Risk Assessment of a Water Supply System under Climate Variability: A Stochastic Approach

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Beatrice Biau Yung

Abstract

Canada has approximately 9% of the world's renewable water (Natural Resources Canada, 2006). In 2000, the Walkerton incident raised the alarm that even a modern domestic water supply can have risks associated with it. These risks can involve water contaminations or water shortage.

In this study, a model is developed to assess risk to a municipal water supply system under the influence of population growth and climate change. To incorporate the uncertainly in water use, a model which combines time series Monte Carlo simulations and a deterministic artificial neural network (ANN) is developed to simulate the daily water demand under climate variability.

The model is then expanded in two directions. One direction is to estimate the effects of demand management programs and system expansion on the reliability, resiliency, and vulnerability of the water supply system. Another direction is to capture the possible impacts of climate change on the risk of a water supply system. Twenty-six scenarios generated from different combinations of demand management programs, system expansions and Global Climate Model (GCM) scenarios were set to illustrate the risk indices: reliability, resiliency, and vulnerability. To illustrate the effects of a change of precipitation frequency and a higher population growth, twenty-five additional scenarios were evaluated.

The simulation results suggest that a rise in temperature and a change in precipitation magnitude will have a negative impact on the performance of the system. For example, under the worst case climate change scenario and the current water supply system, average future reliability, resilience, and vulnerability values are projected to be 0.981, 0.304, and 258.5 m^3, respectively. This compares with average future reliability, resilience, and vulnerability values of the current system with no climate change 0.998, 0.635, and 172.5 m^3. The results also suggest that a reduction of precipitation may worsen the system performance. Conversely, an increase of precipitation may lessen the impacts of a warmer climate.

A more rapid population growth will substantially increase the water demand, showing that expansion of the current system is required. For example, under more rapid growth and without expansion, the current system has an estimated reliability of 0.923 under the worst case climate scenario. With expansion option increasing system capacity by 20%, this reliability is improved to 0.965.

The final phase of the study involves a multiobjective analysis consisting of two objective functions: cost and overall system performance. Four feasible system improvement alternatives were evaluated. By using comprise programming, the nondominated solution of increasing the system capacity by 10% was ranked first. This compromise solution has emphasis on both aspects of cost and the overall risk performance measures.

Uncertainties exist in the GCM projections of the temperature and precipitation change. The individual effects of an increase of average temperature, a reduction in precipitation, and the fluctuations in the GCM estimates on the risk in the system is uncertain. Additional studies are needed to identify the influence of these factors.

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Table of Contents

List of Figures

List of Tables

Chapter 1
Introduction

1.1 Background

Of all of the water on Earth, only 2.5% is freshwater (Environment Canada, 2007). Two thirds are in the form of glaciers and polar ice caps, with the remaining liquid water contained in ground and surface water such as rivers, streams, and lakes. For reasons such as contamination or being too remote for human use, some of the water is not useable, leaving an approximate 0.3% of water that is available (Loucks and Van Beek, 2005).

In many parts of the world, water demand has already exceeded supply causing water stress. For example, in countries such as Australia, China, India, and Spain, etc, water resources authorities are seeking a national hydrological plan to meet the existing demands. Fueled by population growth and climate shift, more areas will likely experience the imbalance in the near future (Loucks and Van Beek, 2005).

Since Canada holds roughly 20% of the world's freshwater (Environment Canada, 2007), it may appear that water is abundant. However, this figure can be misleading, because most of the water is locked in snow and ice (Loucks and Van Beek, 2005). Discounting the water that is out-of-reach, Canada has about 9% of the world's renewable freshwater. However, over half of Canada's water flows north away from the southern population centers leaving scarce water supplies in some of these regions (Meakin, 1993).

Humanity has depleted aquifers, diverted rivers, and polluted water bodies (Barlow and Clarke, 2002). Human activities have altered the natural water cycle and habitat causing even modern water supply systems to become dysfunctional, as can be seen in the 2000 Walkerton incident. With an increasing population and the second largest per capita water usage, Canada's municipal water supply systems may experience more downtime in the future (Ministry of Environment, 2003).

1.2 Purpose

Water is the essence of life. It is crucial to the health of humans and ecological systems. It is an important factor in the development of modern societies. Water is used in all aspects of our daily life. It is the most widely used resource in industrial activities. It is used in cleansing and as a carrier for household wastes to control or eliminate disease. It is used directly and indirectly in the production of energy and all of our consumable goods. As our life depends on it, as well as our society's economic growth, it is important to have a reliable water supply (Frederick, 1995).

Municipal water demand is highly variable, because water usage behaviour varies with season and weather conditions. With an increasing population and a shifting climate, making decisions in preparation for future needs can be difficult. Many water managers are now facing the challenge of planning expenditures under uncertainties and with limited resources. In preparation for climate variation, as well as ensuring sustainable growth, it is important to assess the risk to a domestic water supply. Such information would contribute to the development of an adaptation plan to ensure the reliability of a water supply system. Therefore, it is the purpose of this study to develop a framework for risk analysis of a water supply system under a range of uncertain conditions.

1.3 Scope of Investigation

This study examines the impacts of population growth and fluctuating climate conditions on the performance of a municipal water supply system. It also focuses on the approaches and methodology in developing a hybrid model which combines a data-derived stochastic component to a deterministic artificial neural network. The proposed model takes in climatic variables and water consumption patterns derived from historical records and projects future water demands under different assumed conditions. The model also estimates the effects of water efficiency management programs such as a low flow toilet replacement program, conservation efforts such as education and communication programs, and regulation implementation such as outdoor water use by-law, on improving the system.

As a separate but related goal, this study examines the impacts of future climate scenarios on the performance of a water supply system. First this study looks at the possible outcomes of a changing monthly mean temperature and precipitation magnitude as projected by a selection of Globe Climate Models (GCMs). Because future precipitation deviation may be frequency related (Zhang et al., 2007), a second approach was developed to look at the outcomes if the change of precipitation amount is converted into a change of precipitation pattern by a change of frequency of occurrence of events.

In addition, economic analyses to determine the tradeoffs between expansion options and conservation alternatives under different scenarios are also undertaken. Multi-objective optimization analysis on different water management configurations is performed to determine the most robust water conservation alternatives.

1.4 Thesis Organization

This thesis is organized into six chapters. Chapter two begins with the fundamental concepts of uncertainty, risk, reliability, and robustness of a water supply system. It then reviews the relevant techniques of stochastic simulation and modelling. A summary of the risk performance indices and multi-objective optimization then follows. Chapter three illustrates the architecture of the simulation model and the risk indices calculation process. Methods used to develop the model are also presented. Chapter four briefly describes the case study area, the available data, and the simulation scenario definitions. Chapter five presents the results of the simulations and provides discussion of the findings suggested by the analysis of the results. In the last chapter, Chapter six, conclusions of the study and recommendations on future work are provided.

Chapter 2

Literature Review and Background

2.1 Introduction

This section begins with a brief description of a typical water supply system, its major components and their functions. Following is a review on risk and uncertainties of a water supply system and their consequences illustrated with the use of a few recent examples. This section then presents theories and techniques employed in this study, which include topics on stochastic modelling and simulation, performance measures and multi-objective optimization.

2.2 Water Supply Systems

Water supply systems provide the general population with water in sufficient quantity and quality. A typical water supply system comprises of three components: source, treatment and distribution.

Source Water

Source water refers to the freshwater drawn from surface water and groundwater. A water supply system draws water from the source water. In some regions where the availability of water is limited, desalination is used to generate freshwater. As this method has very high operation costs, it is not widely used.

Surface water includes water from lakes, rivers, and reservoirs and ice and snow. Groundwater refers to water from aquifers through springs or wells. Surface water tends to be more turbid and is more prone to contamination by external factors and to weather conditions. Groundwater usually has higher total dissolved solids because of the minerals that are dissolved from rocks and soils. Depending on the geographical location, some places without direct access to water, or if the local supplies are inadequate to fulfill existing consumption, would need to import water via pipelines, ship cargo, or water trucks. Very often a municipality can have a combination of source water (Tchobanoglous and Schroeder, 1987).

Water Treatment

The primary objective of treating source water is to ensure that the drinking water quality standards are met and water is safe for human consumption. Depending on the characteristic of the raw water quality, the treatment objectives and the costs of operation, different water treatments are provided. Typical water treatment methods include physical operations or chemical processes. Widely used water treatment methods include filtration, coagulation, and flocculation for the removal of turbidity, water colour and suspended matter; and chlorination for disinfection purposes (Tchobanoglous and Schroeder, 1987).

Distribution

The function of a water distribution system is to deliver treated water to consumers adequate in both flow and pressure. A water distribution system comprises of storage facilities, pumping stations and piping networks (Tchobanoglous and Schroeder, 1987). To ensure the overall system stays in operation in case of a component failure, several degrees of redundancy are usually built into the system. For example, twinning of major branches to avoid a cut-off resulting from a water main break or installation of multiple backup pumps and diesel power generators in preparation for a pump or power failure.

2.2.1 Municipal Water Use

Municipal water use can be subdivided into four categories: domestic, commercial and industrial, public services, and unaccounted system losses and leakage. Domestic water use includes the water used in residential areas, commercial districts, and institutional and recreational facilities. Commercial and industrial includes water supplies to canneries or cooling for power generation. Public service water use encompasses water used in public buildings, parks and fire fighting. The water used for fire fighting is small as compared to the total water consumption, but the instantaneous demand is very high and often limited by the hydraulic capacity of the supply system (Tchobanoglous and Schroeder, 1987).

2.3 Risk Management

Defined by the United Nations, Office of the Disaster Relief Co-ordinator (1991), risk management is to assess risk, determine a risk management policy, and communicate the policy to the public. Risk management is of particular importance for the management of water resources system. It involves the process of identifying, evaluating, and executing of all aspects of system management in accordance with other social sections. It involves the identification of loads in a system, plan for possible emergency scenarios in case of an operational failure, and plan for relief and rehabilitation for structural failure. It is a technical, social and economical process to balance the monetary and social costs and benefits.

Different methodologies of risk management are found in the literature. The process of risk management includes the steps: (1) identify feasible alternatives and associated risks; (2) assess all impacts for different levels of risk; (3) select acceptable option to communicate with the public with the consideration of the perception of risk, government policy and other social factors; and (4) implement the optimal choice (Simonovic, 2002). The objective of the process is to first identify the action that can be taken to reduce risk to the acceptable level and then find the available options and the corresponding tradeoffs in costs, benefits, and risks (Haimes, 1998).

2.3.1 Risk Assessment

The primary objective of risk assessment is to estimate risk by identifying the undesired event, the likelihood of occurrence of the unwanted event, and the consequence of such event (Kaplan and Garrick, 1981). As suggested by Biringer and Danneels (2000), there are seven basic steps to assess the risk in critical facilities: (1) Characterize the facility; (2) Identify undesired events and critical assets; (3) Determine the consequences of undesired events; (4) Define threats to the facility; (5) Analyze protection system effectiveness; (6) Estimate risks; and (7) Suggest and evaluate upgrades to the system.

2.3.2 Risk

Risk is traditionally defined as a measure of the probability and severity of adverse effects (Lowrance, 1976). The concept of engineering risk is based upon *load*, *resistance* and *consequence*. Load, L measures the behaviour of a system under external stress or loading. Resistance R is a variable that describes the ability of a system to withstand a load. When the load exceeds the resistance (L>R), a failure or an incident occurs; the associated outcome is the consequence. Depending on the problem domain, L and R are random variables and risk is defined as the product of the probability of failure and the consequences.

Risk = Probability of failure x Consequence

$$= P(L > R) \times C_o \qquad (1)$$

In using this simplistic formulation of risk, it is assumed that there are sufficient data to capture the characteristic of L and R. In the aspect of water resources engineering, load includes flood, pollutant load, drought, etc.; resistance includes protection level, treatment level, system capacity, etc.; and the failures are flooding, water pollution, or water shortage, etc. It is clear that uncertainties exist in water resources systems and it is rare that the uncertainties can be entirely captured by the available data.

The stochastic approach can be used to account for the uncertainties in a system with random variables. Load L and resistance R are random variables and can be represented by probability density functions: $f_L(L)$ and $f_R(R)$. In the probabilistic framework, risk is the probability of load exceeding the resistance multiplied by the consequence.

$$RISK = p_F \times c_0 = P(L > R) \times c_0 \qquad (2)$$

where p_F is the asymptotic limit and can be obtained by integrating the joint probability density function $f_{LR}(L,R)$ for $L>R$ (Simonovic, 2002).

2.3.2.1 Types of Risk

The subjective judgment on the source of risk is unreliability. Very often decision makers apply more weight on the perception of risk rather than the impact of actual risk (Simonovic, 2002). Therefore, it is important to understand the basics of different types of risk. There are three primary types of risk: objective, subjective, and perceived risk. Objective risk is the real or physical risk that would cause damages to properties or to the environment or endanger or kill people. For example, contaminated source water is an objective risk as the consumption of the contaminated water would endanger people's health. Subjective risk is risk that is associated with the degree of belief based on people's judgment. For example, perceived risk is based on individual's feeling of fear (Simonovic, 2002).

2.3.3 Uncertainty

There are different definitions of uncertainty found in the literature. Mitchell (2002) suggests that four types of uncertainty are: risk, uncertainty, ignorance, and indeterminacy, and uncertainty itself is a type of uncertainty. Ignorance is defined as the inadequate knowledge in absence or scarcity of information. Indeterminacy is contributed by the variability inherited from the process or the statistical variability because of sparse information (Bogardi et al., 2002).

Simonovic (2002) proposed that there are two sources of uncertainty: uncertainty caused by inherent stochastic variability and uncertainty due to a fundamental lack of knowledge. The uncertainty caused by variability is a result of the intrinsic fluctuations in the quantity of interest. For example, the values of parameters in a hydrometeorological process are highly variable. The source of variability can be classified into three categories: temporal, spatial and individual heterogeneity. Temporal variability refers to the fluctuation of values with time. Spatial variability refers to the fluctuation of values because of location variation and heterogeneity variability refers to all other sources of variability (Simonovic, 2002). In the domain of water resources processes, variability of physical system inputs or response parameters such as temperature, precipitation, river flow, etc., are mostly spatial and temporal.

Uncertainty due to a fundamental lack of knowledge is more elusive. Such uncertainty exists when a value of interest cannot be presented with complete confidence because of a lack of understanding or limitation of knowledge. Uncertainty due to lack of knowledge is further broken down into three types. They are model and structural uncertainty, parameter uncertainty, and decision uncertainty (Simonovic, 2002).

Model or structural uncertainty arises when a model is oversimplified or failed to capture the important characteristics of the process under investigation. Parameter uncertainty is caused by random error in parameter estimates resulting from subjective judgement error. Decision uncertainty exists when the comparison or weighting of social objectives is controversial or ambiguous. There are three sources of decision uncertainty. They are the uncertainties in the selection of an index to measure risk, the social cost of risk and the quantification of social values (Simonovic, 2002).

2.3.4 Failure

A failure occurs when a system performs unsatisfactorily. Depending on the course of interest, failure can vary in type and magnitude (Hashimoto et al., 1982). For example, flooding in a populated area is considered as a failure of a waterway. It occurs when the volume of water exceeds the total capacity of a water body. At different geographical points, the causes of flooding include overtopping of flood defenses due to hurricanes, rapid snow melt, or extreme rainfall, etc.

The severity of a failure is defined by the extent of the damage. In the flooding example, it would be lost lives and property damage. As risk is defined as the product of the probability of failure and the associated consequence, therefore, without the consequence to a failure, risk does not exist (Smith, 2005).

In a complex system, there can be several pathways that lead to a failure. The failure of a single critical component or a combined failure of multiple components can lead to overall system failure (Pandey, 2005).

2.3.4.1 Types of Failures

There are two major types of failures: performance failure and non-performance failure. Performance failures result from mechanistic or operational failures of a system. Non-performance failures result from natural or anthropogenic disasters (Baxter and Lence, 2003).

2.4 Risk in Water Supply Systems

The two aspects in concern of a water supply system are water quantity and water quality. Water quantity refers to the availability of water. Water quality refers to the physical, chemical and biological characteristics of water. Risk in water supply systems lays in the principle components of the system or the effects of external factors. It includes mechanical, operational, or structural failure of the source, treatment, and distribution system components. These failures can be caused by aging of system components, human factors, or natural disasters (Tchobanoglous and Schroeder, 1987).

A water supply system failure occurs when the system is unable to meet the water quantity and/or quality requirements. For example, a water shortage due to increase of water usage as a result of population growth and change of land use; or external factors such as prolonged drought or heat wave causing sudden change in demand. In older distribution systems, because of corrosion of metal pipe, such as iron or copper mains, metals can be released into water. Depending on the parameter of exceedance, a drinking water that is unable to meet the water quality guideline can be viewed as a failure or deficiency.

Most water supply storage and treatment facilities are operated based on historical data. In the wake of a changing climate, more extreme weather events and fluctuations in weather patterns may happen. Consequently, higher system failure may result.

In this thesis, the risk found in a domestic water supply system is primarily focused on the risk of water shortage due to population growth and climate change.

2.5 Stochastic Modelling and Simulation

When a system is subjected to new conditions in the future such as climate change or population growth, risks may increase. To forecast these future risks, one of the best methods is to construct a stochastic model to capture the statistical characteristics in the historical data and derive the future responses from available information. To do so, it is necessary to examine the raw data and identify and select the probabilistic distributions that best describe the data. Next, the probabilistic mechanism and parameters of the distributions need to be estimated. The estimates obtained should then be investigated to see if the implications are reasonable, that is, if the probability law describes a given change of the independent variable as a function of the dependent variable(s). After the assumptions and possibly the probability laws have been specified, a probability model of the system would have been built (Ross, 1997). However, prior to any data analysis, the knowledge and application of regression is required.

Once the probabilistic model has been constructed, risk measures can be determined analytically in simple cases. However, very often these measures are difficult to derive analytically, and therefore, to estimate the risk measures, simulations are needed (Ross, 1997). The purpose of the modelling is the prediction of the behaviour of the system given a set of parameters and initial conditions. There are in general two types of simulation models: deterministic simulation and stochastic simulation. Given a particular set of input variables and initial conditions, deterministic simulation generates identical simulation results for every simulation trial. Despite the heavy computation requirements, Monte Carlo Simulation is the most robust simulation technique and is therefore employed in this study.

2.5.1 Monte Carlo Simulation

Monte Carlo simulation is widely used in risk assessment for its capability of modelling phenomena with uncertainties. Monte Carlo simulation involves generating random values of stochastic parameters from their corresponding probability distribution. In order to successfully estimate the probability of failure, a large number of simulation trials need to be conducted for the output to reach stability (Pandey, 2005).

2.5.2 Statistical Analysis

2.5.2.1 Distribution Selection

There are a number of fitting methods to determine the "best-fitting" distribution and to estimate the associated parameters (Pandey, 2005). For example, the Method of Moments, which estimates distribution moments by equating them with sample moments; Method of

Maximum Likelihood, which assigns the distribution parameters that maximize the likelihood of the sample; Least Squares Method, which fits a theoretical function to an empirical function by regression techniques, and Graphical Methods which allow visualization of the data via diagrams, charts and plots (Burn, 2003).

The use of a probability paper plot (probability plot) is a popular way to assess if a dataset follows a specific probability distribution. By examining the plots using various goodness-of-fit tests, which will be discussed in the following section, the best-fit distributions for individual independent parameters can be selected.

Among the many probability density functions that exist, some of the more popular and widely used distributions in hydrology include: Normal, Log-Normal, Exponential, Gamma, Gumbel (Extreme Value Type I), and Weibull (Extreme Valve Type III).

2.5.2.2 Goodness of Fit Tests

Usually it is rather difficult to determine the best-fitted distribution of a data set by solely inspecting the probability plots. There are a number of statistical procedures, known as Goodness of Fit Tests, to ascertain whether a given data set follows the tested probabilistic distribution. Some of the widely used distribution measure tests include Chi-Square Test, Kolmogorov-Smirnov (K-S) Test, and Anderson-Darling (NIST, 2006). The two Goodness-of-Fit testing methods, Probability Plot Correlation Coefficient (for its simplicity) and

Anderson-Darling (for its sensitivity as compare to K-S test and applicability to continuous set) are chosen to find the best fitting distributions and are discussed below.

2.5.2.2.1 Probability Plot and Correlation Coefficient

In a probability plot, data are plotted against a fitting distribution. If the data fits the specific distribution well, the data points would form approximately a straight line. If the data points deviate from the straight line, it indicates a deviation of the data from the fitting distribution. The goodness of the fit of the data to a distribution can be measured by the correlation coefficient of the linear best fitted line in the probability plot. As well, the location and scale parameters of the fitting distribution can also be estimated from the slope and intercept of the best fitted line. Several probability plots can be generated for different distributions to see which distribution fits the data best. A probability plot that generates the largest correlation coefficient would indicate a best fitting distribution among the competing distributions (NIST, 2006).

2.5.2.2.2 Anderson-Darling Statistic

The Anderson-Darling (AD) Statistic is a modification of the Kolmogorov-Smirnov goodness-of-fit test. It measures the area between the empirical distribution function and the assumed population distribution (Pandey, 2005). Smaller AD values are generated if there are smaller deviations between the actual and the fitted data. Therefore, by comparing the AD values of competing distributions, the distribution with the smallest deviation would indicate the best-fit distribution.

2.5.3 Time Series Analysis

A time series is a sequence of data points recorded over time and is represented by the notation X={X_1, X_2, X_3,…X_n}. Time series data are typically measured at successive time and in uniform intervals; for example, the daily stock price of a company, daily temperature of a city, or unemployment rate of a city. In a time series dataset, very often, trend, seasonality and other time dependent patterns exist, making the time series nonstationary. However, in developing a model to forecast the process, some stability in the data is needed. Tools such as taking the logarithm, linear operation, or smoothing, can be used to reduce the variability and eliminate trends in the time series data, so as to introduce stationarity in the data. In addition to taking the logarithm and smoothing, Fourier series and neural networks are also used to investigate the time series data of this study and will be discussed in the following sections (Pourahmadi, 2001).

Smoothing

Smoothing is one of the techniques to eliminate trends in the time series data. By smoothing the data, the major features such as seasonal patterns in the data would be emphasized and other features such as random fluctuations would be de-emphasized. One of the smoothing techniques would be moving average, which is defined as:

$$s_t = \frac{\sum_{i=0}^{n-1} x_{t-i}}{n} \qquad (3)$$

where s_t is the new smoothed series and the residuals are defined as:

$y_t= x_t-s_t$, t=1,2,…,n.

2.5.3.1 Fourier Series

The Fourier series named after the physicist and mathematician, Joseph Fourier (1768-1830), was first investigated for the applications of heat flow. In a Fourier series, an arbitrary periodic function is broken down into a set of sine and cosine components. The individual sinusoidal terms can then be solved individually (Mathworld.wolfram, 2007). A generalized Fourier series of a function f(x) is given as

$$f(x) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty} a_n \cos(nx) + \sum_{n=1}^{\infty} b_n \sin(nx), \tag{4}$$

where

$$a_0 = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)dx$$

$$a_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\cos(nx)dx$$

$$b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\sin(nx)dx$$

and n = 1, 2, 3, etc. Figure 1 illustrates the N-harmonic Fourier series for N equals to 1 to 4.

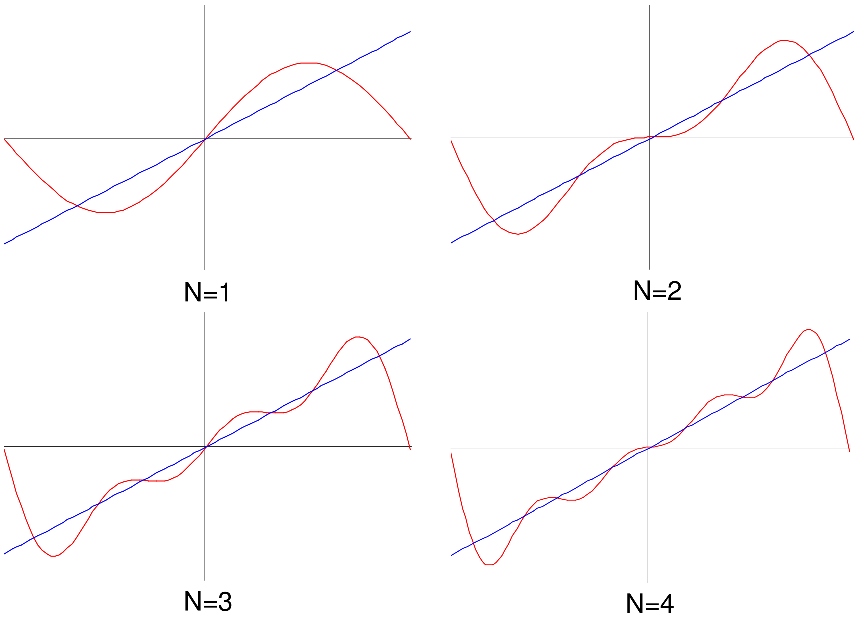


Figure 1. One period of N-harmonic Fourier series

The Fourier series has been used in water resources related area to detect periodic and cyclic components in data, to name but a few, the seasonal fluctuation elevations of lakes and wells (Kite and Adamowski, 1973). The seasonal patterns in a dataset can be approximated by the Fourier series

$$x(t) = a_o + \sum_{m=1}^{N/2} a_m \cos\left(\frac{2\pi mt}{N}\right) + b_m \sin\left(\frac{2\pi mt}{N}\right) \tag{5}$$

where a_0 is the mean of the data set, m is the number of harmonics, N is the length of the data set, and t is the time. The coefficients a_m and b_m for $m \neq N/2$ are defined as

$$a_m = \frac{2}{N}\sum_{m=1}^{N} x_t \cos\left(\frac{2\pi mt}{N}\right) \qquad b_m = \frac{2}{N}\sum_{m=1}^{N} x_t \sin\left(\frac{2\pi mt}{N}\right) \tag{6}$$

whereas for m =N/2,

$$a_m = \frac{1}{N}\sum_{m=1}^{N} x_t (-1)^t \qquad b_m = 0 \tag{7}$$

The variance C_m^2 explained by the *m*th harmonic is defined by

$$C_m^2 = \frac{a_m^2 + b_m^2}{2s^2} \tag{8}$$

where s^2 is the total variance of the time series x(t) (Weisstein, 2004). In this study, the Fourier series is used to mimic the seasonal pattern in the temperature data.

