,96	4,80	3,63	3,83	2,84	3,30
104	3,69	5,76	4,97	4,79	4,28	4,26
105	2,62	2,73	2,18	2,14	1,76	1,83
106	0,90	2,02	1,63	1,52	1,33	1,28
107	0,59	1,08	0,81	0,86	0,63	0,74
108	4,45	0,83	0,64	0,67	0,52	0,58
109	4,87	8,13	7,88	6,73	7,04	5,95
110	11,89	16,31	15,25	15,25	14,16	14,53
111	16,68	20,00	12,68	13,70	9,00	10,17
112	8,62	5,80	2,83	3,22	1,32	1,74
113	17,33	11,14	9,09	9,35	7,83	8,21
114	11,18	5,06	3,43	3,87	2,70	3,21
115	6,01	5,50	4,60	4,45	4,00	3,85
116	4,16	2,20	1,58	1,50	1,19	1,10
117	1,84	1,43	0,99	0,86	0,71	0,56
118	0,30	0,46	0,17	0,20	0,02	0,05
119	5,26	3,33	2,55	2,75	2,14	2,44
120	5,27	2,71	2,40	2,34	2,15	2,13
121	4,12	2,57	2,53	2,13	2,27	1,89
122	3,68	3,17	2,98	2,97	2,77	2,84
123	28,26	28,58	20,65	22,73	17,72	20,85

	DSI Flows (mm)	Model Flows (mm)	A2-2030 (mm)	B2-2030 (mm)	A2-2050 (mm)	B2-2050 (mm)
124	11,10	13,25	7,45	9,19	6,19	7,62
125	13,41	9,48	6,41	7,24	5,56	6,36
126	12,21	7,91	5,35	6,40	4,80	5,87
127	8,78	8,01	6,63	6,62	6,10	6,05
128	5,02	6,11	5,16	4,81	4,66	4,26
129	2,98	0,98	0,32	0,47	0,17	0,29
130	3,24	2,38	1,87	1,43	1,63	1,09
131	6,47	0,46	0,14	0,23	0,07	0,14
132	3,87	0,30	0,09	0,15	0,04	0,09
133	1,44	4,61	4,39	3,75	3,92	3,30
134	7,34	5,57	5,14	5,16	4,77	4,90
135	15,91	33,64	26,89	29,11	23,64	26,98
136	9,47	6,49	4,13	4,87	3,00	4,12
137	5,02	5,92	4,30	4,81	3,48	4,27
138	12,38	10,61	8,76	9,84	8,10	9,50
139	14,94	7,80	7,07	6,94	6,51	6,51
140	8,85	6,10	5,59	5,16	5,07	4,70
141	4,40	5,89	5,49	4,42	4,86	3,77
142	5,84	2,07	1,78	1,41	1,55	1,15
143	3,59	2,31	1,79	1,95	1,52	1,77
144	0,66	0,30	0,19	0,23	0,14	0,19
145	5,03	1,32	1,23	1,08	1,08	0,95
146	3,49	8,60	8,03	8,04	7,46	7,66
147	12,58	10,53	9,74	10,04	9,37	9,81
148	7,37	8,07	6,94	7,29	6,63	7,12
149	29,23	43,14	33,17	35,06	26,78	30,87
150	31,97	26,43	17,96	22,11	14,33	20,10
151	10,86	13,10	8,76	10,21	6,53	8,83
152	8,35	17,68	14,71	14,52	12,64	12,97
153	4,21	6,40	4,36	4,76	3,22	3,99
154	5,24	3,35	1,97	2,49	1,29	2,07
155	3,88	2,43	1,46	1,82	0,98	1,53
156	4,10	1,56	0,92	1,16	0,60	0,97
157	2,10	2,28	1,82	1,79	1,48	1,55
158	7,29	13,69	12,60	12,70	11,61	12,05
159	14,19	13,63	10,40	10,78	9,93	10,49
160	14,87	18,02	9,41	11,89	8,36	9,03
161	14,68	13,31	8,57	9,40	6,85	7,03
162	9,19	8,76	5,33	6,39	4,52	5,14
163	8,81	7,61	5,62	5,69	4,96	4,67
164	11,28	11,24	9,88	8,96	8,98	7,78