2.5.3.2 Autoregressive Moving Average Model

Autoregressive moving average (ARMA) models after George Box and G.M. Jenkins are one of the most popular methods for forecasting time series. There are two parts to this class of models. One is the stochastic autoregressive part, which generates random disturbance, and the other is the deterministic moving average component. In many ARMA models, it is assumed that the time series value being modelled at time t, X_t, depends only on its previous values, X_{t-1} (Box and Gwilym, 1976). The framework of the seasonal autoregressive model was adopted and modified to simulate the daily variations of temperature.

2.5.3.3 Poisson Process

The Poisson process named after the mathematician Simeon-Denis Poisson (1781-1840) is widely used to describe the arrival of events. In introducing the Poisson process, it is always necessary to first present the concept of *counting process*. Thus, in this section, first the counting process is briefly described, then the description of a Poisson process is presented, and lastly the procedures to generate a Poisson process are given.

Counting Process

Suppose that N(t) represents the total number of “events” that have occurred from time 0 to time t, then {N(t), t≥0} denotes a *counting process*. For example, let N(t) be the number of customers that have entered a restaurant at or before time t, then

{N(t), t≥0 } is a counting process and an “event” is a customer entering the restaurant. By definition, a counting process must satisfy a few conditions (Ross, 1985).

N(t)≥0

N(t) is integer valued

If s<t, then N(s)≤N(t).

For s<t, N(t) – N(s) equals the number of events that have occurred in the interval (s,t) as illustrated in Figure 2.

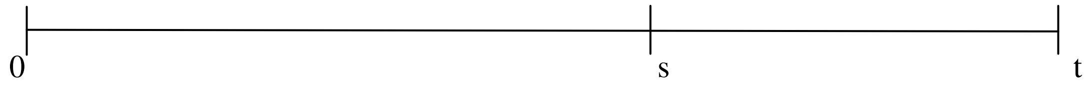


Figure 2. Event time

A counting process also has the property of *independent increment*. That is, the number of arrivals during a time interval is independent of the history of arrivals in other intervals. In other words, the number of events that have occurred by time s, N(s), must be independent of the number of events occurring between times s and t, (N(s) –N(t)) (Ross, 1997).

Poisson Process

A Poisson process is a continuous-time counting process having rate parameter or intensity λ, λ >0, which is the expected number of "events" occurring in an interval. In a Poisson process, the number of events "n" in the time interval (0, t) follows a Poisson distribution

$$\mathrm{P}(n) = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \qquad (9)$$

and the interarrival time is described by the exponential distribution. A Poisson process has five associated properties:

a) N(0)=0

b) The number of events occurring in disjoint time intervals are independent.

c) The distribution of the number of events that occur in a given interval depends only on the length of the interval and not on its location.

d) $\lim_{h\to o} \frac{P\{N(h)=1\}}{h} = \lambda$

e) $\lim_{h\to o} \frac{P\{N(h)\geq 2\}}{h} = 0$

Condition a) says that the process start at time 0. Condition b) refers to the property of *independent increment*. Condition c) is the *Stationary increment assumption*, which states that the probability distribution of N(t+ τ)-N(t) is the same for all values of t. Conditions d) and e) state that in a small interval of length *h*, the probability of one event occurring is approximately λτ, and the probability of two or more events occurring is approximately 0. In other words, there can only be one event occurring in any small increment of time (Ross, 1997). Figure 3 illustrate n increment of time between 0 and t with small interval of length.

Figure 3. n increment of time between 0 and t

Generating a Poisson Process

One way to generate a Poisson process for a length of time T is to draw a total number of n events with a sum of interarrival times exceeding T (Figure 4). To do so, first generate n random numbers $U_1, U_2, \dots U_n$ and set $X_i = -1/\lambda \log U_i$, where X_i represents the time between the $(i-1)$st and the ith event and the generated values of the first n event times are $\sum_{i=1}^{j} X_i,\ j = 1,\dots,n.$ Then, set the actual time of the jth event equal to the sum of the first j interarrival times (Ross, 1997). The interarrival times X_i between successive events are independent exponential random variables each with rate λ.

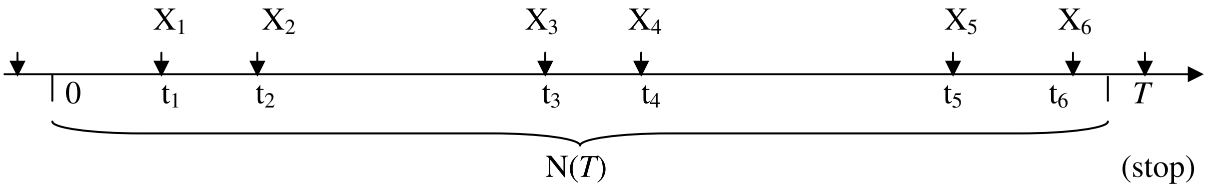


Figure 4. Interarrival times of X_j

2.5.4 Water Demand Modelling

In order to assess risk of the water supply system for future scenarios, it is necessary to develop a water demand forecast model. To project trends in the growth of water use for the need of design, operating and management of water supply system, the development of a water demand forecast model is required.

Climatic variables such as rainfall, air temperature, sunshine duration, relative humidity, wind speed, past water use and the day of the week were found related to water demand in many studies. A large collection of water use prediction methods have been investigated in various studies. Linear regression models developed by Jain et al. (2001) used weekly maximum air temperature, weekly rainfall amount, weekly past water demand, and the occurrence and non-occurrence of rainfall as dependent parameters. The linear regression models developed by Graeser (1958) have the number of previous days with maximum air temperature above 100°F and the number of weeks from last occurrence of one inch of rainfall as dependent variables. Howe and Linaweaver (1967) developed a collection of regression models for domestic sprinkling demands based on summer precipitation, potential evapotranspiration rates, average summer demand and irrigable area.

Another popular approach to predict water demand is the Time-series analysis. Autoregressive models were developed by Jain et al. (2001) to predict maximum water demand. Box and Jenkins models were developed by Maidment et al. (1985) to predict the daily municipal water use.

The regression and time-series models were the most popular water demand forecast methods. However, in more recent studies, artificial neural network (ANN) model are becoming prominent for water demand forecast as the neural network was found to outperform the regression and time-series models in some studies (Bougadis et al., 2005). The pattern of water use is sensitive to the demographic factors of the local community, therefore, a deterministic water demand forecast model needs to be tailored to predict a given water supply system demand.

2.5.5 Artificial Neural Networks

Artificial Neural Networks (ANNs) are a relatively new soft computing tool with architecture inspired by that of the brain. Because of its parallel data processing and learning characteristic, neural networks can detect complex relationships between inputs and outputs. Some common applications of neural networks include nonlinear functional mapping, speech and pattern recognition, categorization and data compression (Karry and De Silva, 2004).

Basic Structure

An artificial neural network comprises neurons (nodes) that are interconnected by weights to form a network of nodes (Figure 5). In each neuron, there is a threshold and an associated activation function (Karry and De Silva, 2004).

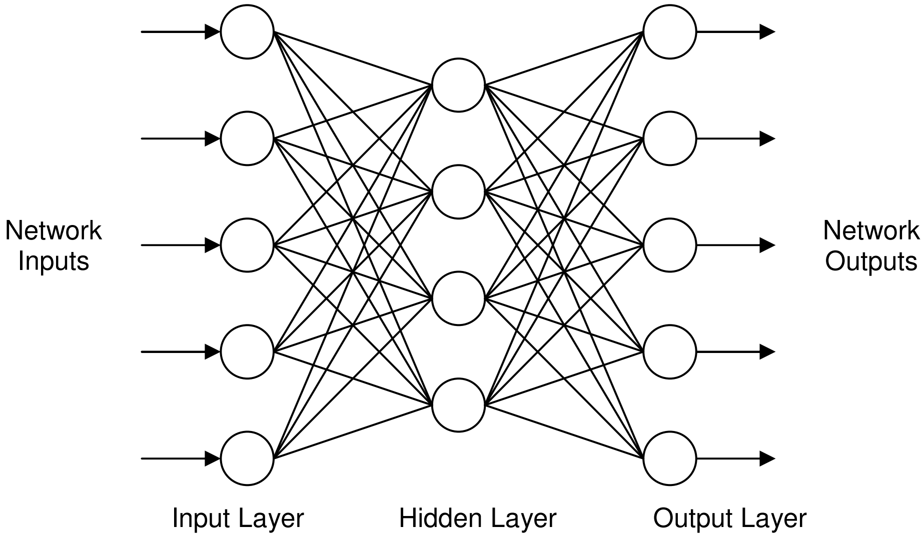


Figure 5. A fully interconnected three-layered back-propagation network

Major Classes of ANNs

There are four major classes of ANNs: Multilayer Perceptron, Radial basis function networks, Probabilistic neural network (PNN), and generalized regression neural networks (GRNN). These ANNs are different in their network topology (feedforward and recurrent), the network transfer functions, and the network learning algorithm (supervised and unsupervised). The detailed architecture of these neural networks is beyond the scope of this thesis, and therefore is not presented. Further references can be found in Bishop (1995) and Karray and De Silva (2004).

Training Process

"Neural networks learn by example". With representative data provided to the training algorithm of the neural network, the pattern in the data will be learned (StatSoft, 2003). Like other data-driven models, such as a linear regression model, an ANN model deciphers the relationship found between the input and output data. Much as coefficients in a regression equation need to be estimated, the interconnecting neurons in the neural network need to be trained (Solomatine, 2002). In this thesis, the ANN is used for non-linear statistical data modelling to model complex relationships between climatic variables and water demand.

2.6 Risk Indices and Multi-objective Optimization

2.6.1 Performance Measures

Under uncertainties induced by climatic shift and human behaviour, a water supply system can encounter a wide range of possible demands and hydrological conditions. The three risk-based system performance evaluation criteria: Reliability, Resiliency, and Vulnerability, suggested by Hashimoto et al. (1982), describe the performance of a water resource system. These performance measures are especially useful for their capability in capturing possible system responses during extreme events such as drought, peak demands, or extreme weather. Further, these measures can aid decision makers in planning system capacities, selecting competing system configurations, establishing operating policies, and setting regulation targets. The following are descriptions of the system performance measures defined by Hashimoto et al. (1982).

2.6.1.1 Reliability

Reliability is the probability that a system operates within specified conditions during a specified period of time or for at least a specified duration of time. Given a system with possible outputs X_t at time t and a threshold criterion, X_t can be divided into two sets: S the set of outputs that satisfies the criterion and *F* the set of outputs that fails to fulfill the criterion (Figure 6).

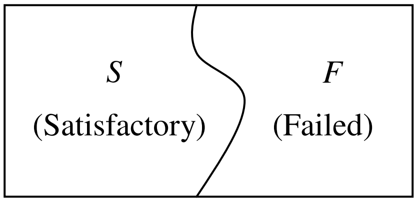


Figure 6. Set of system outputs X_t

In general, reliability is defined as the probability α that a system is in a satisfactory state:

$$\alpha = \text{Prob}[X_t \in S] \tag{10}$$

which is the opposite of risk and can be calculated as one minus the probability of failure P_f:

$$\alpha = 1 - P_f \tag{11}$$

Alternatively, reliability can sometimes be defined as the probability that no failure occurs during the time of interest.

2.6.1.2 Resiliency

After a failure has occurred, a system may return to the satisfactory state or remain unsatisfactory for an extended period. It is more preferable to design a system that recovers quickly as compared to one that recovers slowly. Resiliency describes how quickly a system is likely to recover after a failure occurs. Given the duration of failures (T_F) during an n-period experiment, resiliency can be defined as the inverse of the expected value of T_F (Figure 7).

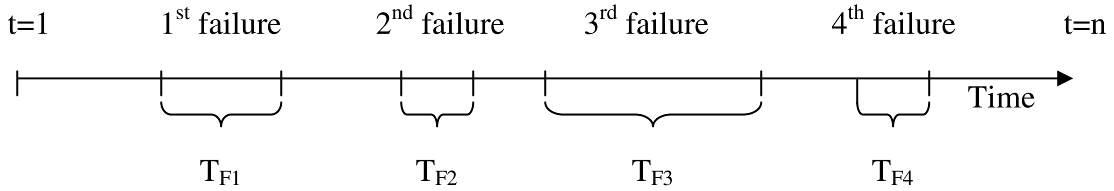


Figure 7. T_F, duration of a system failure.

To estimate the expected duration of a system output failure, Hashimoto et al. (1988) suggested to let

$$Z_t = 1 \qquad X_t \in S$$

$$Z_t = 0 \qquad X_t \in F\,,$$

such that (1/n) $\sum_{t=1}^{n} Z_t$ is the fraction of time that the system performs satisfactory between t = 1 to n time periods. As n approaches infinity, $\lim_{n\to\infty} \frac{1}{n} \sum_{t=1}^{n} Z_t$, the ratio becomes the reliability of the system α.

To capture the transition of the system state switches from satisfactory to unsatisfactory, Hashimoto et al. suggested to let

$$W_t = 1 \qquad X_t \in S \qquad X_{t+1} \in F$$

$$W_t = 0 \qquad \text{otherwise.}$$

For a long period of time, the average of W_t equals the probability that the system is in the set *S* at time period *t* and then goes into the set *F* at *t+1*:

$$\rho = \text{Prob}\,\{X_t \in S, X_{t+1} \in F\} = \lim_{n\to\infty} \frac{1}{n} \sum_{t=1}^{n} W_t \tag{12}$$

The average length of a consecutive failure (T_f) in n time steps is equal to the total time in failure divided by the number of consecutive failures:

$$\overline{T}_f = \frac{1}{n}\sum_{t=1}^{n}(1-Z_t)\left(\frac{1}{n}\sum_{t=1}^{n}W_t\right)^{-1} \tag{13}$$

As n approaches infinity, $\overline{T}_f$ approximates the mean value $(1-\alpha)/\rho$, which is the expected duration or the average duration that a system is expected to remain unsatisfactory once a failure occurred

$$E[T_F] = \frac{1-\alpha}{\rho} \tag{14}$$

Taking the inverse of this gives the system's average recovery rate γ_1

$$\gamma_1 = \frac{\rho}{1-\alpha} = \frac{\text{Prob}\{X_t \in S \text{ and } X_{t+1} \in F\}}{\text{Prob}\{X_t \in F\}} \tag{15}$$

For a prolonged period, the number of transitions from satisfactory to unsatisfactory and the number of transitions from unsatisfactory to satisfactory will be equal. Therefore, the probability of the two types of transitions must equal, that is

$$\text{Prob}\left\{X_t \in S \text{ and } X_{t+1} \in F\right\} = \text{Prob}\left\{X_t \in F \text{ and } X_{t+1} \in S\right\} \tag{16}$$

Hence γ_1 is equivalent to the average probability of a recovery from the failure set in

$$\gamma_1 = \frac{\text{Prob}\{X_t \in F \text{ and } X_{t+1} \in S\}}{\text{Prob}\{X_t \in F\}} \tag{17}$$

$$= \text{Prob}\ \{X_{t+1} \in S \mid X_t \in F\}$$

This indicates that if the system fails during the current time step, γ_1 is the probability that the system would recover in the next time step.

Alternatively, Moy et al. (1986) suggested another resiliency criterion based upon the maximum number of consecutive periods of deficit during the time of interest, given as

$$\gamma_2 = 1 - \frac{MD}{NS} \tag{18}$$

where MD is the maximum number of consecutive time periods of failure and NS is the time of interest.

A third resiliency criterion proposed by Simonovic et al. (1992) is as follows.

$$\gamma_3 = \frac{1}{\left(\frac{MD}{NS} NF\right)} \tag{19}$$

where NF is the number of times the system enters a failure.

2.6.1.3 Vulnerability

Vulnerability describes the likely magnitude of a failure of a system. Assuming that the system's output X_t takes discrete values of $x_1, \ldots, x_n$, the severity of a failure of each discrete failure x_j can be assigned a numerical indicator of the severity of the state s_j (Figure 8). Let e_j be the probability of x_j corresponding to s_j that is the most unsatisfactory and severe outcome that occurs in a sojourn

$$v_1 = \sum_{j \in F} s_j e_j \tag{20}$$

Depending on the decisions makers' attitudes to the characteristic of failure, the magnitude of the most severe failure vulnerability may have more importance. Therefore, in this thesis the vulnerability is also calculated as

$$v_2 = \max(s_j) \tag{21}$$

where s_j is the magnitude of the most severe failure during the time of interest.

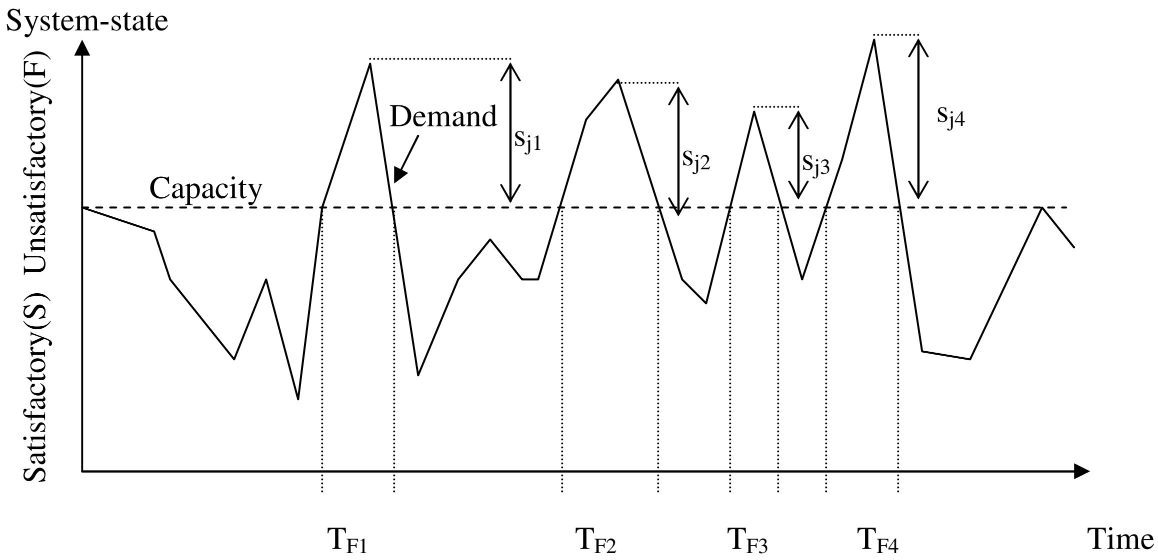


Figure 8. Severity of a failure state s_j

2.6.2 Multi-objective Optimization

To incorporate decision maker's attitudes toward risk and other tradeoffs between competing attributes, comprise programming is an interactive method for multi-objective analysis. Compromise programming has the ability to deal with multiple objectives and its interactivity allows the decision maker to adjust the influence that each objective has on a final solution set. This method does not provide an absolute answer but a set of solutions that are closest to the ideal solution as determined by a measure of distance. The ideal solution is represented by vector $z^* = (z_1^*, z_2^*,\ldots.,z_p^*)$ where the z_i^* are optimal objective function values of p separate single objective optimization models. For example if all were to be maximized,

$$\text{Max } z_i(x) \qquad (22)$$

subject to $x \in X$, $i = 1,2,\ldots\ldots., p$

The $z_i(x)$ in this problem can be the cost and system performance objectives. Each optimal solution, for example, for objective i, that is x_i*, can be used to calculate values of the other objectives. If this is repeated for each objective we have a set of solutions.

A scaling function can then be applied to the resulting $z_i(x)$ to ensure the objective functions are evaluated over the same range. This scaling function is defined by:

$$S_i(Di) = (z_i^* - z_i(x)) / (z_i^* - z_i^{**}) \qquad (23)$$

where z_i* is the best solution in the set and z_i** is the worst solution in the set. The scaled results are then combined to account for all objectives in the problem and ranked in accordance to the results of the following equation:

$$\min\left[L_s(x) = \sum_{i=1}^{p} \alpha_i^s \left(\frac{z_i^* - z_i(x)}{z_i^* - z_i^{**}} \right)^s \right] \qquad (24)$$

The alpha values indicate the importance of the particular objective that they are assigned to. The s values are used to exemplify the weight of a particular objective towards the final decision. For example, as s becomes larger, more weight is applied on the objective of most concern.

Chapter 3

Modelling Approach

3.1 Introduction

In order to assess risks of a water supply system, a water demand simulation model is needed to mimic the response of the water supply system under different conditions so as to facilitate the assessment of risk in relation to the impacts of population growth and climate change. In this section, an overview of the model architecture is first provided to introduce the overall stochastic approach. More in-depth descriptions of the methodology in representing the influencing parameters and the construction of the subcomponents follows.

3.2 Model Architecture and Risk Measures Calculation Process

A computer-based model is constructed to estimate the performance indices of a water supply system. The model employs the Monte Carlo method to generate two time series measures (temperature and precipitation) characterized by probability distributions derived from historical data and utilizes a deterministic artificial neural network (ANN) to calculate the daily water demand. The advantage of this setting is that the stochastic approach is able to capture the uncertainties found in natural climate variability, while the deterministic ANN has the ability to map out and reproduce the complex relationships underlying the water consumption data. Figure 9 illustrates the framework of the proposed model.

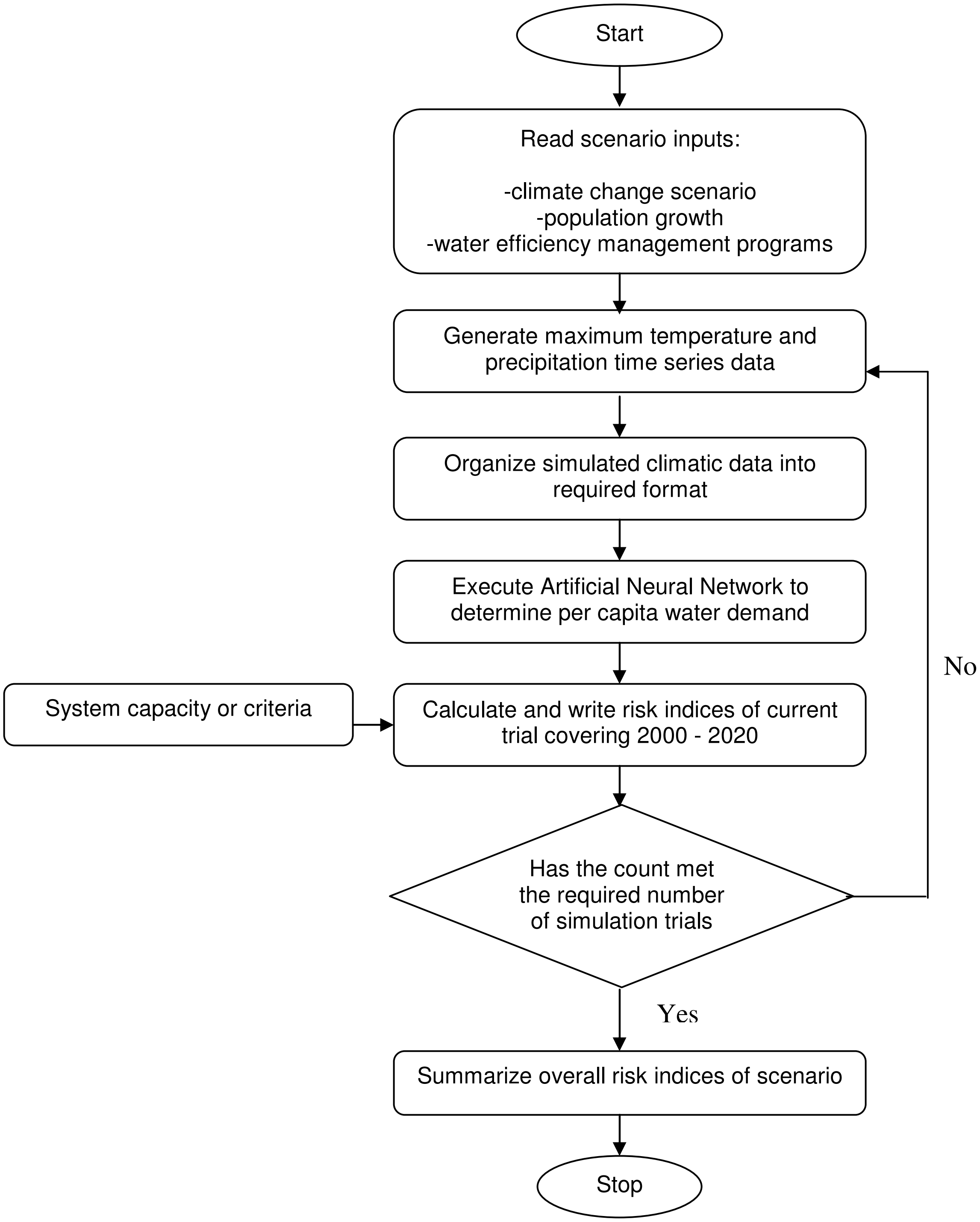


Figure 9. Structure of simulation model schematic for reliability, resilience, and vulnerability (RRV) assessment process

The model begins by reading in input parameters that define the setting of a simulation scenario. These time series input parameters include population growth, water efficiency program configurations, system capacities, outdoor watering by law implementation threshold, and GCM scenario projections, etc. The model then starts the Monte Carlo submodels to generate the time series temperature and precipitation data for the intervening years. Next, the simulated maximum temperature and precipitation data are organized into the required format and fed into the Neural Network Simulation Tool. The water demand is then calculated. The risk measures of the current simulation trial are calculated by using the prescribed system capacity and operation criteria. This process represents one simulation trial and is repeated until the required number of simulation trials is reached, which then completes one simulation cycle.

3.3 Variable Representations

3.3.1 Temperature

To represent the random variations in daily temperature using a stochastic method, the time series temperature T_t is represented by a three-component linear additive model (Figure 10):

$$T_t = U_t + P_t + R_t \qquad (25)$$

where U_t is a linear persistence, P_t is the periodicity component, and R_t is the random residual.

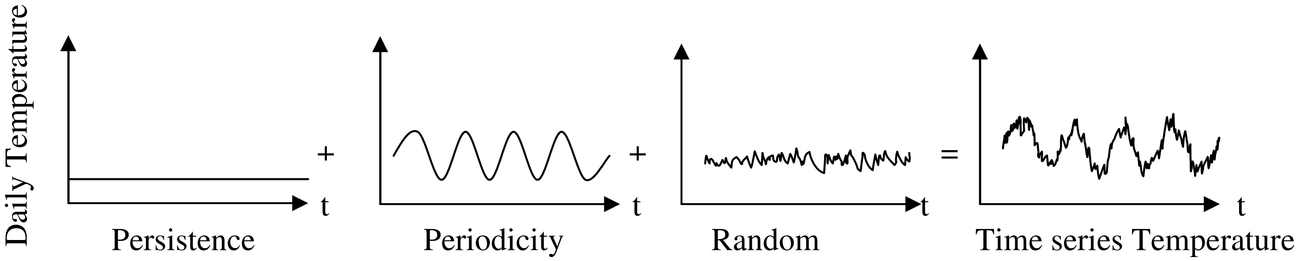


Figure 10. Components of a linear additive time series model

3.3.1.1 Long Term Trends

The annual maximum temperature and annual mean temperature over a long period are used to determine if a linear long-term temperature trend exists. The annual maximum temperature is defined as the average of the daily maximum temperature in a year and the annual mean temperature is the average of the daily mean temperature.

3.3.1.2 Periodic

The temperature data are fitted by the Fourier series to remove the daily random variations to reveal more clearly the seasonal temperature patterns. The coefficients to the series are estimated using the Matlab Curve Fitting Toolbox © 2007.

3.3.1.3 Stochastic Residual

The seasonal autoregressive model is chosen to simulate the random variations of the daily maximum ambient temperature. This procedure captures the daily temperature fluctuations that are known to be strongly correlated. The daily autoregressive model allows a different mean and variance for daily temperature and represents it as a function of the Julian day and is defined as:

$$R_{i,j} = \overline{R}_j + r_j \frac{S_j}{S_{j-1}} (R_{i,j-1} - \overline{R}_{j-1}) + t_{i,j} S_j \sqrt{1 - r_j^{\;2}} \qquad (26)$$

where $R_{i,j}$ are the residuals calculated by subtracting the actual daily highest temperature from the Fourier series, i is the year (i = 1,2,…,n), j is the Julian day(j = 1,2,…,365), $\overline{R}_j$ is the average of the daily temperature residuals across n years, r_j is the correlation coefficient between R_j and $R_{j-1,}$ S_j is the standard deviation of $T_{i,j}$ across n years, $t_{i,j}$ is a normal random variate $t_{i,j}$~$N(0,1^2)$ (Burn, 2003).

3.3.1.4 Time Series Temperature Simulation

To complete the linear addictive model, the stochastic residuals generated from the autoregressive model are added to the results generated from the fitted Fourier series and also added to any persistence.

3.3.2 Precipitation

The use of a combination of a point process and an intensity function to simulate the occurrence of precipitation has a long history. Several rainfall models were formulated by Todorovic and Woolhiser (1974) with the use of point probability model. Marien and Vandewiele (1986) developed a point rainfall generator with internal storm structure. Guttorp (1986) used a continuous time point process to describe rainfall.

In this study, the nature of frequency and duration of precipitation events from the data records were analyzed. The occurrence of precipitation events is assumed to be random and follow a Poisson arrival process:

$$\mathrm{P}[(N(t+\tau)-N(t))=k]=\frac{e^{-\lambda\tau}(\lambda\tau)^{k}}{k!} \qquad (27)$$

where λ is the occurrence rate during a time interval. During a time interval of *t*, the expected number of occurrences is λt. Hence, λ could be the number of days with precipitation over the length of the time period.

Adopted from Ross (1997), the following is an algorithm to generate the first *T* time units of a Poisson Process with rate λ. In this algorithm, *t* is time, *I* is the number of events that have occurred by time *t*, and S(*I*) is the previous event arrival time.

Steps

```
1. set t = 0, I = 0
2. Generate a random number U.
3. $t = t - \frac{1}{\lambda}\log U.$ If $t < T$, stop
4. I = I + 1, S (I) = t.
5. Go to step 2.
```

The interarrival time $-\frac{1}{\lambda}\log U$ is continuous and can sometimes have values less than one. These interarrival times when summed together would allow more than one event to occur on the same day. For example, if $t_1=0.5$ and $t_2=0.3$, then both event one and two would occur in day one. Since the desired time interval is one day, the algorithm needs to be modified to allow a maximum of one event in any day. That is, interarrival times less than one are rounded up to one, whereas interarrival times greater than one are rounded to the nearest integer value.

The historic daily precipitation volume is found best fitted by the exponential distribution and simulated using the typical Monte Carlo method. Therefore, the time series precipitation is simulated using the Poisson process to described the arrival time and the exponential distribution for the precipitation volume (Figure 11).

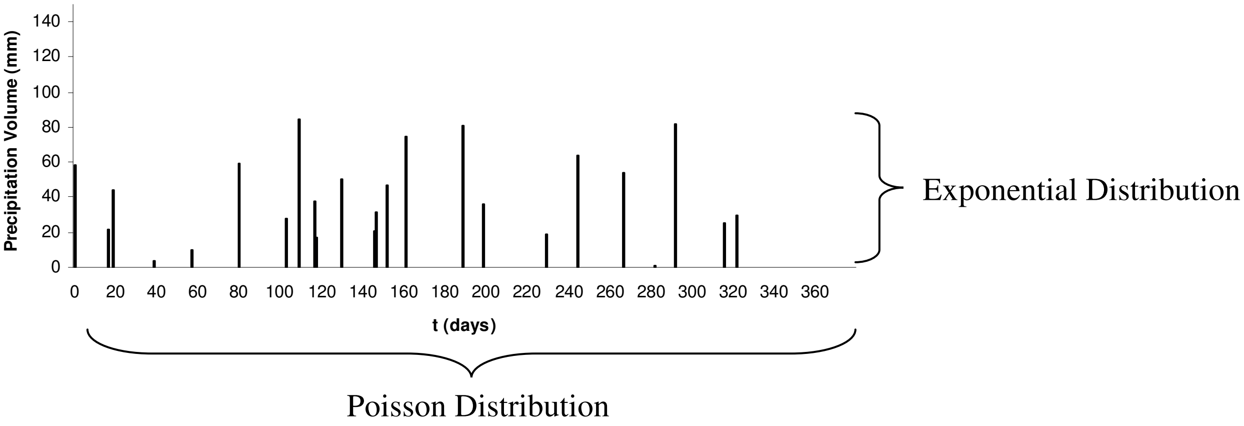


Figure 11. Poisson distributed precipitation arrival and exponential distributed precipitation volume

3.3.3 Global Climate Models (GCMs) Data

General Circulation Models (GCMs) commonly known as Global Climate Models are a class of computer models developed primarily for weather forecasting and climate change projections. These numerical models consist of a variety of integrated physical models such as atmospheric, oceanic, chemical, and biological models. In a GCM, the planet is divided into a 3-dimensional grid and differential equations describe the interactions of ocean and atmosphere. The results of each grid are estimated and interactions with neighboring points are evaluated (NOAA, 2007).

The Canadian Climate Impacts Scenarios (CCIS) Group Scenario Access Website provides climate scenario outputs that were derived from different GCMs and emission scenarios (Figure 12). These outputs illustrate the likely spatial characteristics of future climate change in Canada and North America (Canadian Climate Impacts Scenarios Group, 2003).

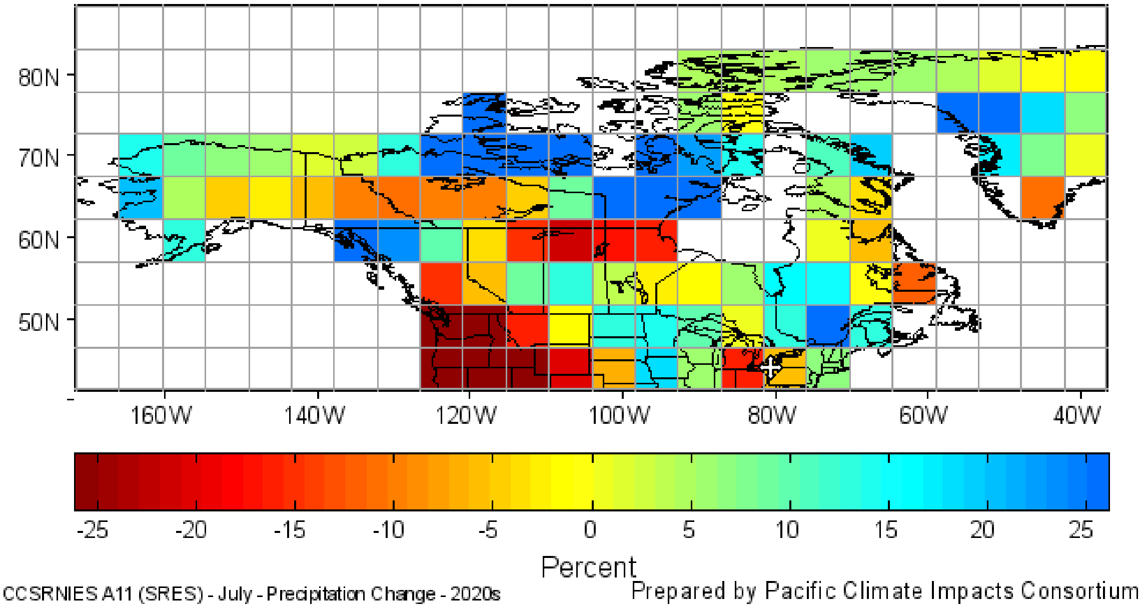


Figure 12. CCSRNIES A11 (SRES) July precipitation change 2020s

Source: CCIS Group Scenario Access Web Page (2004)

There are 63 different GCMs and emission scenarios prepared by the Pacific Climate Impacts Consortium. These GCMs envelope a range of climatology projections. As there are considerable uncertainties in magnitude, timing and spatial details (grid size) among different

GCM forecasts, to understand the potential impact of climate change on a water supply system, different GCMs should be utilized (Weart, 2007). Since the SRES are the more recent scenarios that incorporate future emission projections, they are included in the preliminary selection.

The annual-maximum temperature and annual-precipitation for the 1960-1990 baseline, as well as the annual-maximum temperature change and annual-precipitation change for the 2020s of the SRES GCMs are tabulated in Appendix A. The scenarios associated with the most extreme temperature and precipitation changes are indicated in Figure 13.

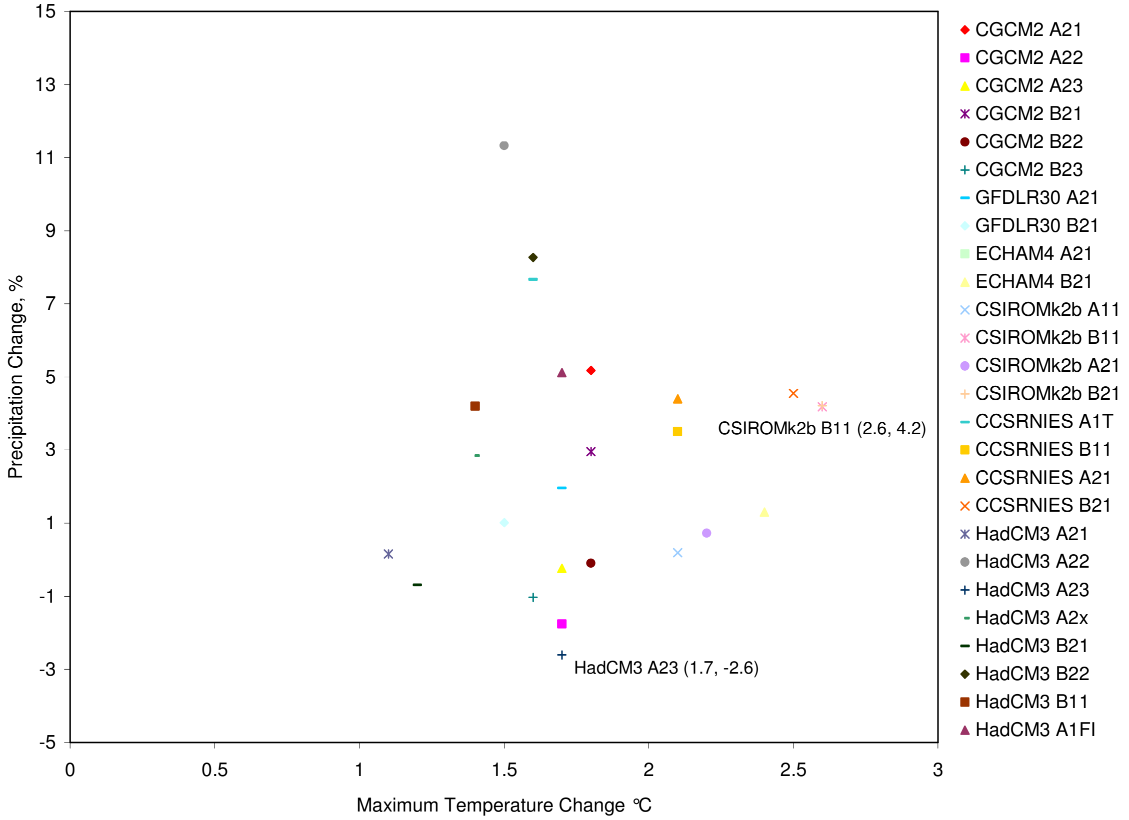


Figure 13. Maximum temperature change versus precipitation change for time slice 2020s scenarios.

HadCM3 A23 projects the largest decrease in precipitation and CSIROMk2b B11 suggests the largest increase in temperature. Two other average case scenarios are also considered. They are CGCM2 A22, and CCSRNIES A21. The monthly absolute differences of temperature and precipitation of the two most extreme scenarios CSIROMK2b B11 and HadCM3 A23 are shown in Figure 14.

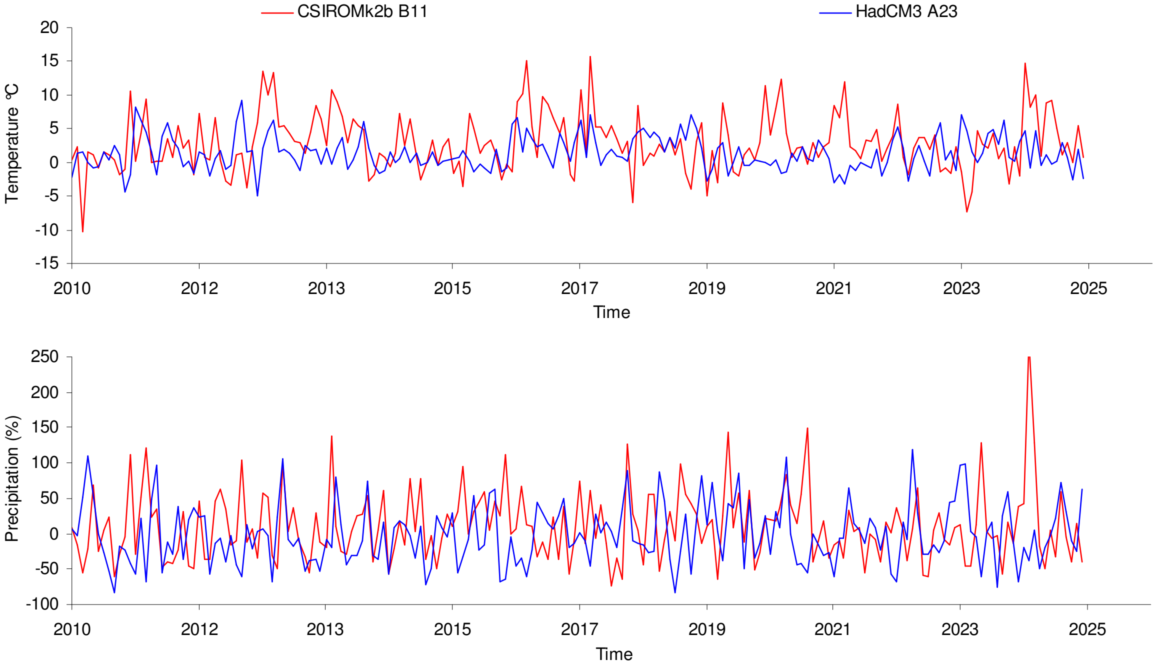


Figure 14. Monthly maximum temperature and monthly precipitation changes projected by scenario CSIROMk2b B11 and HadCM3 A23.

Table 1. Average Difference Relative to Baseline in Maximum Temperature and Precipitation of the Four Selected Scenarios.

GCM Scenario	Average Difference	
	Maximum Temperature ˚C	Precipitation %
HadCM3 A23	1.7	-2.6
CSIROMk2b B11	2.6	4.2
CGCM2 A22	1.7	-1.8
CCSRNIES A21	2.1	4.4

In measuring the estimated contribution of risk to the water supply system in future climate change scenarios, anomalies in temperature and precipitation are incorporated into the stochastic time series climate generation. As the anomaly data values are in monthly bases, the values were added to the monthly average values. For temperature:

$$T_{i,j} = P_{i,j} + R_{i,j} + A_{i,j} \qquad (28)$$

where $T_{i,j}$ is the simulated daily temperature, $P_{i,j}$ is the simulated periodic component, $R_{i,j}$ is the simulated residual, and $A_{i,j}$ is the monthly maximum temperature anomaly value projected by a GCM. For precipitation:

$$P_{i,j} = X_{i,j} \times (1 + B_{i,j}/100) \qquad (29)$$

where $P_{i,j}$ is the simulated daily precipitation, $X_{i,j}$ is the simulated precipitation magnitude and $B_{i,j}$ is the percentage of monthly mean precipitation increase or decrease projected by a GCM. Note that in equation 28 and 29, the uncertainty of future climate change impact is handled parametrically

3.3.4 Population Growth, Demand Management and Cost

Population growth and water demand management are two major factors that define the performance of a water supply system. To meet the future water demands, many municipalities are aware of the need to conserve water and better manage their water supplies. Therefore, this study estimates the impacts of different population growth rate and demand management programs on future residential water demand.

3.3.5 Water Demand

Many studies report the variation of water demand is weather related (Chen et al., 2005). Research has been conducted to capture the nonlinear relationships between water demand and other exogenous variables. However, the randomly fluctuating daily water demand is also influenced by local behaviour and regulations. As such, the risks and uncertainty of water consumption related to climate change are dependent on the local climatic features (Downing et al., 2003). With a changing climate and increase of population, water demand may become more variable.

3.3.6 Prediction Model Type Selection

To develop a model that best describes the observed water demand pattern, a preliminary model was developed using linear regression and autoregressive method. The linear regression model was developed by using the forward fitting method and has a coefficient of determination R^2 of 0.22 which indicates poor prediction accuracy. The seasonal autoregressive time series is stochastic and does not represent the data well.

In a few recent studies, it was found that the ANN models outperformed traditional modelling methods, in particular in predicting complex functions (Bowden et al., 2005). Therefore, in this study the ANN model was selected to develop a deterministic daily demand prediction model. The Excel add-in program, Palisade NeuralTools © 2007 was chosen for such purpose.

3.3.7 Artificial Neural Network Training

Like other data-driven based models, such as a linear regression model, an ANN model deciphers the relationship found between the input and output data. Just as the coefficients in a regression equation need to be estimated, the interconnecting neurons in the neural networks need to be trained (Solomatine, 2002) and thus learn based on available system input and output data.

By providing representative data to the training algorithms of the neural network, the pattern in the data will be learned (StatSoft, 2003). The network training process involves three major steps: data selection, input variable selection, and best net selection. Details of these steps are discussed in the following sub-sections.

3.3.7.1 Data Selection

Since we are most interested in the extreme demand, it is more important to focus on the training of the performance of the neural network in predicting the extreme demands. To screen a data set that is of most interest, and therefore representative, the data set is divided into two subsets delineated by a threshold temperature.

3.3.7.2 Input Variable Selection

Selection of appropriate input variables is crucial to the design of a neural network. Before starting the use of neural networks, prescreening is required to determine the set of most representative input variables. A combination of expert knowledge of the problem domain and statistical tests were used to select the variables (StatSoft, 2003).

3.3.7.3 Best Net Selection

After the input variables are identified, a number of steps are required in determining the best network design. First, an initial network configuration is selected. The typical initial setting would be a network with one hidden layer and hidden nodes set to half as many as the number of inputs. Next, different network configurations are evaluated. Depending on the nature of the dataset, networks with different number of hidden layers and hidden nodes would have different prediction abilities. In evaluating each of these configurations, to avoid convergence to a local minimum, a number of experiments are required. The configuration that has the best prediction ability would be the best network design.

In assessing the prediction ability of the neural network, the model is tested by a test set. Ideally, the test set should be a set independent from the train set and should only be used once. However, we usually have less data than we would desire. To accommodate, a subset randomly sampled from the original dataset can be used as the test set. With the use of resamplings, the results would be more reliable (StatSoft, 2003).

Chapter 4
Case Study Application

4.1 Study Area

The Village of Ayr is a rural farming community located within the Township of North Dumfries in the Region of Waterloo, Ontario, Canada. Land use in the community is primarily agricultural with some residential. The Village of Ayr covers an area of approximately 2.5 kilometers square and has a population of 4500 as of 2006 (Figure 15 to Figure 17). Situated approximately two kilometers south of a major highway (Highway 401), Ayr is growing into the suburban center within the Township (Region of Waterloo, 2001).