	DSI Flows (mm)	Model Flows (mm)	A2-2030 (mm)	B2-2030 (mm)	A2-2050 (mm)	B2-2050 (mm)
165	3,73	3,35	2,39	2,06	1,96	1,42
166	5,08	3,92	3,17	2,31	2,77	1,65
167	3,71	1,52	0,90	1,04	0,69	0,79
168	4,20	0,90	0,57	0,61	0,46	0,46
169	6,04	7,15	6,83	5,81	6,09	5,08
170	18,90	12,60	11,71	11,72	10,87	11,13
171	16,50	3,34	3,02	3,13	2,89	3,02
172	33,47	17,57	12,62	13,24	12,04	12,92
173	11,50	5,89	4,15	4,18	4,00	4,08
174	29,73	30,55	17,31	24,73	13,38	19,97
175	19,12	12,87	7,52	9,73	5,73	7,46
176	7,48	6,64	2,98	4,50	1,79	2,97
177	4,13	3,28	0,78	1,97	0,04	1,00
178	6,34	11,13	9,10	7,10	7,90	5,34
179	3,89	1,62	0,44	1,00	0,08	0,55
180	2,69	3,02	2,09	2,41	1,70	1,99
181	3,69	5,34	4,72	4,27	4,10	3,62
182	22,78	10,18	9,22	9,39	8,48	8,83
183	13,98	15,40	12,19	12,67	11,67	12,30
184	13,73	6,11	4,67	4,98	4,42	4,81
185	50,28	58,92	50,19	52,09	41,84	46,56
186	25,82	26,68	19,50	22,76	16,06	20,17
187	11,11	17,04	13,31	14,32	10,89	12,48
188	6,40	11,32	8,77	9,30	7,06	7,98
189	5,05	5,83	4,09	4,68	3,03	3,90
190	5,55	4,38	3,18	3,45	2,43	2,87
191	4,08	2,70	1,89	2,17	1,40	1,80
192	3,83	4,99	4,22	4,31	3,64	3,88
193	3,69	4,16	3,73	3,41	3,21	2,97
194	4,03	9,50	8,72	8,80	8,00	8,31
195	30,46	30,49	22,75	24,97	19,66	22,98
196	19,40	10,18	6,99	7,96	5,69	7,14
197	6,37	6,94	5,00	5,52	4,14	4,97
198	10,86	13,20	10,16	11,49	9,49	11,17
199	30,82	36,46	28,35	28,71	22,54	24,46
200	8,01	13,36	9,54	9,71	6,95	7,82
201	5,64	10,33	7,68	7,24	5,72	5,70
202	5,94	4,62	2,84	3,12	1,73	2,33
203	5,13	4,69	3,18	3,46	2,26	2,82
204	3,69	2,26	1,42	1,55	0,90	1,18
205	6,00	7,37	6,70	5,89	5,76	5,08

	DSI Flows (mm)	Model Flows (mm)	A2-2030 (mm)	B2-2030 (mm)	A2-2050 (mm)	B2-2050 (mm)
206	5,83	6,51	5,79	5,85	5,19	5,44
207	25,28	42,95	35,55	38,10	31,92	35,77
208	24,27	52,70	44,37	48,00	40,03	45,33
209	22,05	32,67	27,91	29,35	24,46	27,15
210	23,14	58,97	48,95	56,03	45,48	54,51
211	19,96	27,82	23,49	25,73	21,46	24,57
212	13,54	25,07	22,10	22,63	20,25	21,34
213	5,99	11,40	9,36	10,30	8,40	9,72
214	6,59	7,27	5,88	6,61	5,27	6,27
215	4,17	4,76	3,82	4,39	3,42	4,18
216	3,48	4,18	3,48	3,83	3,13	3,64
217	4,13	3,79	3,32	3,35	2,98	3,10
218	7,43	14,12	13,05	13,22	12,11	12,61
219	33,30	26,58	18,55	20,18	13,86	16,71
220	43,26	50,54	41,59	45,06	36,11	41,83
221	85,58	70,60	64,94	66,40	59,55	63,06
222	37,57	40,60	32,98	37,39	29,21	35,40
223	30,50	23,69	19,97	21,48	17,61	20,07
224	12,78	14,07	11,52	12,66	9,98	11,76
225	8,68	11,77	10,00	10,23	8,74	9,36
226	10,40	7,07	5,85	6,18	5,09	5,69
227	7,41	8,14	6,60	7,20	5,73	6,66
228	6,05	3,88	3,26	3,49	2,86	3,25
229	6,04	3,26	2,86	2,85	2,51	2,60
230	5,76	4,04	3,62	3,74	3,29	3,54
231	6,77	8,24	7,54	7,83	7,19	7,62
232	8,58	9,10	8,32	8,76	7,90	8,53
233	21,74	15,59	11,45	11,55	11,04	11,31
234	20,90	28,87	20,63	26,27	15,90	23,63
235	12,88	15,02	11,56	13,04	9,36	11,65
236	9,45	7,99	5,61	6,59	4,12	5,64
237	5,79	5,68	4,03	4,44	2,93	3,67
238	5,27	2,73	1,61	2,14	0,97	1,74
239	3,50	1,98	1,17	1,60	0,71	1,33
240	5,50	1,17	0,65	0,93	0,36	0,76
Mean=	14,76	14,38	11,67	12,42	10,13	11,35
Std.Dev.=	17,72	16,85	14,36	15,31	12,87	14,40
Skewness=	3,54	2,74	3,04	2,94	3,25	3,05