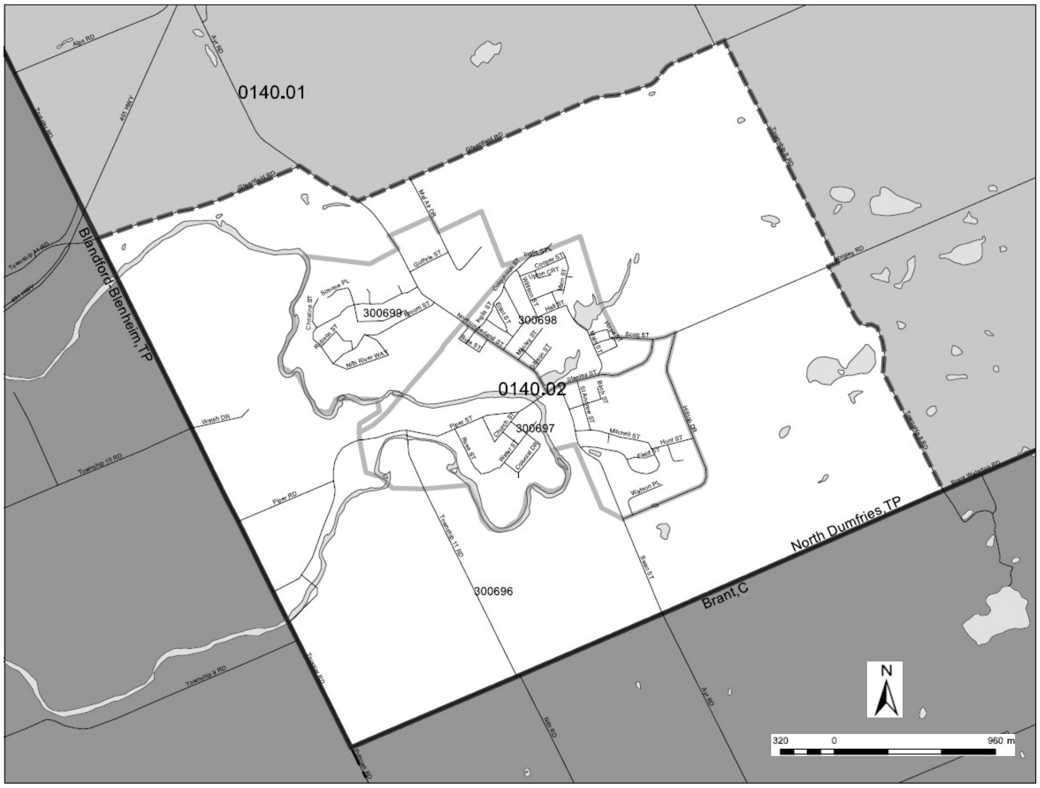


Figure 15. The village of Ayr (2002 Census)

Figure 16. Area municipalities and rural municipal

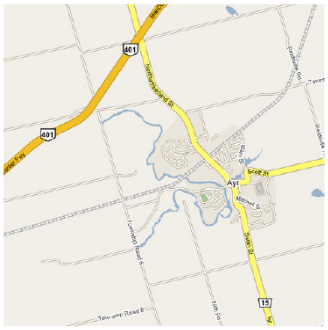


Figure 17. Aerial photo of Ayr

(Source: http://www.region.waterloo.on.ca/web/region.nsf/DocID/99C287F72ABA2D8685256AF700553208?OpenDocument#)

Ayr's water supply comes exclusively from groundwater. The water supply system consists of two wells, a treatment facility and an above ground storage tank. Water extracted from the two wells is treated by two filtration components for the removal of iron and is disinfected by the use of hypochlorite. The two wells each can produce up to 2770 m^3/day and the pressure filter components can treat up to 2470 m^3/day in fulfillment of the aesthetic objective for iron of less than 0.3 mg/L. The two wells can be operated in parallel or alternate to meet the water demand (Regional Municipality of Water Services, 2003).

Ayr's water supply system is owned and operated by the Region of Waterloo. As documented in the 2006 Water and Wastewater Monitoring Report, the 2005 daily average water use was 1160 m^3/day and the maximum day water use during the May-September peak demand period was recorded as 4100 m^3/day.

In recent years, the Ayr water supply system has operated at its design capacity and during hot and dry days has exceeded its allowable maximum daily instantaneous taking rate. Therefore, the Region has implemented and considered a number of alternative management options.

Several assumptions on the water savings from water use restrictions and conservation programs and the population growth rate of Ayr are made. These assumptions are combined in different ways to create an ensemble of scenarios for the studied time horizon in the study.

In this case study, when the simulated daily water demand exceeds the system capacity (2470 m^3), the system is considered to have entered the failure state. In reality some storage would mitigate some failure events. However, for simplicity, it is assumed that there is no storage in the simulated supply system.

4.2 Available Data

In order to assess risks and provide projections of future system performance, the construction of a model is required. To build a representative model, it is necessary to collect a large quantity of valid and high-quality data. Data collected for this study include climate data, water demand records, water sampling records, and water conservation programs and system expansion cost-figures acquired from the Region of Waterloo Water Services Office. Samples of the collected raw data are included in Appendix A.

Climate data were downloaded from the Environment Canada climate service's website. Daily weather records consist of daily high, average, and low temperature and precipitation for the period January 1, 2000 to December 30, 2006 recorded at the Roseville weather station, which is located at latitude 43° 21' N, longitude 80° 28' W, and has an elevation of 328 m. A separate set of climate data from the University of Waterloo Weather Station was used to in-fill missing data and correct erroneous records found in the Roseville dataset.

The water sampling data include bi-weekly testing results at the raw, treated, and distribution points in the water system. The summary of the results of microbiological, inorganic, and organic parameters concentration showed that iron was the only exceedance. Iron is an aesthetic parameter and the sampling is not frequent enough to provide a complete data set to conduct a representative analysis on Ayr's water supply system water quality. Therefore, in this study, the primary focus of the risk assessment is on water quantity.

4.3 Data Analysis

4.3.1 Temperature

4.3.1.1 Long Term Trends

The annual maximum temperature and annual mean temperature over the seven year period are used to determine if a linear temperature trend exists. The average annual maximum temperature and the average annual mean temperature between 2000 to 2006 are 7.7 °C and 12.6 °C respectively. There is no apparent linear increasing or decreasing trend observed in the available historical temperature data (see Figure 18).

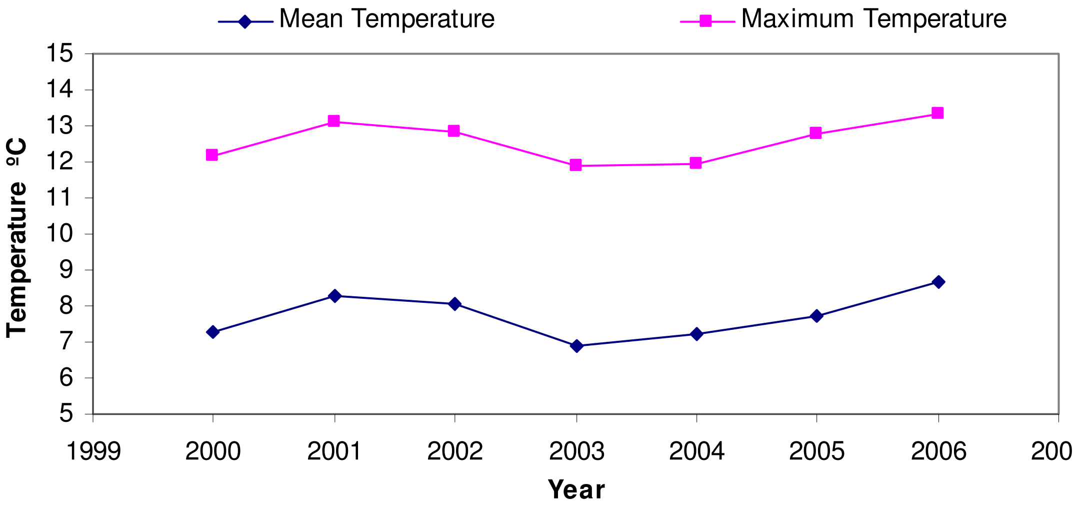


Figure 18. Annual mean and maximum temperature

4.3.1.2 Periodic

The correlation coefficient, R^2, indicates that the Fourier series with one harmonic is sufficient in describing the seasonal pattern in the data. The general Fourier model with one harmonic is given as:

$$f(t) = a_0 + a_1\cos(t \times w) + b_1\sin(t \times w) \qquad (30)$$

where the coefficients (with 95% confidence bounds) values are $a_0 = 12.58$ (12.39, 12.77), $a_1 = -13.65$ (-13.97, -13.33), $b_1 = -5.139$ (-5.659, -4.619), $w = 0.0172$ (0.01717, 0.01722), and t is time from 1 to 2555 day. The coefficients a_0 represents the overall average temperature, a_1 and b_1 represent the amplitude deviation from a_0 and *w* represents the width of the period.

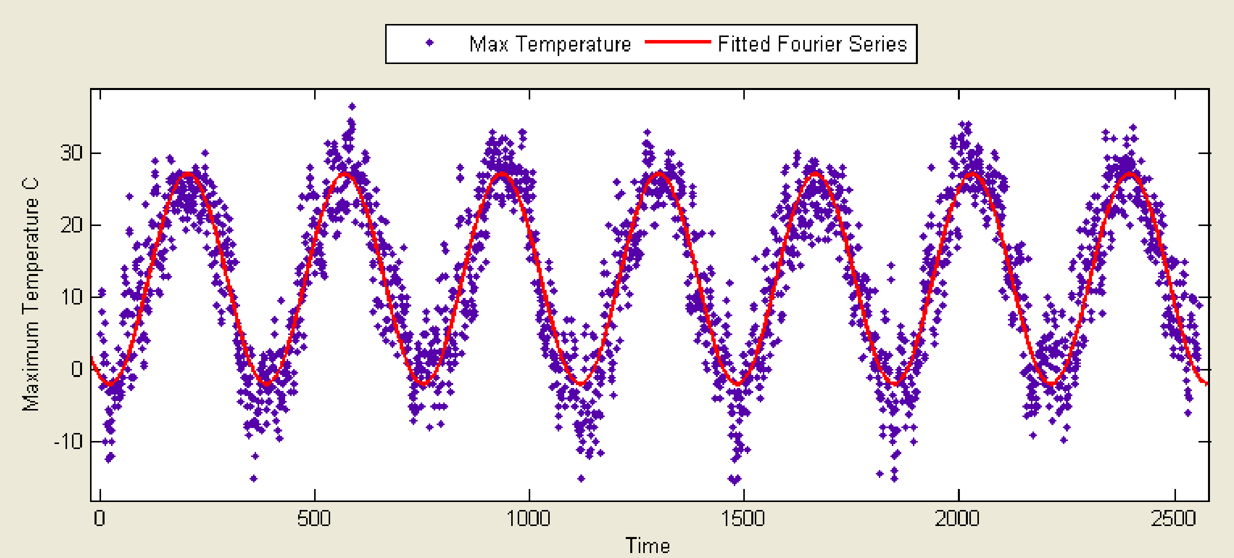


Figure 19. Maximum temperature data fitted using Matlab Curve Fitting Tool

Table 2 shows the first ten days of the cycle component of the temperature generated from the fitted Fourier series (second last column in Table 2). Residuals were calculated by subtracting the Fourier series data from the actual temperature data. The calculated residuals are inputs of the seasonal autoregressive model described in the following section.

Table 2. Fourier Series Temperature Smoothing

		Fourier Series						
Date	Recorded Maximum Temperature, X_i	t	a0+dT$_{Climate Change}$	a1*cos(t*w)	b1*sin(t*w)	Without Climate Change Factor P_{ij}=x(t)	With Climate Change P_{ij}=x(t)	Residual, R
01-Jan-00	5	1	12.58	-14	-0.1	-1.2	-1.16	6.16
02-Jan-00	11	2	12.58	-14	-0.2	-1.2	-1.24	12.24
03-Jan-00	10.5	3	12.58	-14	-0.3	-1.3	-1.32	11.82
04-Jan-00	8	4	12.58	-14	-0.4	-1.4	-1.39	9.39
05-Jan-00	-2.5	5	12.58	-14	-0.4	-1.5	-1.46	-1.04
06-Jan-00	1	6	12.58	-14	-0.5	-1.5	-1.53	2.53
07-Jan-00	-1	7	12.58	-14	-0.6	-1.6	-1.59	0.59
08-Jan-00	4	8	12.58	-14	-0.7	-1.6	-1.65	5.65
09-Jan-00	2	9	12.58	-13	-0.8	-1.7	-1.70	3.70
10-Jan-00	6.5	10	12.58	-13	-0.9	-1.7	-1.75	8.25

4.3.1.3 Time Series Temperature Simulation

The autoregressive model set up in Excel spreadsheet is as shown in Table 3. The column headings are labeled with the same conventions as in equation (27) under section 3.3.1.3. A randomly selected value from the last recorded values was used as the starting value of the simulation and is highlighted in the table. Figure 20 shows the seven years of actual daily temperature data and the first four years of simulated temperature data. It shows that the simulated value follows the general trends as shown in the actual data.

Table 3. Stochastic Time Series Temperature Simulation

Julian Day, j	Original Data Residual, Ri,j							Simulation Date (i,j)	Autoregressive Model							
															$T_{i,j} = P_{i,j} + R_{i,j}$	
	2000 (i=1)	2001 (i=2)	2002 (i=3)	2003 (i=4)	2004 (i=5)	2005 (i=6)	2006 (i=7)		$\overline{R}_j$	r_j	S_j	Rand()	$t_{i,j}$	$R_{i,j}$	With Climate Change Factor	Without Climate Change Factor
1	6.2	-5	-3.8	-0.3	3.1	1.2	3.2	01-Jan-06	0.7	0.040	4	0.894	1.25	-4	-0.47	-5.15
2	12.2	-4.2	-1.7	-1.8	8.7	8.3	2.8	02-Jan-06	3.5	0.880	6	0.698	0.52	-2	1.88	-2.80
3	11.8	-3.1	-0.7	0.3	13.3	3.4	4.3	03-Jan-06	4.2	0.893	6	0.766	0.73	2	5.17	0.49
4	9.4	-0.6	0.9	-0.1	2.4	2.9	5.9	04-Jan-06	3.0	0.686	4	0.061	-1.55	-2	1.32	-3.36
5	-1.0	1.5	3.0	-1.5	-1.6	-3.0	5.5	05-Jan-06	0.4	0.057	3	0.868	1.12	4	6.77	2.09
6	2.5	-1.4	1.6	-2.0	-4.5	-0.4	-0.5	06-Jan-06	-0.7	0.251	2	0.813	0.89	2	5.08	0.40
7	0.6	0.6	-3.9	3.6	-7.4	-0.9	0.6	07-Jan-06	-1.0	0.326	4	0.563	0.16	1	3.99	-0.69
8	5.6	-6.8	2.7	5.7	-3.4	1.2	2.7	08-Jan-06	1.1	0.417	5	0.498	-0.01	2	5.10	0.42
9	3.7	-2.8	4.7	4.7	-13.3	3.7	3.2	09-Jan-06	0.6	0.716	7	0.324	-0.46	-1	2.43	-2.25
10	8.2	-0.2	5.3	-3.2	-4.3	1.3	4.8	10-Jan-06	1.7	0.599	5	0.393	-0.27	0	3.15	-1.53

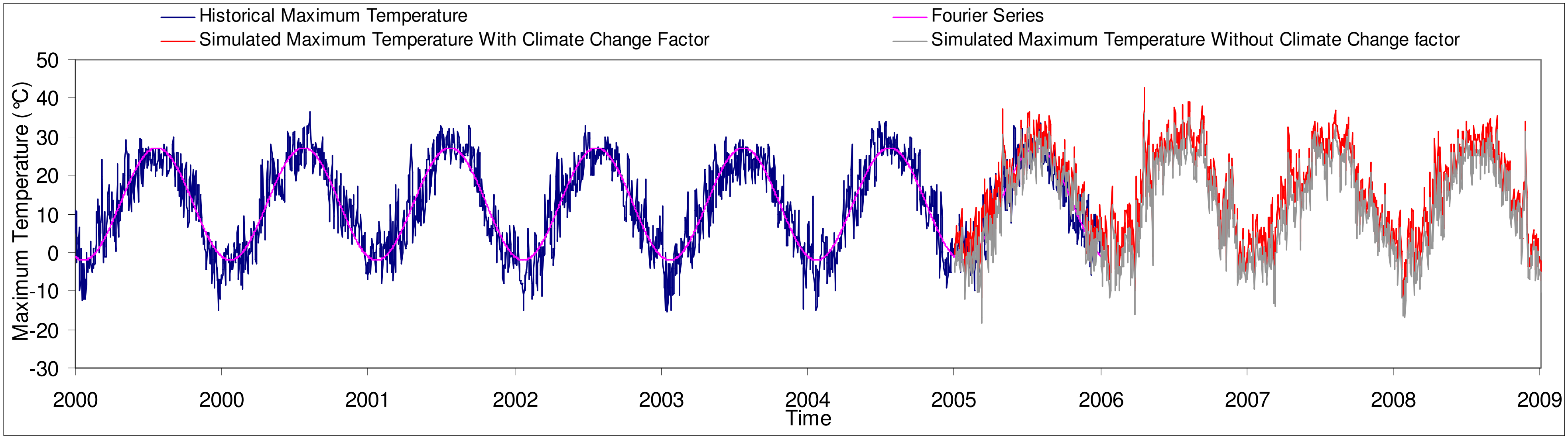


Figure 20. Simulated highest maximum daily temperature with and without climate change factor

4.3.2 Precipitation

The annual total precipitation and maximum day precipitation of Ayr over the seven year period are plotted in Figure 21. The overall averages of annual total precipitation and maximum day precipitation between 2000 to 2006 are 957.8 mm and 51.3 mm respectively. As shown, there is no apparent linear increasing or decreasing trend observed in the available historical precipitation data.

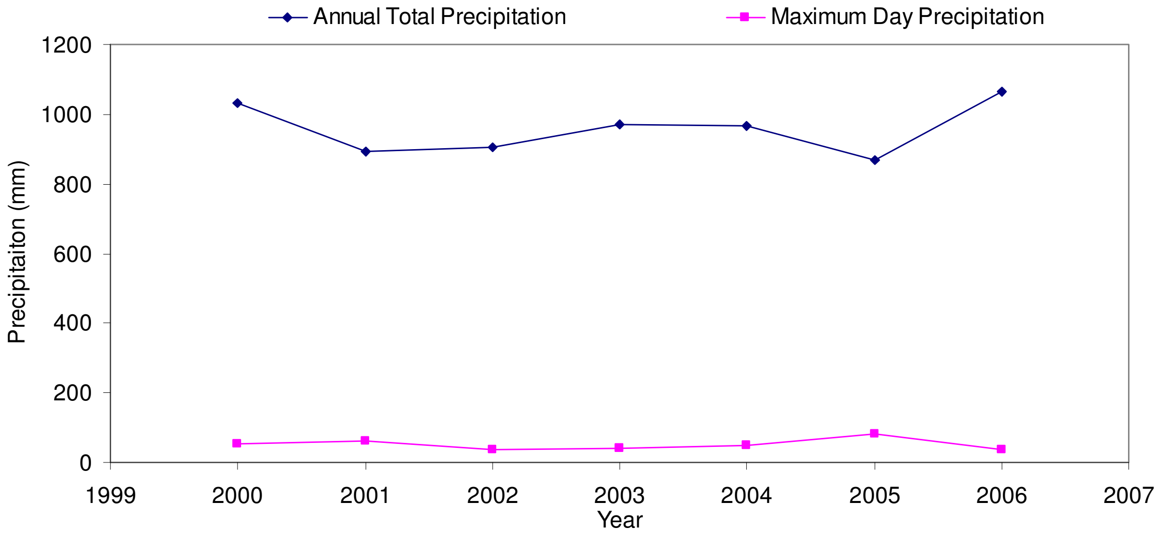


Figure 21. Annual mean and maximum precipitation

The magnitude of the precipitation appears to follow the exponential distribution and was fitted to the corresponding distribution using the software program Bestfit. The fitted distribution has parameters μ=0.192, β=7.017, A-D statistic of 6.00. There is no one simple statistical test to validate the theoretical properties of a point process, therefore the adequacy of the Poisson process is difficult to evaluate. Hence, most time series analysis are empirical. One of the sensible methods is to verify if the properties observed in the input data are preserved in the simulated process (Pourahmadi, 2001). Daily precipitation magnitude is highly variable. Therefore, for model validation, the observed annual total precipitation is compared with the results of the fitted distributions. The observed frequencies and the corresponding annual total precipitation simulated by the fitted Poisson distribution are compared in Table 4 and Table 5, which illustrate that the properties observed in the data are preserved in the simulated data.

Table 4. A Summary of Recorded Precipitation Data

Year	no. of days with rain	Probability of having rain	Total Precipitation (mm)
2000	140	0.384	1032
2001	127	0.348	893
2002	127	0.348	906
2003	126	0.345	972
2004	149	0.408	967
2005	115	0.315	869
2006	145	0.397	1065
Total	929	0.364	6704
Average	133	0.364	958

Table 5. Summary of an Example of Simulated Time Series Precipitation

Year	no. of days with rain	Probability of having rain	Total Precipitation (mm)
1	146	0.400	780
2	134	0.367	981
3	101	0.277	728
4	118	0.323	805
5	130	0.356	1022
6	153	0.419	949
7	130	0.356	900
Total	912	0.357	6165
Average	130	0.357	881

A second model validation, the adequacy of the point process models is evaluated. As listed in Table 4, the probability of having precipitation for any day ranges between 0.315 to 0.408, and has an overall average of 0.364. Therefore, to allow simple comparison, the interarrival times between precipitation events were simulated for a duration of seven years (2557 days) with λ set to 0.364. In addition to temporal comparison, the duration between precipitation events of the simulated and actual data are also found to be similar (Figure 22).

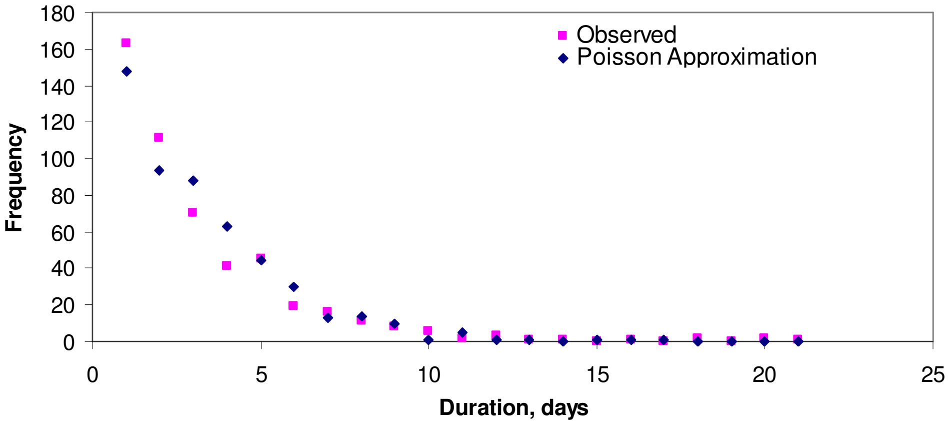
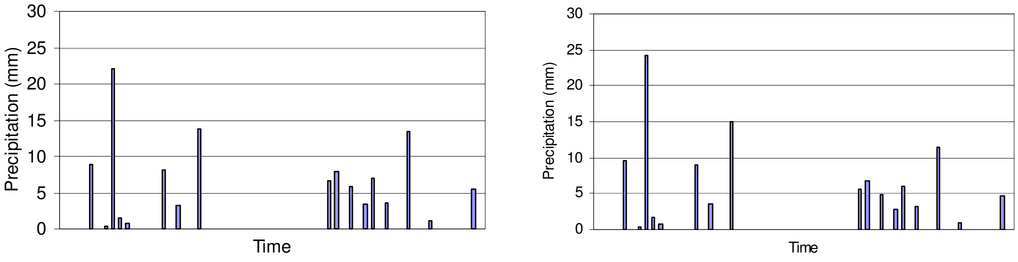


Figure 22. Comparison of Observed Frequency and Poisson Approximation with λ = 0.364.

4.3.2.1 Precipitation Changes

Garbrech et al. (2002) identified that there is a recent change in seasonal pattern of precipitation normals. Changes of precipitation pattern involves changes in both magnitude and occurrence rate. In a GCM, deviations of monthly mean precipitation are projected. There are two ways in representing these precipitation changes in simulation.

One way is to represent these changes by adjusting the simulated precipitation magnitude. To simulate this effect, the time series precipitation is first generated using the process described in section 3.3.2 (see left section of upper Table 6). The time series data are then scaled by the monthly average changes projected by a GCM (columns 3 to 5 of the bottom half of Table 6). In this example, the GCM projects an 8% increase of precipitation for March 2006. Therefore, on March 10, 2006, the simulated precipitation with GCM effect is equal to 12.43 mm x 1.08 = 13.46 mm. Figure 23 illustrate the changes.



Original Magnitude scaled

Figure 23. Illustration of scaled precipitation magnitude

Another way to reflect a change of precipitation pattern is by converting the changes of magnitude into changes of event arrival rate. To simulate this effect, the time series precipitation is first generated using a process similar to that previously described but with λ varying monthly. These λs are obtained by scaling the historical λ to the GCM projected monthly mean precipitation deviations (see right section of upper Table 6). As the precipitation pattern generated by using this process would be different from that solely with magnitude scaled, to introduce some consistencies, the precipitation magnitude is post processed. In post processing, the total precipitation volume in time horizon of interest generated by frequency change is adjusted such that it equals the scaled magnitudes (see Table 6). Figure 24 illustrates the time series precipitation generated using the three processes: original, the original with scaled magnitude, and varying λs with post processing.

Table 6. Stochastic Precipitation Simulation

	Constant λ			Changing λ		
Random Number **U**	Time between (i-1)th and ith event **X i**	Event time **t**	Event Date	Time between (i-1)th and ith event **X i**	Event time **t**	Event Date
0.834	7	68	10/03/2006	6	65	07/03/2006
0.425	1	69	11/03/2006	1	66	08/03/2006
0.324	2	71	13/03/2006	2	68	10/03/2006
0.047	3	74	16/03/2006	3	71	13/03/2006
0.312	8	82	24/03/2006	8	79	21/03/2006
0.151	3	85	27/03/2006	3	82	24/03/2006

Simulation Outputs							
		Constant λ			Changing λ		
Time	p=rand()	Precipitation >0 (Y/N)	Precipitation (mm) without Climate Change Effects **$F^{-1}(p)$**	Precipitation (mm) with GCM scaled Magnitude **$F^{-1}(p)$ × GCM Data**	Precipitation >0 (Y/N)	Precipitation (mm) with change of frequency **$F^{-1}(p)$**	Scaled Precipitation (mm) with change of frequency and magnitude to match total volume **$F^{-1}(p)$ × k**
07/03/2006	0.325	0	0.00	0.00	1	2.95	2.98
08/03/2006	0.438	0	0.00	0.00	1	4.23	4.29
09/03/2006	0.394	0	0.00	0.00	0	0.00	0.00
10/03/2006	0.825	1	12.43	13.46	1	12.43	12.59
11/03/2006	0.071	1	0.71	0.77	0	0.00	0.00
12/03/2006	0.401	0	0.00	0.00	0	0.00	0.00
13/03/2006	0.143	1	1.28	1.39	1	1.28	1.30
14/03/2006	0.907	0	0.00	0.00	0	0.00	0.00

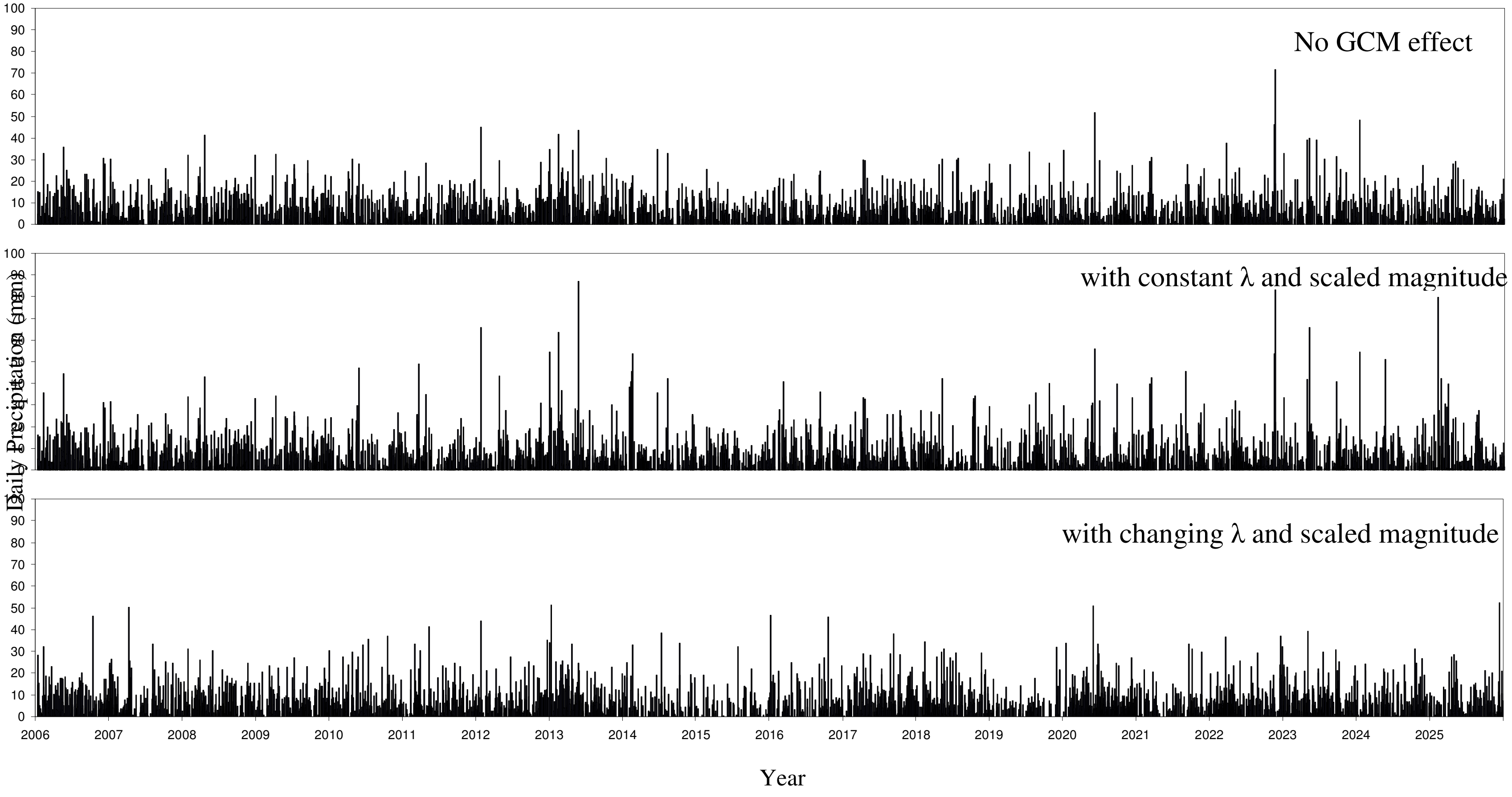


Figure 24. Example of Stochastic Precipitation generated using Poisson Process with a constant λ and changing λ

4.3.3 GCM Base Line Testing

4.3.3.1 Temperature

To see if the GCM baseline and the simulated temperature based upon records are statistically different, the one-way Analysis of Variance Analysis (ANOVA) was performed to test the null hypothesis (H_0: $\sigma_1^2 = \sigma_2^2$). Table 7 is a summary of the ANOVA.

Table 7. ANOVA Table of Simulated Temperature Data Versus GCM Scenario Baseline Temperature Data

ANOVA Summary	
Total Sample Size	1440
Grand Mean	12.33
Pooled Std Dev	11.12
Pooled Variance	123.65
Number of Samples	2
Confidence Level	95.00%

ANOVA Sample Stats	Temperature GCM Baseline	Temperature Simulated based on recorded temperature
Sample Size	720	720
Sample Mean	12.03	12.64
Sample Std Dev	11.78	10.42
Sample Variance	138.76	108.55
Pooling Weight	0.5000	0.5000

One Way ANOVA Table	Sum of Squares	Degrees of Freedom	Mean Squares	F-Ratio	p-Value
Between Variation	137.09	1	137.09	1.11	0.2926
Within Variation	177813.95	1438	123.65		
Total Variation	177951.03	1439			

Since F=1.11 does not exceed the critical F ($F_{0.05(720,720)}$= 1.38), the null hypothesis (H_0: $\sigma_1^2 = \sigma_2^2$) cannot be rejected. As well since the p-value is greater than 0.05, there is insufficient evidence against the null hypothesis. Thus, scaling is not required to adjust the GCMs monthly temperature anomaly data for the use of simulation. The data can be added to the simulated temperature data to mimic the possible raising or lowering of temperature predicted by the GCMs.

4.3.4 Artificial Neural Network Input Variable Selection

The ANN model was selected to develop a deterministic daily demand prediction model. A set of 24 possible input variables was included in the initial prescreening. After different combinations of variables were tested, sensitivity analysis was also conducted to determine the relative importance of variables (StatSoft Inc., 2003). Screening experiments were conducted in the described fashion to iterate through the possible combination of variables. The experiment settings and description are defined in Table 8. To avoid network training convergence to locate a poor local minimum, 12 trials were conducted on each experiment configuration. In each experiment a different 20% randomly selected samples were used as the testing set to examine the predicting ability of the neural network. In Table 8, *T(t)* refers to the maximum temperature of current day and *T(t-i)* refers to the maximum temperature of *i* days ago. Similarly, *P(t)* represents the precipitation amount of current day and *P(t-i)* refers to the precipitation *i* days ago. *P(t)>0?, P(t)>5?, P(t)>10?,* and *P(t)>25?* are binary flags indicating if the precipitation amount exceeded 0 mm, 5 mm, 10 mm, and 25 mm respectively. *D(t-1)* is the previous day demand and *Weekend?* is a binary flag indicating if the current day is in a weekend. The Root Mean Square Error and the percentage of bad predictions for the training and testing sets are included in Table 9. Detailed results are included in Appendix B.

Table 8. Definition of Experiments

Experiment no.	Input Variables
1	T(t), T(t-1), T(t-2), T(t-3), T(t-4), T(t-5), T(t-6), T(t-7), P(t), P(t-1), P(t-2), P(t-3), P(t-4), P(t-5), P(t-6), P(t-7), P(t)>0?, P(t)>5?, P(t)>10?, P(t)>25?, D(t-1), Day of Week, Weekend?, Random Variable
2	T(t), T(t-1), T(t-2), T(t-3), T(t-4), T(t-5), T(t-6), T(t-7), P(t), P(t-1), P(t-2), P(t-3), P(t-4), P(t-5), P(t-6), P(t-7), P(t)>0?, D(t-1), Day of Week, Weekend?, Random Variable
3	T(t), T(t-1), T(t-2), T(t-3), P(t), P(t-1), P(t-2), P(t-3), P(t)>0?, D(t-1), Random Variable, Day of Week, Weekend?
4	T(t), Average [T(t-1) to T(t-3)], P(t), Sum[P(t-1) to P(t-3)], P(t)>0?, D(t-1), Day of Week, Weekend?

Table 9. Sensitivity Analysis of Inputs Experiment

Experiment Configuration	Training set		Testing set	
	RMSE	% Bad Predictions (20% Tolerance)	RMSE	% Bad Predictions (20% Tolerance)
1	0.0457	11.6%	0.0650	24.6%
2	0.0437	12.6%	0.0676	25.3%
3	0.0459	12.3%	0.0687	25.2%
4	0.0440	11.2%	0.0677	24.9%

During the training section of the ANN, variable screening was conducted to prune the initial set of 25 time series input variables into a final set of eight, while preserving the prediction ability of the network.

The final set of input parameters to the neural network consists the follows: Per Capita Inflated Demand (t-1), Maximum Temperature (t), Average Maximum Temperature (t-1 to t-3), Precipitation (t) >0? (Y/N), Precipitation (t), Total Precipitation (t-1 to t-3), Day of Week (Monday=1), Weekend (Y/N).

4.3.5 Population Growth

To properly approximate the future water demand, two population forecasts were collected. The 2001 Statistics Canada census forecast adopted by the Region in early studies suggested that the village of Ayr's population was expected to reach 5900 by 2025 (ROW, 2001). In the more recent 2006 population projection prepared by the Region of Waterloo Planning Information and Research Section, it was shown that the rate of increase would be more than that previously anticipated (Figure 25).

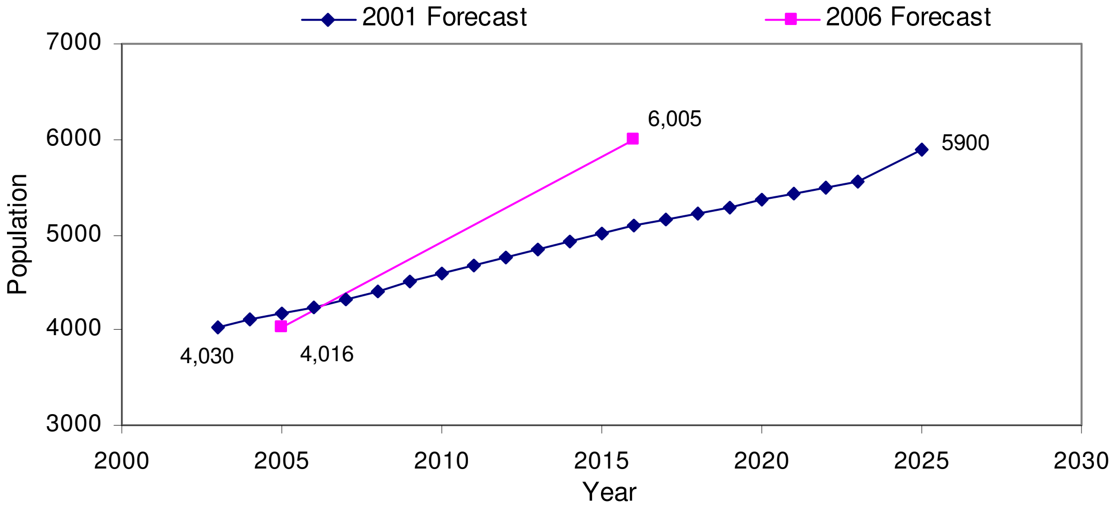


Figure 25. Ayr's Population Forecast

4.3.6 Demand Management and Water Savings

The Region of Waterloo initiated and implemented extensive water efficiency programs to reduce water consumption (ROW, 2006). In 2001, the Toilet Replacement Program (TRP) was implemented in Ayr to alleviate pressure on the water supply system, which was operating close to capacity. The TRP program provided rebates to encourage the replacement of inefficient toilets with 6-liter low flush models. When the TRP ended in

2003, it was estimated over 70% of residential units had toilets replaced with more water efficient models (ROW, 2004). Water savings achieved during the TRP program were estimated using an equation from “Final Report - Ayr Water Efficient Toilet Replacements, June 2003” and estimated water savings are tabulated in Table 10 and were calculated using

4 flushes/person/day x avg. 12 liters/flush saved x 2.926 people per unit x # toilets/ 1000 = TRP water savings (m^3/day) (31)

Table 10. Estimated Water Savings of Ayr’s TRP

Date	Number of Toilets Installed	Water Savings (m^3/day)
01/11/2001	22	4
01/01/2002	155	27
01/05/2002	293	51
01/09/2002	359	63
27/02/2003	634	111
31/03/2003	711	125

As part of the Region’s Water Supply Master Plan, the Region also incorporated water efficiency programs including subsidized rain barrel distribution, Outdoor Water Use By-Law, and increasing public awareness of water conservation. Suggested in the Proposed Water Efficiency Master Plan, 2007-2015 prepared by the Region, it was estimated that the Outdoor Water Use By-Law water savings during the Maximum Week Demand is approximately 50 Liters/day per capita during the months June, July, and August. An additional of 5 Liter per capita per day was estimated to be achieved via the general education program. The water consumption reduction efforts were evident by a decreasing wastewater flow trend in the wastewater monitor program (ROW, 2003).

4.3.6.1 Costs

In accordance to cost figures included in the Water Efficient Management Programs (WEMPs) Master Plan, each WEMP has a different associated cost. Each cost includes the material and operating costs for executing the program for a year. The costs were estimated as a lump sum for the entire region. In Table 11, the costs were proportionally adjusted to reflect the share that the Ayr population would bear.

Table 11. Summary of Projected Program Costs and Water Savings from 2006 Water Efficiency Master Plan Update Appendix A.

WEMPs	Estimated Water Savings	Cost
Ayr's TRP	125 m^3/day	$185,200
Education and Communication Programs	5 Liters/capita/day	($110598)/450000 people x 4300 people =$1056
Outdoor By-Law	50 Liters/day/capita during maximum week demand	($80,000)/450000 people x 4300 people =$764

*The Regional Municipality of Waterloo is responsible for water supply to approximately 450,000 people in the Cities of Cambridge, Kitchener and Waterloo.

Cost estimates for Ayr Water Supply System Expansion are provided by the Regional Office. The breakdowns of the expansion are tabulated below.

Table 12. Summary of Ayr Water Supply Expansion Costs and Capacity Increase

Expansion Components	Capacity Increase	Cost
Additional Well Installation	2500 m^3	$250,000
Expansion Contract		$5725,000
Consulting Costs		$500,000
Total		$6,475,000

In accordance with the ROW Water Efficiency Master Plan, it is proposed to continue the implementation of the WEMPs and the charges tabulated should be inflated based on the estimated rate of inflation in the Master Plan, which is 2.5% and is adopted in this study.

4.3.7 Water Demand

The case study area land usage is primarily residential and commercial. Therefore, it is assumed that most of the water demand in the study encompasses domestic water use as described in section 2.2.1.

Six years of daily water consumption records for the period January 1, 2000 to December 31, 2005 were collected from the Region. In accordance with the compliance reports, discharges from the Ayr Water Treatment Plant were consistently exceeding the maximum allowable discharge from June 2001 to January 2002, which was contributed to erroneous pump settings (Figure 26).

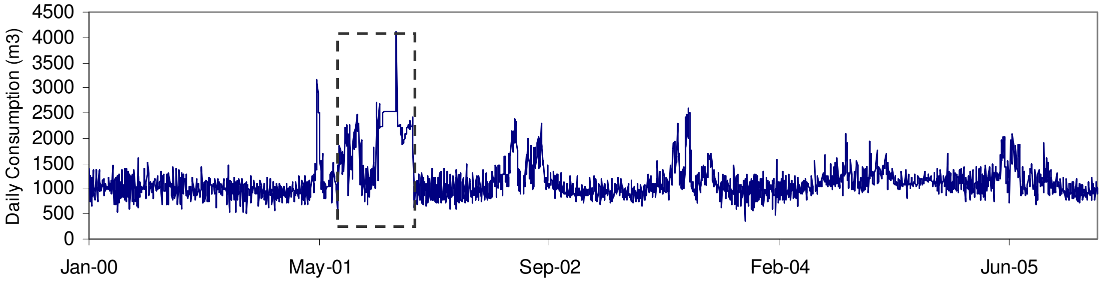


Figure 26. Suspected Erroneous Record in 2000 to 2005 Original Water Demand Data

To understand the relationship between water demands and the exogenous variables, influences of regulations, conservation, and population growth needed to be removed from the daily water demands (Figure 27). Therefore, the daily demand was inflated by the estimated water savings as described in section 4.4.3 to approximate the actual demand if WEMPs were not implemented. The inflated water demand was then divided by the population of the year to determine the per capita water demand. The inflated per capita water demand varies between 106 to 708 L/day with an average of 301L/day, which agrees with the typical domestic water use in Canada which has an average of 638 L/capita/day (MOE, 2005).

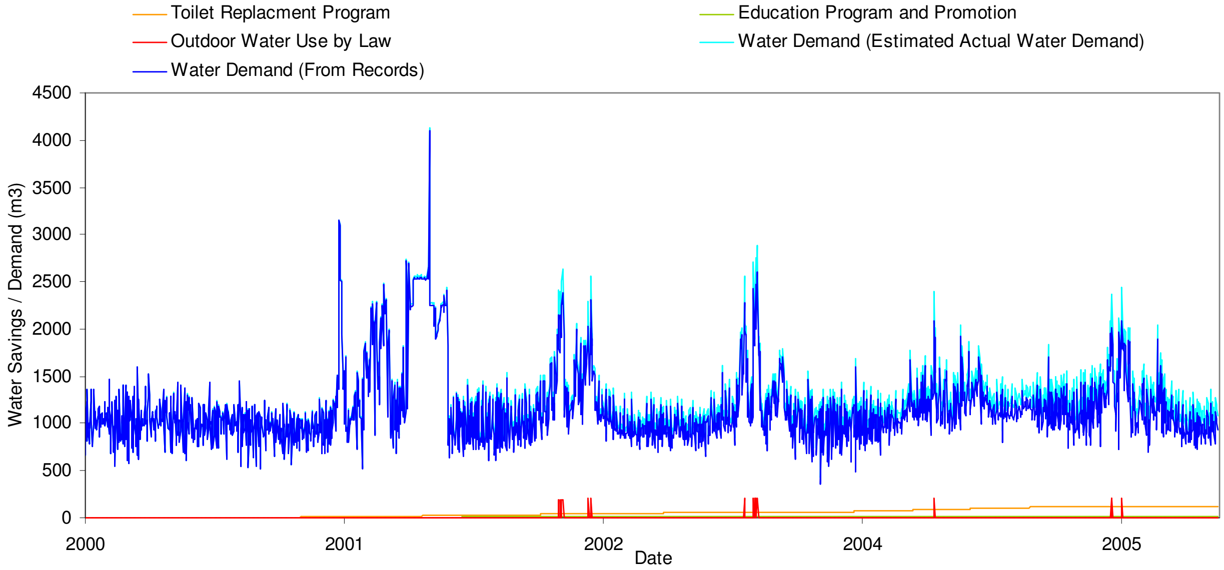


Figure 27. 2000 to 2005 Water Savings and Inflated Water Demand

4.4 The Water Demand Model

Figure 28 is a plot of the observed daily water use, temperature and precipitation data aligned on the same time axis. The water use departs from the base water use (800 m^3/day) most evidently during the warm and dry season (May to August). The plot also indicates that there is a tendency for these data to have water demand double or triple the average water use. On the contrary, cool and wet days show the opposite pattern (with a quarter to a half reduction).

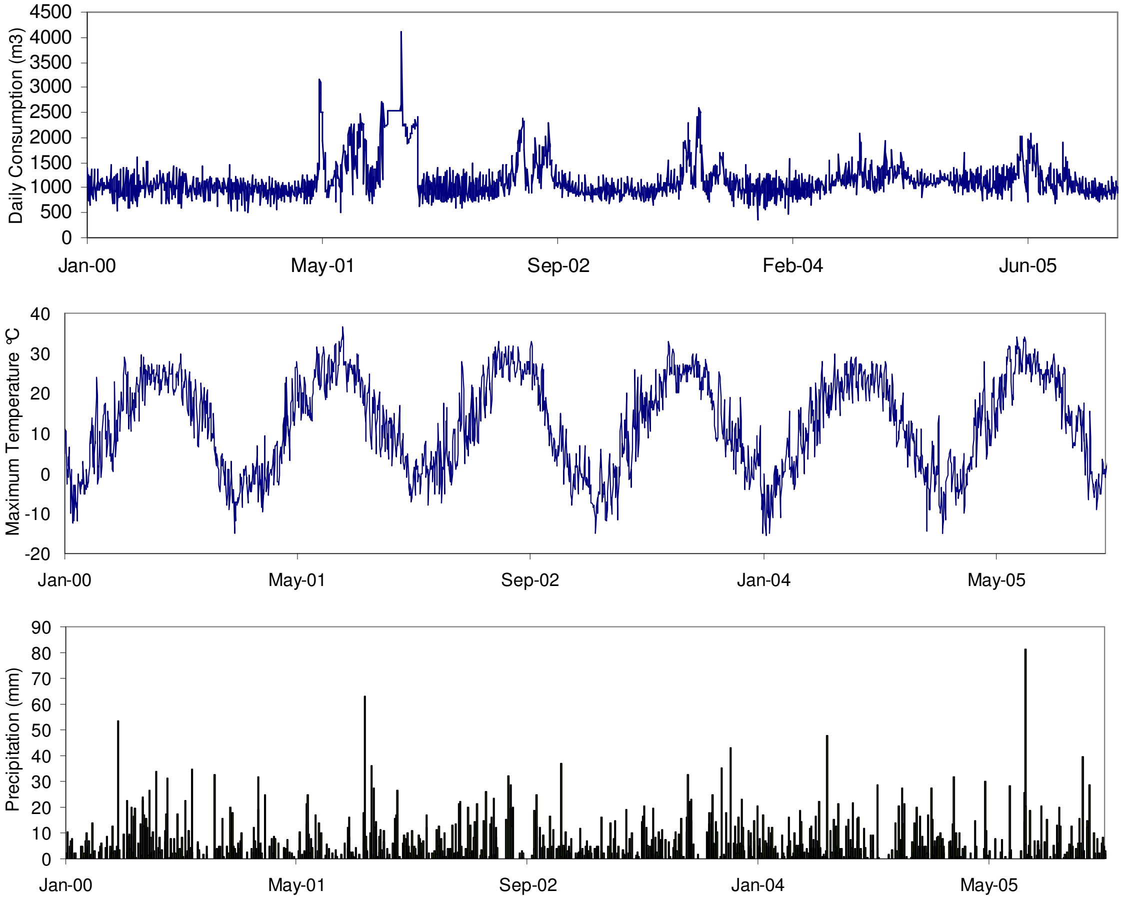


Figure 28. Time Series Plot of Input Parameters

An initial set of testing variables for predicting daily water demand was hypothesized to include the previous day water demand, current day minimum, mean, maximum temperature, current day precipitation, the day of week, and a binary flag which indicates if the current day is in a weekend or not. Maximum temperature and precipitation with n days of lagging where n ranges from one to seven were also included in the set to investigate if past weather conditions have impacts on current water demand. The occurrence of a rainfall exceeding 0, 5, 10, and 25 mm were also included in the testing set for a total of 25 independent parameters.

The days of the week were denoted by integers from one to seven with one representing Mondays and seven representing Sundays. The occurrence of rainfall above a particular amount was represented by a binary series, with one indicating days with rainfall and zero indicating days without rainfall. The Weekend (Y/N) parameter flags Saturdays and Sundays with ones and the rest of the days with zeros. For preliminary investigation, the cross-correlation coefficients of water demand and the above-noted variables were calculated (Table 13).

As shown in Table 13, the previous day demand is strongly correlated to the current day demand with a positive correlation coefficient of 0.589. The current day minimum, mean, and maximum temperatures are also correlated to the current day demand where maximum temperature at time t is the most correlated and has a correlation of 0.431. In the set of lagged maximum temperature, there is an almost linear decreasing trend in correlation as lagging duration increases. Similar to temperature, for precipitation, the current day precipitation has the strongest relation and a diminishing correlation was observed. The correlation value of -0.110 means that water use decreases with an increase of rainfall.

Table 13. Cross-correlation coefficients of water demands and Climatic Variables

Variable	Per Capita Inflated Water Demand (t)
Per Capita Inflated Water Demand (t-1)	0.559
Minimum Temperature (t)	0.343
Mean Temperature (t)	0.399
Maximum Temperature (t)	0.431
Maximum Temperature (t-1)	0.415
Maximum Temperature (t-2)	0.404
Maximum Temperature (t-3)	0.396
Maximum Temperature (t-4)	0.387
Maximum Temperature (t-5)	0.380
Maximum Temperature (t-6)	0.372
Maximum Temperature (t-7)	0.373
Precipitation (t)	-0.110
Precipitation (t-1)	-0.108
Precipitation (t-2)	-0.085
Precipitation (t-3)	-0.077
Precipitation (t-4)	-0.056
Precipitation (t-5)	-0.042
Precipitation (t-6)	-0.030
Precipitation (t-7)	-0.056
Precipitation (t) >0? (Y/N)	-0.154
Precipitation (t) >5? (Y/N)	-0.101
Precipitation (t) >10? (Y/N)	-0.071
Precipitation (t) >25? (Y/N)	-0.033
Day of Week (Monday=1)	0.128
Weekend (Y/N)	0.184

However, the occurrence of rainfall appears to be even more significant than the magnitude of the rainfall as shown with a large negative value of -0.154. The day of week also has impacts on daily demand. The value of 0.128 means that water demand increases for the later part of the week. However, this pattern may be contributed by the weekend effects as can be seen from the larger correlation of the binary weekend flag.

There is a close relationship between maximum temperature and water demand. To gain a sense of the type of relationship between daily demand and temperature, trend lines were fitted between the two variables (Figure 29). The fitted functions are linear (orange), exponential (green) and polynomial (red). As indicated by the R^2, the polynomial function has the largest regression coefficient among the fitted functions, which suggests that there is a non-linear relationship between the daily water demand and the maximum temperature.

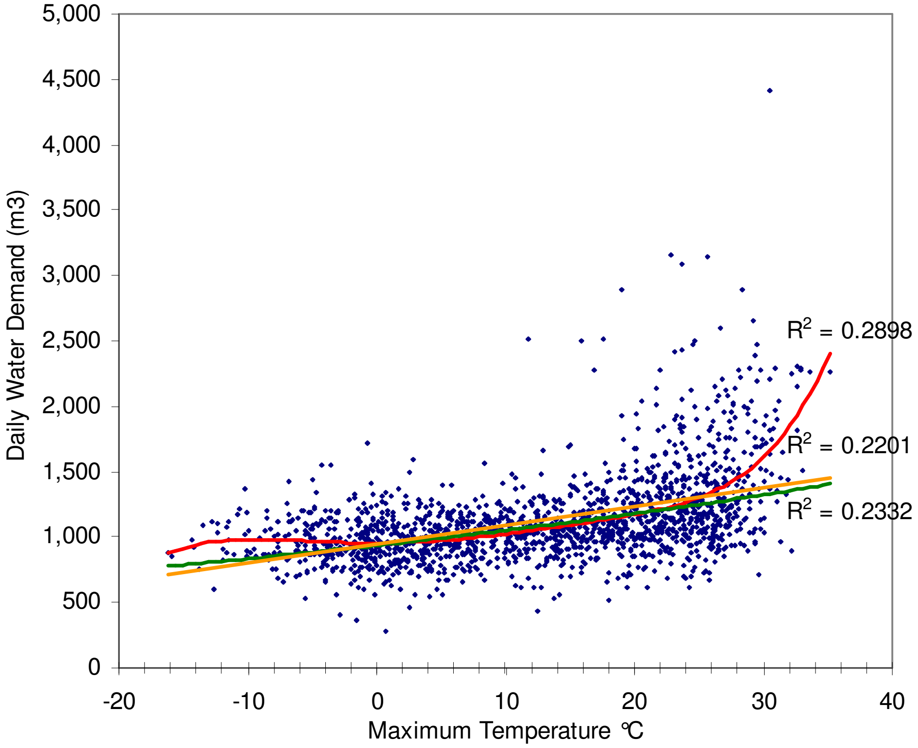


Figure 29. Maximum Temperature versus Water Demand

Akuoko-Asibey et al. (1993) found that if the mean weekly temperatures exceeded 10°C, the municipal water consumption would dramatically increase. It is clear, from Figure 29, a threshold temperature exists in the data. When the maximum temperature gets above around 22°C, the data points become more dispersed. To determine the critical temperature, a simple correlation analysis was performed. Correlations between the per capita demand and the maximum temperature at 22 ± 1°C are calculated. The correlation coefficients confirm the hypothesized critical temperature of 22°C (Table 14).

Table 14. Correlation Coefficients between Maximum Temperature and Per Capita Water Demand

Maximum Temperature	Correlation Coefficients between Maximum Temperature and Per Capita Inflated Water
21°C	0.456
22°C	0.462
23°C	0.456

By using the 22°C cutoff point, the data set is delineated into two data sets. One for warm weather with maximum temperature at or above 22°C and another one for cool weather. The first set consists of 510 days of daily water demand, temperature, rainfall, and data related variables derived from the warm weather 2000, 2002, 2003, 2004, and 2005 data set. The latter set consists of 1347 days of data.

4.5 Simulation Scenarios

Water demand under a shifting climate and an uncertain population growth can be highly variable. An increase of system capacity or a decrease of demand, or both, can decrease the system failure rate. Twenty-six scenarios generated from different combinations of demand management programs, system expansions levels and four Global Climate Model (GCM) scenarios were set up to illustrate the impacts of these three factors on the Reliability, Resiliency, and Vulnerability (RRV) indices. Assumptions were made on the WEMPs implementation and the level of system expansion. It is assumed that there are two levels of WEMPs implementation: normal and intensive, representing 5% and 15% of additional water savings as according to the 2007 Region of Waterloo's estimation. It is also assumed that there are two levels of system expansion. They are 10% and 20% of the proposed expansion capacity, as the preliminary analysis indicates that an expansion of 2500 m^3 is not required for short-term needs. The costs of the WEMPs programs and the system expansion were estimated base upon the total implementation cost of the programs. The scenarios are defined in Table 15.

Table 15. Scenario 1 to 26 Settings

Scenario number	Description
1	Base Case
2	Base Case with no WEMPs implemented
3	Base Case with 5% additional WEMPs savings
4	Base Case with 15% additional WEMPs savings
5	Base Case with 10% additional system capacity
6	Base Case with 20% additional system capacity
7	Had CM3 A23 with base case settings
8	Had CM3 A23 with 5% additional WEMPs savings
9	Had CM3 A23 with 15% additional WEMPs savings
10	Had CM3 A23 with 10% additional system capacity
11	Had CM3 A23 with 20% additional system capacity
12	CSIROMk2b B11 with base case settings
13	CSIROMk2b B11 with 5% additional WEMPs savings
14	CSIROMk2b B11 with 15% additional WEMPs savings
15	CSIROMk2b B11 with 10% additional system capacity
16	CSIROMk2b B11 with 20% additional system capacity
17	CCSRNIES A21 with base case settings
18	CCSRNIES A21 with 5% additional WEMPs savings
19	CCSRNIES A21 with 15% additional WEMPs savings
20	CCSRNIES A21 with 10% additional system capacity
21	CCSRNIES A21 with 20% additional system capacity
22	CGCM2 A22 with base case settings
23	CGCM2 A22 with 5% additional WEMPs savings
24	CGCM2 A22 with 15% additional WEMPs savings
25	CGCM2 A22 with 10% additional system capacity
26	CGCM2 A22 with 20% additional system capacity

The first scenario describes the existing condition of the water supply system, which includes the estimated water savings incurred from the Toilet Replace Program and Outdoor Water Use By-Law. The toilet replace program involves the replacement of older 18-liter toilet with six-liter ultra-low flush toilet. The outdoor water use by-law involves water use restrictions on non-essential residential water uses, such as lawn and garden watering, and car washing. Scenario 2 is a separate scenario in the set that describes the system condition if no WEMPs were implemented. The next four scenarios (3-6) describe the base case settings with two levels of WEMPs implemented and two system capacity expansions. Scenarios 7 to

10, 12 to 16, 17 to 21, and 22 to 25 are parallel to scenario 1 and 3 to 6 with each set of five consisting of different climatic realizations projected by the four selected GCM scenarios (see section 3.3.3). These scenarios were set up to illustrate the possible impact of climate change on the system performance.

4.5.1 Sensitivity Analysis Scenarios

Initially the simulation model was set up to determine the effects of climate change on the case study system using the GCM projections that project deviations of temperature and precipitation magnitudes from the historical norms. However, a recent study led by the Climate Research Division, Environment Canada found that there are changing precipitation patterns. The same study projects that over most regions, the precipitation pattern is likely to be intensified with "less frequent but more intense events, and precipitation extremes are very likely to increase" (Zhang et al., 2007). Therefore, in this study, as a separate but related goal, the effect of a change in precipitation magnitude by means of changing the precipitation occurrence frequency was investigated. For this purpose, a subset of scenarios are selected from the original set of 26. The configurations of this set of scenarios are defined in Table 16.

Table 16. Sensitivity Analysis Scenario to Investigate the Effect of a Change of Frequency of Occurrence of Precipitation

Scenario no.	Description
7a	Had CM3 A23 with base case settings
8a	Had CM3 A23 with 5% additional WEMPs savings
9a	Had CM3 A23 with 15% additional WEMPs savings
10a	Had CM3 A23 with 10% additional system capacity
11a	Had CM3 A23 with 20% additional system capacity
12a	CSIROMk2b B11 with base case settings
13a	CSIROMk2b B11 with 5% additional WEMPs savings
14a	CSIROMk2b B11 with 15% additional WEMPs savings
15a	CSIROMk2b B11 with 10% additional system capacity
16a	CSIROMk2b B11 with 20% additional system capacity

The impact of a higher population growth on the performance of the water supply system is of interest. Therefore, a second set of sensitivity analysis scenarios is set up (Table 17). A third set of scenarios is established to estimate the possible combined effects of climate change and a more rapid growth of population on the supply system (Table 18).

Table 17. Sensitivity Analysis Scenario to Investigate the Effect of Higher Population Growth

Scenario no.	Description
1b	Base Case with higher population projection
3b	Base Case with 5% additional WEMPs savings with higher population projection
4b	Base Case with 15% additional WEMPs savings with higher population projection
5b	Base Case with 10% additional system capacity with higher population projection
6b	Base Case with 20% additional system capacity with higher population projection

Table 18. Sensitivity Analysis Scenario to Investigate the Effect of Climate Change and a More Rapid Population Growth

Scenario no.	Description
7c	Had CM3 A23 with base case settings with higher population projection
8c	Had CM3 A23 with 5% additional WEMPs savings
9c	Had CM3 A23 with 15% additional WEMPs savings
10c	Had CM3 A23 with 10% additional system capacity
11c	Had CM3 A23 with 20% additional system capacity
12c	CSIROMk2b B11 with base case settings
13c	CSIROMk2b B11 with 5% additional WEMPs savings
14c	CSIROMk2b B11 with 15% additional WEMPs savings
15c	CSIROMk2b B11 with 10% additional system capacity
16c	CSIROMk2b B11 with 20% additional system capacity

Chapter 5
Results and Analysis

5.1 Introduction

The three factors, system capacity, water demands, and GCM projections of climate change are combined to produce an ensemble of predictions on extreme events. In each simulation scenario, the performance indices are calculated and compared against the base case. The objective of evaluating the performance indices of these scenarios is twofold. One is to demonstrate the use of the performance indices, together with the capability in capturing the assumptions and uncertainty of the impacts of climate change and human behaviour to the water supply system. The set of results can also be used as a tool to assess the effectiveness of system expansion and water conservation alternatives under different climatic scenarios to ensure that the water supply system operates satisfactorily and ultimately aid the decision maker in selecting the optimal expenditure scheme.

In conducting the simulations, 100 trials were run for each scenario to assure that a representative sample is drawn while considering the constraints of computation time and computer memory. Note that each of the 100 simulation trials represents one random climatic realization of the future and the corresponding water usage response to that particular climatic condition.

To allow parallel comparison, the stochastic climatic realization of a particular simulation trial is kept the same within the set of scenarios subjected to the influence of a particular GCM. For example, the climatic realization of all trial number ones are the same throughout scenario 1 to 6. Plots illustrating an example of these climatic realizations along with the associated simulated water demand are included in Appendix C.

5.2 Result Analysis Approach

In most failure mode or risk analysis studies, the potential failure to a system is first determined and analyzed. A simulation model is then created to mimic the potential failure settings and the Monte Carlo simulation is left to run over a long enough horizon to allow eventual convergence. However, in this study, to account for the stochastic nature of the climate process and to incorporate the GCM time series projection, the simulation is allowed to run for the study time horizon (2006 to 2025) with multiple trials. Because of this nature, there are a few challenges in interpreting the simulation results. The following describes the issues and the approach taken to resolve them.

Too much data

The simulation comprises 26 scenarios with each scenario consisting of 100 trials to distinguish the system performance under a particular climatic scenario. The large quantity of results makes organizing or summarizing all details a challenge. The common approach for such situations is to examine the expected value or the average, such that the general trend can be observed and the overall performance of the system can be measured. However, by solely relying on the use of the average, details may be overlooked and anomalies that may be of interest may be omitted.

Multi-criteria Evaluation

Alternatively the best and worst trial of each scenario can be compared to determine the significance a certain climatic scenario poses on the simulated system. However, there is no one criterion that can be used to identify the best or the worst trial in a scenario. For instance, the worst trial can be defined as the trial that has the highest total number of failure days or with the greatest total severity. Furthermore, because of the nature of the system response, the best scenario does not necessarily have the best performance across all performance criteria. To illustrate, consider the following example.

In Figure 30 (top) plotted the reliability and vulnerability of the 100 trials of scenario 1. The figure indicates that there is only one best trial (in solid circle). This trial has the highest reliability and the lowest vulnerability. However, the figure also indicates that there are two worst trials (in dash circles). The worst trial on the left has a lower reliability but a lower vulnerability as compared to the one on the right. In terms of reliability and resiliency (middle Figure 30), there are also one best trial and two worst trials. However, in the context of resiliency and vulnerability, there are one best and four worst trials (bottom Figure 30).

No one best or worst trial

Under a specific performance criterion, such as the number of failure days, there is usually a best trial and a worst case trial in a scenario. However, as observed in the results, because of the system's responses, in some cases the best or worst case trial is not consistent within the

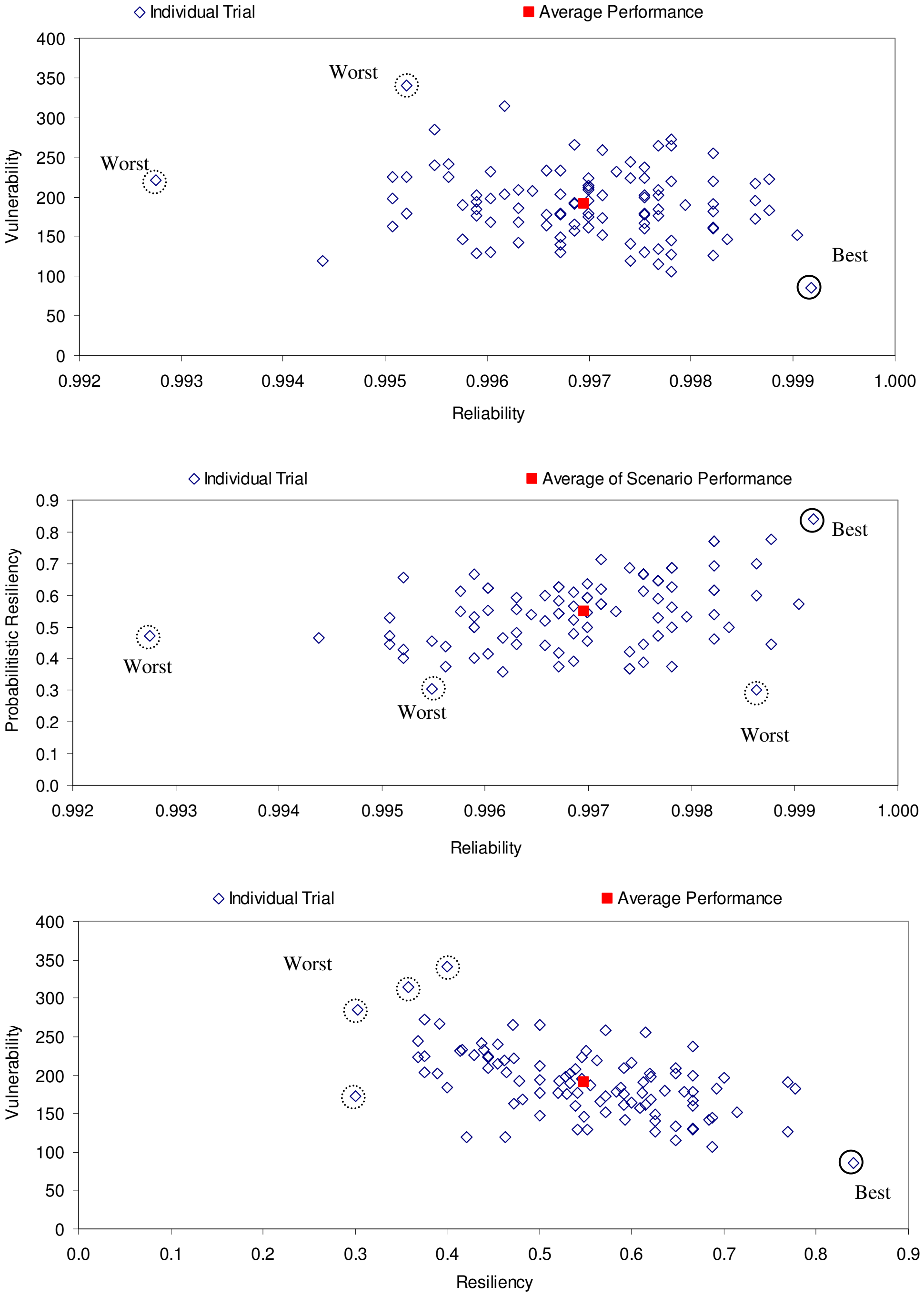


Figure 30. Scenario 1 Results. (Top) Reliability versus Resiliency. (Middle) Reliability versus Vulnerability. (Bottom) Resiliency versus Vulnerability.

set of scenarios under the same climate projection. For example, in scenario 1, the climate realization of trial 87 has the least number of failure days. However, in scenario 2, the climate realizations of trial 4 and 38 have the least number of failure days. A detailed summary table of the best and worst trials of the scenarios are included in Appendix C.

Limitation of Traditional Probabilistic Resiliency Measures

In section 2.6.1.2, the probability based resiliency index ($\gamma_1 = \frac{1}{E[T_F]}$) suggested by Hashimoto et al. is described. There may be a disadvantage in using γ_1, as follows. Consider a system has initial and improved failure states as shown in Figure 31 and Figure 32 respectively.

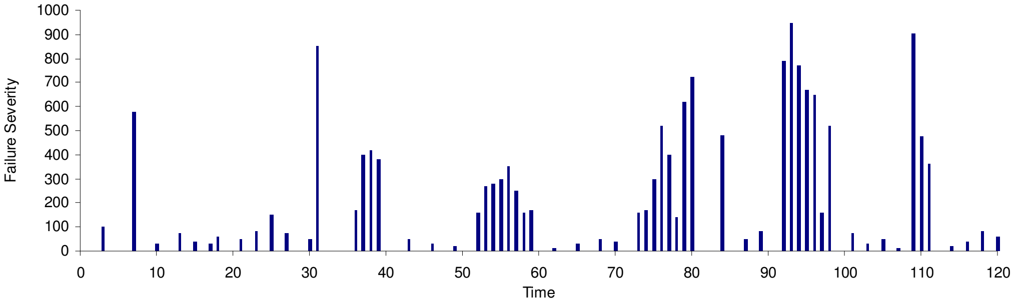


Figure 31. Initial System State of the Example Case.

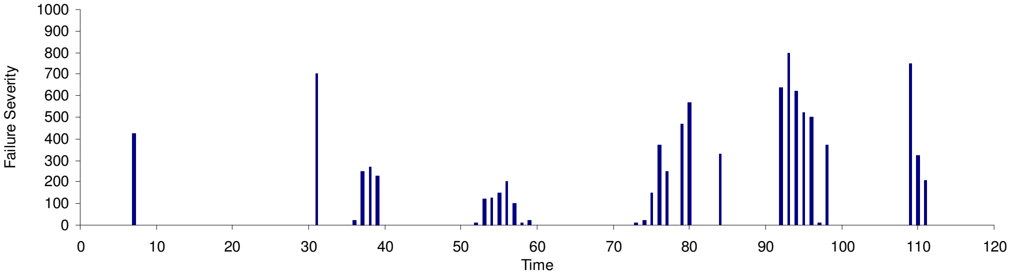


Figure 32. An Illustration of the Increase in Average Duration of Failure $E(T_f)$ with an Improved System.

Initially, the system has 61 days of failure and entered into failure 34 times. After the system is improved, the number of failure days and the number of times the system enters into failure decreased (Table 19).

Table 19. Resiliency indices of example cases

	Initial State	Improved State
No. of failure days	61	24
No. of times the system enters into failure	34	10
Average Duration of failure	1.79	2.40
System resiliency, $\gamma_1 = \frac{1}{E[T_F]}$	0.56	0.42

One would expect system resiliency to improve after an obvious improvement in the system. Instead, the resiliency decreased from 0.56 to 0.42. This was due to longer average failure duration. Looking closely at the system-state figures, a number of small events are mitigated by the improvement made to the system, leaving the improved system with only severe and prolonged failures. These prolonged failures contribute to a larger average time of failure. Because of the formulation of resiliency, $\gamma_1 = \frac{1}{E[T_F]}$ (see section 2.6.1.2), it leads to a smaller resiliency. A smaller resiliency usually implies that if a system is in failure in the current time step, it is less likely to recover in the next time step. However, in the above example, the implication of a smaller resiliency conflicts with the fact that the system has indeed improved, which shows that γ_1 should not be used alone.

The simplified resilience index suggested by Moy et al. (1986) was derived for optimization purposes only and is solely based on the maximum number of consecutive periods of deficit.

Depending on the relative duration of MD to NS, as NS increases, the ratio MD/NS approaches 0 and γ_2 consequently approaches 1. Therefore, for a very long time of interest NS, γ_2 may not be a good indicator of system resiliency. For this reason, γ_2 is not used in this thesis.

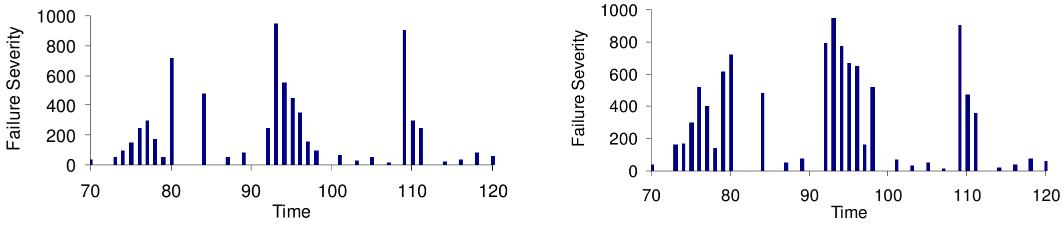
Because of the limitation of the probabilistic resiliency, to avoid possible misleading results, the resiliency index (γ_3) suggested by Burn et al. can be used for evaluation purposes. However, there is one potential draw back to using γ_3. Recall that $\gamma_3 = \dfrac{1}{\left(\dfrac{MD}{NS} NF\right)}$ where MD is the maximum number of consecutive days of failure, NS is the time of interest, and NF is the number of times the system enters a failure. When MD approaches zero, γ_3 approaches infinity. Therefore, a system that is performing well would have a very large γ_3, but a poorly performing system would have a small γ_3. Hence γ_3 can be very different in magnitude, which renders a comparison across all scenarios difficult. Therefore, γ_1 and γ_3 are both employed in the results analysis and used together as a two-tier indicator.

Use of Maximum Vulnerability and Average Vulnerability

In this thesis, the average vulnerability of a failure is calculated as follows:

$$v_3 = \frac{\sum_{t=1}^{n} s_t}{n} \qquad (32)$$

where s_t is the severity of a failure at time t and n is the total duration of the system in failure state. To illustrate the usage difference of ν_1 and ν_3, consider the following example case (Figure 33 and Table 20). The maximum severity of the sojourn and the number of failures are the same in the two systems. System 1 has a vulnerability (ν_1) of 325 and an average vulnerability (ν_3) of 235. System 2 has a vulnerability of 325 and an average vulnerability of 343. Note that system 2's vulnerability (ν_1), which describes the likely most unsatisfactory outcome in a sojourn, is less than the average vulnerability (ν_3). Therefore, to be conservative, the average vulnerability could be used for making decisions in concerning system 2.



System 1

System 2

Figure 33. Illustration of the usage of typical severity of a failure state s_j

Table 20. Vulnerability Indices of Example Case

	System 1	System 2
Vulnerability, ν_1	325	325
Average Vulnerability, ν_3	235	343

Standardization

The average vulnerability is standardized by the existing system capacity ($v_3' = v_3 / 2500\,\mathrm{m}^3$). The purpose of standardization is to facilitate comparison, in particular because the other two indices, reliability, α and resilience, γ_1, range between 0 and 1.

To allow comparison of the performance indices across all scenarios, the minimum, average, maximum values and the standard deviation of the performance indices of the 100 trials in a scenario are calculated.

5.3 Results Overview

In this section, the results of scenarios 1 to 26 are first reported with discussions immediately following. The findings in the 26 scenarios are then summarized. Next, the results of the sensitivity analysis scenarios are presented. Accompanying are the interpretations of the trends observed. The final section offers general conclusions on the findings of all of the scenarios. Detailed results of individual scenarios are included in Appendix C. Unless indicated otherwise, the discussions on the results are centered on the averages of all of the trials in a scenario.

Scenario 1: Base case

To represent Ayr's existing water supply and demand conditions, in scenario 1, the simulated system capacity and demand management implementations are set to the 2006 levels. The results indicate that under the simulated climatic conditions derived from the seven years of historical records, the existing system would have an average reliability of 0.9987, resiliency of 0.5477, and a vulnerability of 212 m^3 over the simulation horizon (2006 to 2025). See Table 21 for the results of scenario 1 to 6. As scenarios 1 to 6 represent the base case condition, the indices are used as a benchmark in analysing the results for the rest of the base case scenarios.

Scenario 2: If no WEMPs were implemented

In scenario 2, the discounts of the system demands from the water efficiency management programs (WEMP) are taken out. The results show that despite the relatively small WEMPs savings (180 m^3 out of 2500 m^3 of system capacity), without the implementation of the demand management programs, the system would have twice as many failure days, almost twice as many consecutive failures, 50% longer failure, and 50% higher failure severity. As well, the lower bound of the failure statistics, for example number of days failed, would also increase (from 6 to 21). Similar conclusions can be reached for other indices and the associated standard deviations.

Scenario 3: Additional 5% WEMPs savings

In scenario 3, the WEMPs are hypothesised to have an additional 5% effect as that indicated in the ROW's 2007 estimates. Comparing the results of scenario 3 to those of scenario 1 shows that the additional water savings would not significantly influence the overall system performance.

Table 21. Scenario 1 to 6 Failure Statistics and Performance Measures. In brackets are the minimum, average, and maximum values of a measure with associated standard deviation in the row underneath.

Scenario no.	No. of Days Failed (days)	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
1	(6 , 22.3 , 53)	(3 , 11.9 , 25)	(2 , 4.7 , 10)	(1.2 , 1.9 , 3.3)	(210 , 553 , 888)	(450 , 2459 , 5695)	(515 , 4310 , 11925)
	7.99	3.96	1.88	0.43	127.3	863.2	2043.6
2	(21 , 46.2 , 84)	(9 , 22.2 , 37)	(3 , 6.7 , 14)	(1.3 , 2.1 , 3.3)	(364 , 706 , 1043)	(1789 , 4885 , 10224)	(2896 , 9370 , 22033)
	12.55	5.20	2.51	0.36	127.9	1423.8	3380.4
3	(6 , 21.6 , 53)	(3 , 11.6 , 25)	(2 , 4.6 , 10)	(1.2 , 1.9 , 3.3)	(202 , 545 , 880)	(412 , 2371 , 5504)	(469 , 4143 , 11655)
	7.89	3.90	1.87	0.44	127.2	839.2	1991.63
4	(5 , 20.1 , 50)	(3 , 10.8 , 24)	(2 , 4.5 , 10)	(1.3 , 1.9 , 3.6)	(187 , 530 , 865)	(347 , 2205 , 5137)	(388 , 3824 , 11135)
	7.42	3.74	1.85	0.44	127.2	797.0	1891.2
5	(0 , 6.9 , 23)	(0 , 4.3 , 11)	(0 , 2.8 , 9)	(0 , 1.6 , 3.3)	(0 , 306 , 641)	(0 , 684 , 2337)	(0 , 1104 , 5554)
	3.79	1.89	1.62	0.56	126.3	373.5	869.6
6	(0 , 1.4 , 10)	(0 , 1 , 4)	(0 , 1.1 , 7)	(0 , 1 , 7)	(0 , 80 , 394)	(0 , 96 , 899)	(0 , 151 , 2228)
	1.7	0.9	1.2	1.0	101.5	137.4	312.5

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
1	(0.9927 , 0.9987 , 0.9992)	(0.3 , 0.5477 , 0.8333)	(17.2 , 103.6 , 608.8)	(90 , 212 , 347)	(86 , 191 , 341)	(0.1346 , 0.2994 , 0.5349)
	0.0011	0.1105	92.7	50	45	0.0706
2	(0.9885 , 0.9937 , 0.9971)	(0.3061 , 0.4911 , 0.7419)	(6.2 , 30.4 , 116)	(145 , 220 , 312)	(121 , 200 , 313)	(0.1895 , 0.3147 , 0.4921)
	0.0017	0.0801	18.2	37	36	0.0571
3	(0.9927 , 0.997 , 0.9992)	(0.3 , 0.5502 , 0.8333)	(17.2 , 109.7 , 608.8)	(82 , 211 , 343)	(78 , 189 , 333)	(0.1226 , 0.2959 , 0.5228)
	0.0011	0.1151	96.8	51	44	0.0696
4	(0.9932 , 0.9972 , 0.9993)	(0.2813 , 0.554 , 0.8)	(18.3 , 123.8 , 730.5)	(87 , 210 , 379)	(78 , 188 , 359)	(0.1219 , 0.2944 , 0.5639)
	0.0010	0.1135	112.5	53	48	0.0754
5	(0.9969 , 0.9991 , 1)	(0.3077 , 0.6832 , 1)	(47.7 , 842.7 , 7305)	(0 , 161 , 405)	(0 , 149 , 326)	(0 , 0.234 , 0.512)
	0.0005	0.2041	1077.2	65	55	0.0868
6	(0.9986 , 0.9998 , 1)	(0.1429 , 0.838 , 1)	(146.1 , 4719.8 , 7305)	(0 , 69 , 388)	(0 , 62 , 297)	(0 , 0.0981 , 0.466)
	0.0002	0.2601	2864.3	91	77	0.1206

Scenario 4: Additional 15% WEMPs savings

In scenario 4, the hypothesised increase in water savings is further increased to 15%. It shows that with an additional 15% savings, the overall performance of the system would improve slightly. The average reliability would increase by 0.002, resiliency by 0.006 and vulnerability by 2 m^3.

Scenario 5: Additional 10% system capacity

When the system capacity increased by 10% (250 m^3), there is a significant increase in the system's reliability. Of interest, by examining the entries in Table 21, one may wonder why the improved system has a greater upper bound vulnerability than the unimproved system. The total severity and average vulnerability confirm that the system did experience less water shortage. However, in the improved conditions, some small failures would disappear and only the severe failures are left behind. As the traditional vulnerability calculates the expected maximum severity of a failure, therefore, without the small but frequent failures to balance out the large but infrequent failures, a higher vulnerability results.

Scenario 6: Additional 20% system capacity

When the system capacity expanded by 20%, further improvement is observed. In general, similar system response as in scenario 5 is observed.

Scenario 7-11: HadCM3 A23

In scenarios 7 to 11, the climatic condition projected by HadCM3 A23 defines climate inputs. HadCM3 A23 projects the highest precipitation reduction among all GCMs. It estimates an overall increase of 1.7˚C in average annual maximum temperature and a decrease of 2.6% in average annual precipitation. The settings of water efficiency programs, system capacity, and population growth in this set of scenarios are parallel to that in scenario 1, and 3 to 6.

Comparing the results of the two sets of scenarios (Table 21 and Table 22) indicates that if the system is subjected to the projected climate condition, the average number of failure days would increase by approximately six fold; the number of consecutive failures and the average failure duration would double and the average maximum severity would increase by two-thirds. Translating the failure statistics into performance measures, the reliability of the system on average would decrease by 0.019 , the resiliency would also decrease by 0.33, and the vulnerability would increase by 135.6 m^3.

Another noteworthy feature is observed in the results. Although the extreme climate exerts higher water demands on the water supply system, the 20% system expansion would make the system's reliability go up by 0.012, resiliency up by 26.3, and vulnerability go down by 149 m^3 to 182 m^3, and results in system performance similar to the base case conditions. Apparently, in more adverse climate, the benefits provided by WEMPs and system expansion may become more prominent. To illustrate, in scenario 8, the increase of 5% of water savings means a reduction of 2.4 failure days; in scenario 3, it only means a reduction of 0.7 days. Table 23 illustrates the rest of the pair wise comparisons.

Table 22. Scenario 7 to 11 Failure Statistics and Performance Measures.

Scenario no.	No. of Days Failed (days)	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
7	(79 , 122.1 , 170)	(20 , 36.1 , 54)	(10 , 23.8 , 49)	(2.3 , 3.4 , 5.4)	(782 , 827 , 1112)	(6312 , 9980 , 14637)	(22435 , 40419 , 58651)
	17.9	5.7	8.3	0.5	43.3	1701.6	7131.9
8	(78 , 119.7 , 168)	(20 , 35.4 , 51)	(9 , 23.2 , 49)	(2.3 , 3.4 , 5.6)	(775 , 820 , 1104)	(6162 , 9772 , 14796)	(21834 , 39496 , 57529)
	17.8	5.7	8.2	0.5	43.3	1686.4	7021.4
9	(73 , 114.6 , 155)	(18 , 33.8 , 49)	(8 , 22.5 , 49)	(2.4 , 3.4 , 5.1)	(759 , 804 , 1089)	(5785 , 9357 , 14708)	(20674 , 37706 , 55311)
	17.0	5.6	8.3	0.5	43.3	1647.9	6806.8
10	(35 , 64.9 , 92)	(12 , 18.9 , 30)	(6 , 14.9 , 28)	(2.1 , 3.5 , 5.8)	(535 , 580 , 865)	(2731 , 4779 , 7133)	(9763 , 18518 , 29728)
	12.5	3.6	5.0	0.7	43.3	1003.4	4055.7
11	(15 , 33.9 , 52)	(5 , 10.5 , 17)	(3 , 10.8 , 24)	(1.7 , 3.4 , 7)	(288 , 333 , 618)	(751 , 1678 , 2856)	(1900 , 6167 , 10337)
	8.5	2.8	4.3	1.0	43.3	481.0	1782.4

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
7	(0.9767 , 0.9833 , 0.9892)	(0.1864 , 0.2982 , 0.43)	(1 , 2.9 , 6.5)	(187 , 278 , 378)	(246 , 331 , 419)	(0.3856 , 0.5198 , 0.6579)
	0.0024	0.0442	1.3	34	35	0.0545
8	(0.977 , 0.9836 , 0.9893)	(0.1795 , 0.2982 , 0.4286)	(1 , 3.1 , 7.9)	(184 , 278 , 383)	(245 , 330 , 429)	(0.3851 , 0.5181 , 0.6731)
	0.0024	0.0451	1.4	35	35	0.0555
9	(0.9788 , 0.9843 , 0.99)	(0.1947 , 0.2976 , 0.4255)	(1 , 3.4 , 8.5)	(206 , 279 , 357)	(243 , 329 , 418)	(0.3819 , 0.5164 , 0.6559)
	0.0023	0.0467	1.5	34	35	0.0553
10	(0.9874 , 0.9911 , 0.9952)	(0.1739 , 0.2963 , 0.4717)	(3.1 , 9.1 , 26.5)	(178 , 255 , 341)	(210 , 285 , 354)	(0.3289 , 0.4481 , 0.5558)
	0.0017	0.0555	4.8	37	32	0.0508
11	(0.9929 , 0.9954 , 0.9979)	(0.1429 , 0.3216 , 0.6)	(7.1 , 29.3 , 162.3)	(74 , 162 , 243)	(118 , 182 , 256)	(0.185 , 0.2863 , 0.4026)
	0.0012	0.0880	25.8	34	31	0.0481

Table 23. A Comparison of the Average Number of Failure Days between Scenarios 3 to 6 and 8 to 11 in Comparison to the Base Case

	Base Case Scenarios 3 to 6	HadCM3 A23 Scenarios 8 to 11
5% of water savings	0.7	2.4
15% of water savings	2.2	7.5
10% system capacity	15.4	57.2
20% system capacity	20.9	88.2

This finding can further be interpreted as under different climatic conditions, the effects of system improvements may vary. Further discussions on this variation are provided at the end of this section.

Scenario 12-16: CSIROMK2b B11

For scenario 12 to 16, the climatic projecting is based upon the CSIROMK2b B11. This model projects the highest temperature change in the four GCMs integrated in this study. It approximates an overall increase of 2.6˚C in average annual maximum temperature and an increase of 4.2% in average annual precipitation.

To minimize the comparison effort, averages of measures are taken across scenario 1,3 to 6 and scenario 12 to 16. By comparing the averages in Table 21 and Table 24, as compared to the base case scenarios, in scenario 12 to 16, the number of failure days increases almost ten times (from 14.5 to 138.6 days); the maximum failure duration increases five fold (from 3.54 to 18.64 days); the maximum severity of failure increases 81% (from 403 to 730 m^3). In terms of performance indices, the reliability of the system would decrease from 0.998 to 0.961, resiliency γ_1 would

Table 24. Scenario 12 to 16 Failure Statistics and Performance Measures.

Scenario no.	No. of Days Failed (days)	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
12	(135 , 190.1 , 244)	(36 , 53.8 , 68)	(11 , 23.4 , 53)	(2.7 , 3.6 , 5.2)	(613 , 884 , 951)	(10621 , 15583 , 20140)	(33725 , 59186 , 81593)
	20	6	8	0	37	2077	9959
13	(134 , 186.8 , 240)	(36 , 53.1 , 67)	(11 , 22.9 , 53)	(2.6 , 3.6 , 5.2)	(606 , 876 , 943)	(10285 , 15276 , 19728)	(32582 , 57752 , 79965)
	20	6	8	0	37	2079	9829
14	(129 , 179.8 , 231)	(34 , 51.3 , 66)	(11 , 22 , 52)	(2.6 , 3.5 , 5.4)	(590 , 861 , 927)	(10022 , 14658 , 18907)	(30408 , 54961 , 76773)
	20	6	8	0	37	1988	9570
15	(59 , 106.4 , 146)	(23 , 31.9 , 43)	(8 , 15.8 , 38)	(2.2 , 3.4 , 5)	(366 , 637 , 704)	(3677 , 6876 , 9723)	(8248 , 23981 , 39395)
	18	5	6	1	37	1232	5914
16	(3 , 30.1 , 54)	(3 , 9.9 , 17)	(1 , 9.3 , 19)	(1 , 3 , 6)	(119 , 390 , 457)	(187 , 2074 , 3899)	(187 , 7007 , 15747)
	10	3	4	1	37	633	2906

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
12	(0.9666 , 0.974 , 0.9815)	(0.1915 , 0.2852 , 0.3654)	(0.6 , 1.9 , 4.1)	(230 , 290 , 366)	(220 , 310 , 380)	(0.346 , 0.4869 , 0.5958)
	0.0028	0.0354	0.7	28	31	0.0494
13	(0.9671 , 0.9744 , 0.9817)	(0.1915 , 0.2861 , 0.3787)	(0.6 , 1.9 , 4.1)	(224 , 289 , 365)	(220 , 308 , 377)	(0.3456 , 0.4835 , 0.5921)
	0.0028	0.0364	0.7	29	31	0.0490
14	(0.9684 , 0.9754 , 0.9823)	(0.1848 , 0.2875 , 0.3836)	(0.7 , 2.1 , 4.3)	(215 , 287 , 359)	(219 , 304 , 371)	(0.3434 , 0.4779 , 0.5822)
	0.0028	0.0379	0.8	29	31	0.0485
15	(0.98 , 0.9854 , 0.9919)	(0.1985 , 0.3046 , 0.4576)	(1.4 , 5.1 , 15.5)	(138 , 216 , 303)	(116 , 223 , 293)	(0.1824 , 0.3508 , 0.4606)
	0.0024	0.0518	2.3	27	32	0.0508
16	(0.9926 , 0.9959 , 0.9996)	(0.1667 , 0.3566 , 1)	(8.5 , 66.9 , 2435)	(62 , 211 , 345)	(62 , 227 , 306)	(0.0981 , 0.357 , 0.4809)
	0.0014	0.1164	244.7	45	41	0.0650

decrease from 0.63 to 0.30, and the average vulnerability would increase from 155.8 to 274 m^3. This result reflects that the system performance as a whole, when subjected to the CSIROMK2b B11 climate projection, would result in more frequent failures that are more severe and would last longer. One would expect that the increase in precipitation would achieve some outdoor water savings and therefore counteract some of the impacts caused by an increase of temperature. However, as previously described in section 3.3.7, precipitation magnitude by itself does not have substantial impacts on water demands. Therefore, the increase of precipitation does not have substantial effect in relieving water strain due to heat stress.

Scenario 17-21: CCSRNIES A21

The future climate scenario CCSRNIES A21 projects a milder climate change as compared to CSIROMk2b B11 in both changes in temperature and precipitation. It projects a 1.7°C increase in annual average temperature and 1.8% decrease in average precipitation.

As compared to the base case scenarios (Table 21 and Table 25), on average in scenario 17 to 21, the number of failure days would increase almost five times (from 14.46 to 75.32 days), the maximum failure duration would increase by three fold (from 3.54 to 9.62 days), the maximum severity of failure would increase by 31% (from 403 to 530 m^3). In representation of performance indices, the reliability of the system on average would decrease from 0.99802 to 0.98968, resiliency would decrease from 0.6346 to 0.423, and the average vulnerability would increase from 155.8 to 202 m^3. The results show that the system performance in CCSRNIES A21 scenario follows a similar trend as in CSIROMk2b B11.

Table 25. Scenario 17 to 21 Failure Statistics and Performance Measures.

Scenario no.	No. of Days Failed (days)	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
17	(67 , 108.6 , 148)	(29 , 41.6 , 60)	(5 , 11.9 , 27)	(1.9 , 2.6 , 3.6)	(565 , 684 , 1112)	(6535 , 10210 , 14220)	(12923 , 27132 , 48842)
	17	6	4	0	114	1487	5664
18	(64 , 106.1 , 144)	(29 , 40.7 , 57)	(5 , 11.7 , 27)	(1.9 , 2.6 , 3.4)	(557 , 676 , 1104)	(6300 , 9920 , 13886)	(12410 , 26318 , 47742)
	17	6	4	0	114	1452	5554
19	(58 , 100.7 , 139)	(25 , 38.8 , 53)	(5 , 11.5 , 27)	(1.9 , 2.6 , 3.6)	(542 , 661 , 1089)	(5831 , 9357 , 13225)	(11420 , 24748 , 45601)
	16	6	4	0	113	1401	5339
20	(18 , 46.4 , 86)	(10 , 18.7 , 27)	(3 , 8.3 , 18)	(1.5 , 2.5 , 4.1)	(318 , 437 , 865)	(1527 , 3758 , 6634)	(2393 , 9259 , 20724)
	11	4	3	0	114	810	2652
21	(2 , 14.8 , 40)	(2 , 7.5 , 18)	(1 , 4.7 , 16)	(1 , 2 , 4)	(71 , 190 , 618)	(100 , 541 , 1453)	(117 , 1032 , 3246)
	6	3	2	1	114	257	579

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
17	(0.9797 , 0.9851 , 0.9908)	(0.2816 , 0.387 , 0.5224)	(2.3 , 6.6 , 17.9)	(196 , 246 , 323)	(173 , 249 , 337)	(0.2721 , 0.3908 , 0.5288)
	0.0023	0.0481	3.0	26	26	0.0414
18	(0.9803 , 0.9855 , 0.9912)	(0.291 , 0.3884 , 0.5313)	(2.4 , 6.9 , 18.2)	(196 , 244 , 316)	(171 , 247 , 332)	(0.2684 , 0.3879 , 0.5205)
	0.0023	0.0489	3.1	26	26	0.0413
19	(0.981 , 0.9862 , 0.9921)	(0.2809 , 0.39 , 0.5345)	(2.5 , 7.5 , 19.6)	(188 , 242 , 308)	(177 , 245 , 328)	(0.2781 , 0.3845 , 0.515)
	0.0022	0.0521	3.5	27	27	0.0424
20	(0.9882 , 0.9936 , 0.9975)	(0.2466 , 0.412 , 0.6471)	(5.3 , 24.3 , 101.5)	(146 , 202 , 285)	(133 , 198 , 243)	(0.2087 , 0.3115 , 0.3811)
	0.0015	0.0672	14.9	25	19	0.0302
21	(0.9945 , 0.998 , 0.9997)	(0.25 , 0.5384 , 1)	(16.3 , 205.1 , 3652.5)	(30 , 73 , 153)	(25 , 71 , 222)	(0.0387 , 0.1112 , 0.3486)
	0.0008	0.1415	382.5	27	32	0.0496

Scenario 22-26: CGCM2 A22

CGCM2 A22 projects a 2.1°C increase in temperature and 4.4% increase in precipitation. As compared to the base case scenario, on average the system in this set of scenarios has five times as many failure days (from 14.46 to 36.96 days), twice as long maximum failure duration (from 3.54 to 5.74 days), 31% as severe failures (from 403 to 565 m^3) (see Table 26). In terms of performance indices, the reliability of the system on average would decrease from 0.99802 to 0.98968, resiliency would decrease from 0.6346 to 0.423, and the average vulnerability would increase from 155.8 to 202 m^3. The results show that the system performance in CGCM2 A22 scenario follows a similar trend as in HadCM3 A23.

Summary of scenario 1 to 26 results

Overall, the simulation results suggest that a rise in temperature and a change in precipitation magnitude will have negative impact on the performance of the system. Shown in Table 27 are averages of system performance taken across a set of five scenarios of a particular climate scenario. Therefore, each entry in the table in fact is the average of 500 trials (5 scenarios x 100 trials). For reference, the GCM projected change in average maximum temperature and average precipitation are also included. Ranking the system by the overall performance, the order from best-case scenario to worst-case climate scenario is: Base Case, CGCM2 A22, CCSRNIES A21, HadCM3 A23 and CSIROMK2b B11.

Table 26. Scenario 22 to 26 Failure Statistics and Performance Measures.

Scenario no.	No. of Days Failed (days	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
22	(29 , 55.6 , 88)	(14 , 26.1 , 38)	(3 , 7.4 , 15)	(1.5 , 2.2 , 3)	(411 , 719 , 945)	(2458 , 5964 , 9274)	(4035 , 12075 , 24583)
	12	6	2	0	128	1538	3778
23	(27 , 53.8 , 86)	(14 , 25.4 , 36)	(3 , 7.1 , 15)	(1.4 , 2.1 , 3)	(404 , 711 , 937)	(2352 , 5763 , 9053)	(3822 , 11658 , 24031)
	12	5	2	0	128	1482	3699
24	(24 , 50 , 82)	(11 , 23.6 , 34)	(3 , 6.8 , 12)	(1.5 , 2.1 , 3.1)	(388 , 696 , 922)	(2168 , 5405 , 8612)	(3430 , 10866 , 22959)
	12	5	2	0	128	1415	3545
25	(6 , 19.9 , 46)	(3 , 10.4 , 17)	(2 , 4.7 , 10)	(1.2 , 1.9 , 3.3)	(164 , 472 , 698)	(314 , 1977 , 3984)	(480 , 3764 , 11792)
	7	3	2	0	128	728	1756
26	(0 , 5.5 , 20)	(0 , 3.1 , 8)	(0 , 2.7 , 8)	(0 , 1.8 , 8)	(0 , 226 , 451)	(0 , 398 , 1335)	(0 , 742 , 4710)
	3	2	2	1	126	273	693

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
22	(0.988 , 0.9924 , 0.996)	(0.3333 , 0.4745 , 0.6757)	(7.8 , 21.6 , 64.1)	(128 , 229 , 337)	(114 , 215 , 341)	(0.1791 , 0.3372 , 0.536)
	0.0017	0.0711	11.9	39	39	0.0606
23	(0.9882 , 0.9926 , 0.9963)	(0.3333 , 0.4787 , 0.6944)	(8.3 , 23.2 , 67.6)	(129 , 227 , 330)	(114 , 214 , 334)	(0.1793 , 0.3363 , 0.524)
	0.0017	0.0713	12.8	39	38	0.0600
24	(0.9888 , 0.9932 , 0.9967)	(0.3188 , 0.4776 , 0.6765)	(8.9 , 26.4 , 97.4)	(146 , 230 , 322)	(127 , 214 , 333)	(0.1995 , 0.3364 , 0.5224)
	0.0016	0.0734	15.1	38	38	0.0592
25	(0.9937 , 0.9973 , 0.9992)	(0.3077 , 0.5438 , 0.8571)	(19.9 , 114.8 , 521.8)	(77 , 189 , 332)	(69 , 184 , 319)	(0.1077 , 0.2895 , 0.5003)
	0.0010	0.1152	102.8	42	44	0.0687
26	(0.9973 , 0.9992 , 1)	(0.125 , 0.6397 , 1)	(60.9 , 1399.8 , 7305)	(0 , 133 , 383)	(0 , 122 , 365)	(0 , 0.1916 , 0.5732)
	0.0005	0.2480	2007.0	89	77	0.1208

Table 27. Scenario 1 to 26 Results

	Scenario Descriptions				
	Base Case 1,3 to 6	Had CM3 A23 7 to 11	CSIROMk2b B11 12 to 16	CCSRNIES A21 17 to 21	CGCM2 A22 22 to 26
Number of failure days	14	91	139	83	37
Number of consecutive failures	7.9	26.9	40.0	31.1	17.7
Maximum failure duration	4	19	19	12	6
Maximum severity of failure	402.8	672.8	729.5	615.2	564.7
Reliability	0.998	0.988	0.981	0.990	0.995
Resiliency	0.635	0.302	0.304	0.005	0.004
Vulnerability	172.5	250.4	258.5	218.3	201.6
GCMs projected change in average maximum temperature (˚C)	0^A	1.7	2.6	1.7	2.1
GCMs projected change in average precipitation (%)	0^A	-2.6	4.2	-1.8	4.4

A- not applicable. No climate change assumed. Therefore GCM projections are not used.

The simulation model is sensitive to a change in temperature but not particularly sensitive to a change in precipitation magnitude. However, as reflected in the rankings, CSIROMK2b B11 has the highest projection in temperature increase and is the worst-case scenario. Instead of CGCM2 A22, which projects the second highest temperature increase, the HadCM3 A23 which has a precipitation reduction of 2.6%, is the second worst-case scenario. This shows that a reduction of precipitation may worsen the system performance. Conversely, an increase of precipitation may lessen the impact from a warmer climate. However, uncertainties exist in the projections of the temperature and precipitation change (see Figure 34). The individual effects of an increase of average temperature, a reduction in precipitation, and the fluctuations in the GCM estimates, on the system is uncertain. If an estimate of the individual effects these two factors were desired, additional studies would be needed to identify the influence of these factors. As noted earlier, the efficiency of system improvements towards the performance of a system may vary under different climatic conditions.

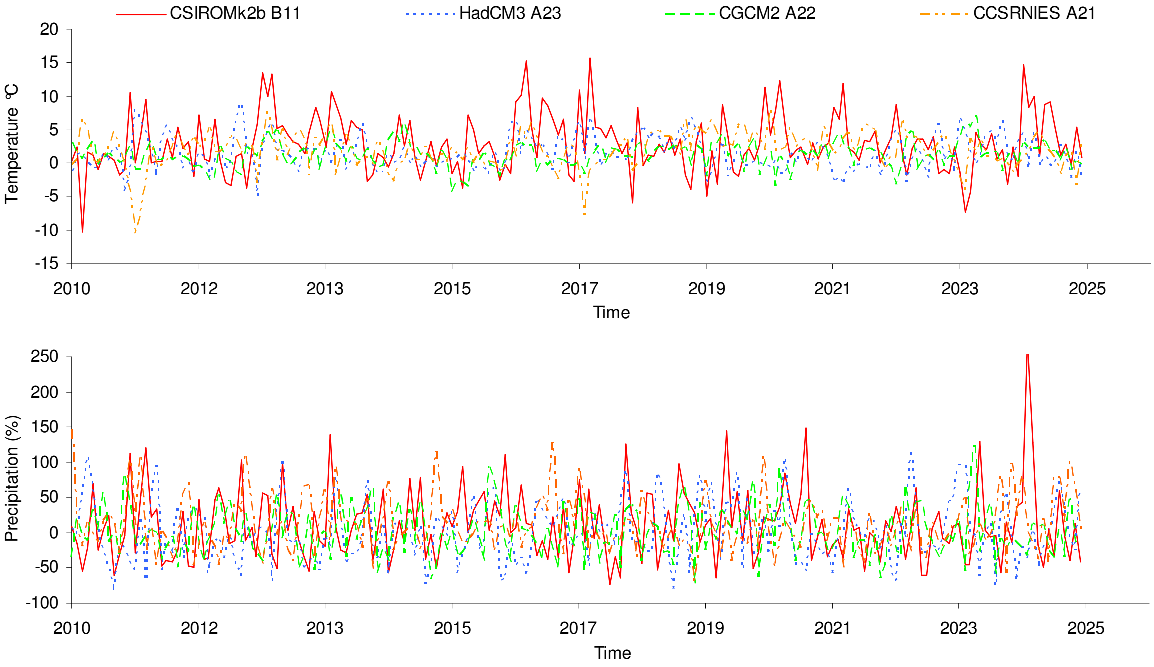


Figure 34. Monthly Temperature and Precipitation Projected Climatic Measures in GCMs.

Figure 35 illustrates the relative changes of system performance as a function of water savings and system expansion under different climatic scenarios. Further, this might explain why a distribution exists in the water savings of conservation actions. A possible explanation of this variation would be: the additional capacity introduced by reduction in water demand or via capacity expansion are being fully utilized when there is a severe failure caused by extreme climate. However, this explanation cannot be proven true until a closer look at the detailed data is made. It is important to point out that the results presented here only give several points of the response curve. The relationship in between points can only be defined by more simulations.

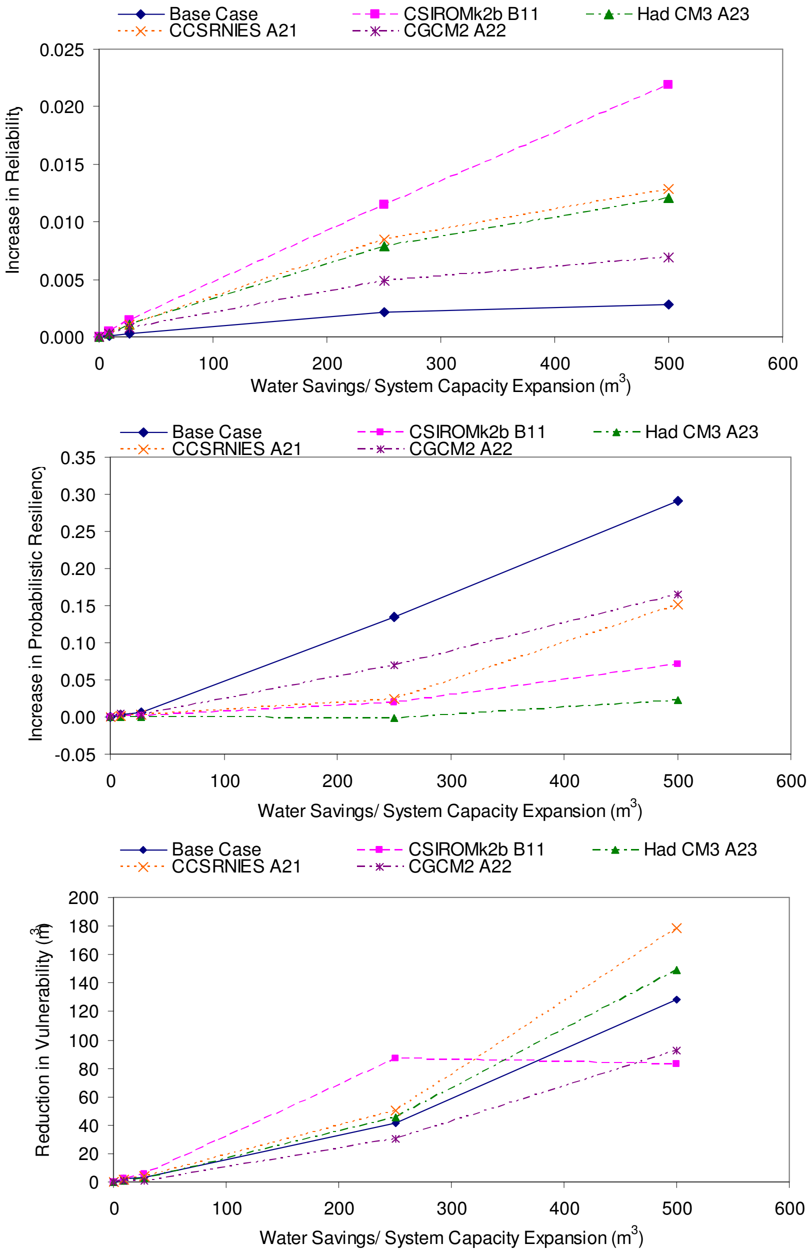


Figure 35. Relative Changes of System Performance as a Function of Water Savings and system expansion under Different Climate Conditions.

5.3.1 Sensitivity Analysis

The overall objective of the sensitivity analysis is to identify the impacts of: (i) a changing precipitation pattern; and (ii) a more rapid population growth on the performance of the water supply system. This section first describes the performance of the water supply system subjected to the GCM scenarios HadCM3 A23 (scenario 7a to 11a) and CSIROMK2b B11 (scenario 12a to 16a) with the change of precipitation value converted into a change of precipitation event occurrence. Discussions of the impacts of a doubling population growth rate in base case condition (scenario 1c to 6c) are then provided. Lastly, the combined effects of a higher population growth and a change of precipitation occurrence simulated in scenario 7c to 11c and scenario 12c to 16c are presented. The information generated in this sensitivity analysis can be used to provide information for managing the water supply system.

Scenario 7a to 11a versus Scenario 7 to 11 (Had CM3 A23)

In scenarios 7a to 11a, the change of precipitation value projected by HadCM3 A23 is produced by a varying frequency of occurrence (see section 3.3.2 for methodology). Recall that scenario HadCM3 A23 predicts an overall decrease of 0.83% of precipitation. Therefore, a small reduction in the number of precipitation events would result.

Table 28. Scenario 7a to 11a Failure Statistics and Performance Measures.

Scenario no.	No. of Days Failed (days)	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
7a	(73 , 126.6 , 172)	(27 , 39.2 , 52)	(8 , 21.4 , 61)	(2.3 , 3.3 , 4.6)	(769 , 826 , 942)	(5865 , 10867 , 16355)	(22063 , 39355 , 51397)
	18.5	6.1	9.1	0.5	39.3	1822.0	6646.4
8a	(70 , 123.6 , 165)	(26 , 38.5 , 53)	(8 , 21 , 61)	(2.3 , 3.2 , 4.6)	(761 , 819 , 935)	(5659 , 10664 , 16000)	(21513 , 38399 , 50306)
	18.2	6.2	9.0	0.5	39.3	1806.9	6533.7
9a	(65 , 117.9 , 159)	(24 , 37 , 53)	(8 , 20.1 , 49)	(2.3 , 3.2 , 4.8)	(746 , 803 , 919)	(5986 , 10208 , 15312)	(20467 , 36554 , 48189)
	18.1	6.2	8.5	0.5	39.3	1769.5	6311.4
10a	(35 , 63.2 , 89)	(13 , 20.4 , 33)	(5 , 13.5 , 26)	(2 , 3.1 , 4.5)	(522 , 579 , 695)	(2753 , 5038 , 8482)	(8577 , 17390 , 24939)
	11.3	4.0	4.3	0.5	39.3	1066.0	3779.5
11a	(12 , 31.5 , 48)	(5 , 10.4 , 18)	(3 , 10.1 , 23)	(1.3 , 3.2 , 6)	(275 , 332 , 448)	(587 , 1691 , 2941)	(1534 , 5661 , 9430)
	7.7	2.8	3.9	1.0	39.3	504.5	1815.8

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
7a	(0.9765 , 0.9827 , 0.99)	(0.218 , 0.3123 , 0.4273)	(0.7 , 3.2 , 8.3)	(206 , 279 , 351)	(236 , 311 , 380)	(0.3703 , 0.4887 , 0.5964)
	0.0025	0.0440	1.5	36	32	0.0509
8a	(0.9774 , 0.9831 , 0.9904)	(0.2154 , 0.3142 , 0.4407)	(0.7 , 3.4 , 8.5)	(208 , 278 , 354)	(237 , 311 , 383)	(0.3716 , 0.4884 , 0.601)
	0.0025	0.0439	1.5	34	33	0.0512
9a	(0.9782 , 0.9839 , 0.9911)	(0.2063 , 0.3166 , 0.4312)	(1 , 3.7 , 8.9)	(212 , 277 , 349)	(232 , 311 , 392)	(0.364 , 0.4877 , 0.6157)
	0.0025	0.0457	1.7	33	33	0.0520
10a	(0.9878 , 0.9914 , 0.9952)	(0.2239 , 0.3273 , 0.5)	(3.7 , 10.3 , 33.2)	(160 , 248 , 316)	(195 , 275 , 369)	(0.306 , 0.4313 , 0.5794)
	0.0015	0.0564	5.6	30	34	0.0531
11a	(0.9934 , 0.9957 , 0.9984)	(0.1667 , 0.3459 , 0.75)	(9.3 , 33.6 , 202.9)	(83 , 165 , 319)	(91 , 178 , 268)	(0.1423 , 0.2793 , 0.4214)
	0.0011	0.1103	31.2	39	35	0.0550

Overall, subjected to the small reduction in the number of precipitation events, the system performance is slightly degraded. By comparing the results of scenario 7 to 11 and scenario 7a to 11a (Table 28), it is found that there is a small increase in the number of failure days (from 91.04 to 92.56 days) and the number of consecutive failures (from 26.94 to 29.1). Interestingly, there is also a small decrease in maximum failure duration (from 19.04 to 17.22 days) and maximum severity of failure (from 673 to 672 m^3). In representation of performance measures, the system reliability would decrease from 0.98754 to 0.98736, resiliency would increase from 0.30238 to 0.32326, and the average vulnerability would decrease from 291.4 to 277.2 m^3.

Scenario 12 to 16 versus scenario 12a to 16a (CSIROMk2b B11)

Similar to scenarios 7a to 11a, the change of precipitation value projected by CSIROMK2b B11 is also produced by a varying frequency of occurrence. Recall that scenario CSIROMK2b B11 predicts an overall increase of 4.2% of precipitation. Therefore, an approximately 4.2% increase in the number of precipitation events would result.

Comparing the results of scenario 12 to 16 to scenario 12a to 16a (Table 29) shows that the reliability of the system would decrease from 0.99102 to 0.98238, resiliency would increase from 0.304 to 0.301, and the average vulnerability would decrease from 258.6 to 255.2 m^3. The results indicate that with an increase of precipitation events, the system is likely to have fewer failures while the system's resiliency and vulnerability level would remain more or less the same.

Table 29. Scenario 12a to 16a Failure Statistics and Performance Measures.

Scenario no.	No. of Days Failed (days)	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
12a	(129 , 176.5 , 242)	(35 , 50.1 , 65)	(10 , 23.2 , 60)	(2.5 , 3.6 , 4.9)	(508 , 882 , 1113)	(9355 , 14247 , 19322)	(34004 , 54757 , 78417)
	23.5	6.5	8.3	0.5	48.3	2087.6	9187.4
13a	(127 , 173.2 , 240)	(33 , 49.2 , 65)	(10 , 22.9 , 60)	(2.5 , 3.6 , 4.7)	(500 , 875 , 1105)	(9097 , 13903 , 18882)	(32945 , 53426 , 76696)
	23.4	6.6	8.2	0.5	48.3	2066.2	9041.4
14a	(121 , 166.3 , 232)	(29 , 47.3 , 62)	(10 , 22.3 , 60)	(2.6 , 3.6 , 5.1)	(485 , 859 , 1090)	(8623 , 13307 , 18955)	(30908 , 50839 , 73314)
	22.6	6.4	8.0	0.5	48.3	2026.2	8755.7
15a	(54 , 99.5 , 149)	(17 , 29.9 , 45)	(6 , 16 , 38)	(2.3 , 3.4 , 6.2)	(261 , 637 , 866)	(2825 , 6281 , 9366)	(7646 , 22559 , 35876)
	16.3	5.3	5.7	0.6	51.2	1348.5	5473.2
16a	(2 , 28.1 , 53)	(2 , 8.9 , 15)	(1 , 9.5 , 22)	(1 , 3.2 , 6)	(14 , 388 , 619)	(26 , 1929 , 3603)	(26 , 6822 , 13999)
	9.7	2.8	4.2	1.0	48.3	693.9	2778.7

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
12a	(0.9669 , 0.9758 , 0.9823)	(0.206 , 0.2864 , 0.3933)	(0.6 , 2.1 , 4.9)	(222 , 285 , 344)	(236 , 310 , 406)	(0.3704 , 0.4868 , 0.6379)
	0.0032	0.0384	0.9	27	31	0.0482
13a	(0.9671 , 0.9763 , 0.9826)	(0.2108 , 0.2865 , 0.3931)	(0.6 , 2.1 , 5)	(219 , 283 , 342)	(231 , 308 , 410)	(0.3634 , 0.4842 , 0.6432)
	0.0032	0.0388	0.9	27	31	0.0491
14a	(0.9682 , 0.9772 , 0.9834)	(0.1973 , 0.2869 , 0.3901)	(0.6 , 2.3 , 5.2)	(211 , 282 , 350)	(226 , 306 , 412)	(0.3547 , 0.4796 , 0.6462)
	0.0031	0.0391	0.9	29	31	0.0490
15a	(0.9796 , 0.9864 , 0.9926)	(0.1604 , 0.3044 , 0.43)	(1.7 , 5.4 , 15.6)	(128 , 210 , 293)	(92 , 226 , 329)	(0.1446 , 0.3544 , 0.5171)
	0.0022	0.0503	2.4	31	36	0.0564
16a	(0.9927 , 0.9962 , 0.9997)	(0.1667 , 0.343 , 1)	(8.2 , 78.3 , 3652.5)	(13 , 216 , 318)	(13 , 239 , 333)	(0.0205 , 0.3745 , 0.5222)
	0.0013	0.1230	363.1	48	45	0.0705

The two sets of scenarios, 7a to 11a and 12a to 16a, present the possible outcomes of a change of precipitation value through a change of event frequency. The average system performance of scenario 7 to 11, 7a to 11a, 12 to 16, and 12a to 16a are summarized in Table 27. The results suggest that a change of event frequency may amplify the effects of an increase or reduction of precipitation, which can be described by “Dry drier, wet wetter”.

Table 30. Overall System Performance in Scenario 7 to 11, 7a to 11a, 12 to 16, and 12a to 16a

	Had CM3 A23		CSIROMk2b B11	
	7 to 11	7a to 11a	12 to 16	12a to 16a
Number of failure day	91	93	139	129
Number of consecutive failures	26.9	29.1	40.0	37.1
Maximum failure duration	19	17	19	19
Maximum severity of failure	672.8	672.1	729.5	728.4
Reliability	0.988	0.987	0.981	0.982
Resiliency	0.302	0.323	0.304	0.301
Vulnerability	250.4	249.6	258.5	255.4

Scenario 1b, 3b to 6b (Base Case with more rapid population growth)

In these scenarios, the population input is set to the 2006 estimates to describe a faster growth rate. The more rapid growth rate is approximately double that in scenario 1 to 6 (180.82/80.4219=2.24). By comparing the results of scenario 1 to 6 to scenario 1b to 6b (Table 31), it can be seen that doubling the population growth will significantly reduce the resiliency of the system. With the higher population growth, Ayr’s water supply system may experience seven times more down time (number of failure days from 22.2 to 193).

Table 31. Scenario 1b to 6b Failure Statistics and Performance Measures.

Scenario no.	No. of Days Failed (days)	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
1b	(139 , 196 , 243)	(52 , 70.7 , 85)	(7 , 13.8 , 29)	(2.2 , 2.8 , 3.4)	(1042 , 1442 , 1898)	(15654 , 23534 , 31235)	(38525 , 64184 , 98380)
	23.7	7.0	4.0	0.3	189.0	3336.9	12105.7
3b	(137 , 191.8 , 238)	(52 , 69.3 , 84)	(7 , 13.7 , 29)	(2.2 , 2.8 , 3.4)	(1034 , 1434 , 1889)	(15238 , 23010 , 30667)	(37235 , 62635 , 96469)
	23.7	7.1	3.9	0.3	189.0	3309.3	11951.0
4b	(130 , 183 , 224)	(49 , 66.1 , 83)	(7 , 13.6 , 29)	(2.2 , 2.8 , 3.3)	(1018 , 1418 , 1873)	(14439 , 22059 , 29588)	(34788 , 59639 , 92841)
	23.1	7.0	3.9	0.3	188.9	3247.1	11643.5
5b	(61 , 98.2 , 141)	(22 , 37.3 , 50)	(5 , 10.8 , 22)	(2.1 , 2.6 , 3.5)	(795 , 1195 , 1651)	(6862 , 12038 , 18464)	(13553 , 29244 , 52694)
	18.9	5.8	3.5	0.3	189.0	2475.8	7791.4
6b	(21 , 45.5 , 88)	(9 , 19.7 , 33)	(3 , 7.2 , 18)	(1.5 , 2.3 , 4.1)	(548 , 948 , 1404)	(2296 , 5917 , 11971)	(4067 , 12197 , 26499)
	12.9	5.0	2.7	0.5	189.0	1747.0	4496.5

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
1b	(0.9667 , 0.9732 , 0.981)	(0.2963 , 0.3634 , 0.4573)	(1.2 , 3 , 6.2)	(238 , 333 , 440)	(236 , 326 , 421)	(0.371 , 0.512 , 0.6602)
	0.0032	0.0354	0.9	38	38	0.0594
3b	(0.9674 , 0.9737 , 0.9812)	(0.2983 , 0.3637 , 0.4459)	(1.2 , 3 , 6.3)	(243 , 332 , 433)	(236 , 325 , 424)	(0.37 , 0.5106 , 0.6662)
	0.0032	0.0341	0.9	37	38	0.0591
4b	(0.9693 , 0.975 , 0.9822)	(0.2986 , 0.3635 , 0.4528)	(1.2 , 3.2 , 6.6)	(251 , 334 , 448)	(238 , 324 , 423)	(0.3741 , 0.5094 , 0.6635)
	0.0032	0.0343	1.0	37	38	0.0597
5b	(0.9807 , 0.9866 , 0.9916)	(0.2837 , 0.3854 , 0.4878)	(2.7 , 8 , 24)	(205 , 323 , 462)	(193 , 296 , 430)	(0.3025 , 0.4645 , 0.6749)
	0.0026	0.0467	3.4	46	44	0.0686
6b	(0.988 , 0.9938 , 0.9971)	(0.2453 , 0.4452 , 0.6667)	(4.6 , 28.9 , 116)	(195 , 302 , 485)	(178 , 266 , 414)	(0.2797 , 0.4179 , 0.65)
	0.0	0.0813	17.7	56	52	0.0810

By comparing the averages, relative to the base case scenarios, in scenario 1, 3 to 6, the number of failure days increases almost ten times (from 14.5 to 142.9 days); the maximum failure duration increases three fold (from 3.54 to 11.82 day); the maximum severity of failure increases 81% (from 403 to 1287 m^3). In terms of performance indices, the reliability of the system would decrease from 0.998 to 0.98046, resiliency would decrease from 0.6346 to 0.38424, and the average vulnerability would increase from 155.8 to 324.8 m^3. Figure 36 illustrates the reduction of the RRVs for the base case scenarios and the base case scenarios with double population growth.

Scenario 7-11 versus 7c to 11c (Had CM3 A23)

To investigate the possible outcomes from the combined effect of climate change and rapid population growth, scenarios 7c to 11c determine the system performance subject to future climate scenario Had CM3 A23 with a changing precipitation occurrence rate and a higher population growth rate.

As compared to scenarios 7 to 11, all of the failure measures would increase for the 7c to 11c settings (Table 22 and Table 32). The number of failure days would increase almost four times from 91.04 to 377.84 days; the number of consecutive failures will increase from 26.94 to 84.68; the maximum failure duration would also increase from 19.04 to 41.1 days; and the maximum severity of failure would increase from 673 to 1670 m^3.

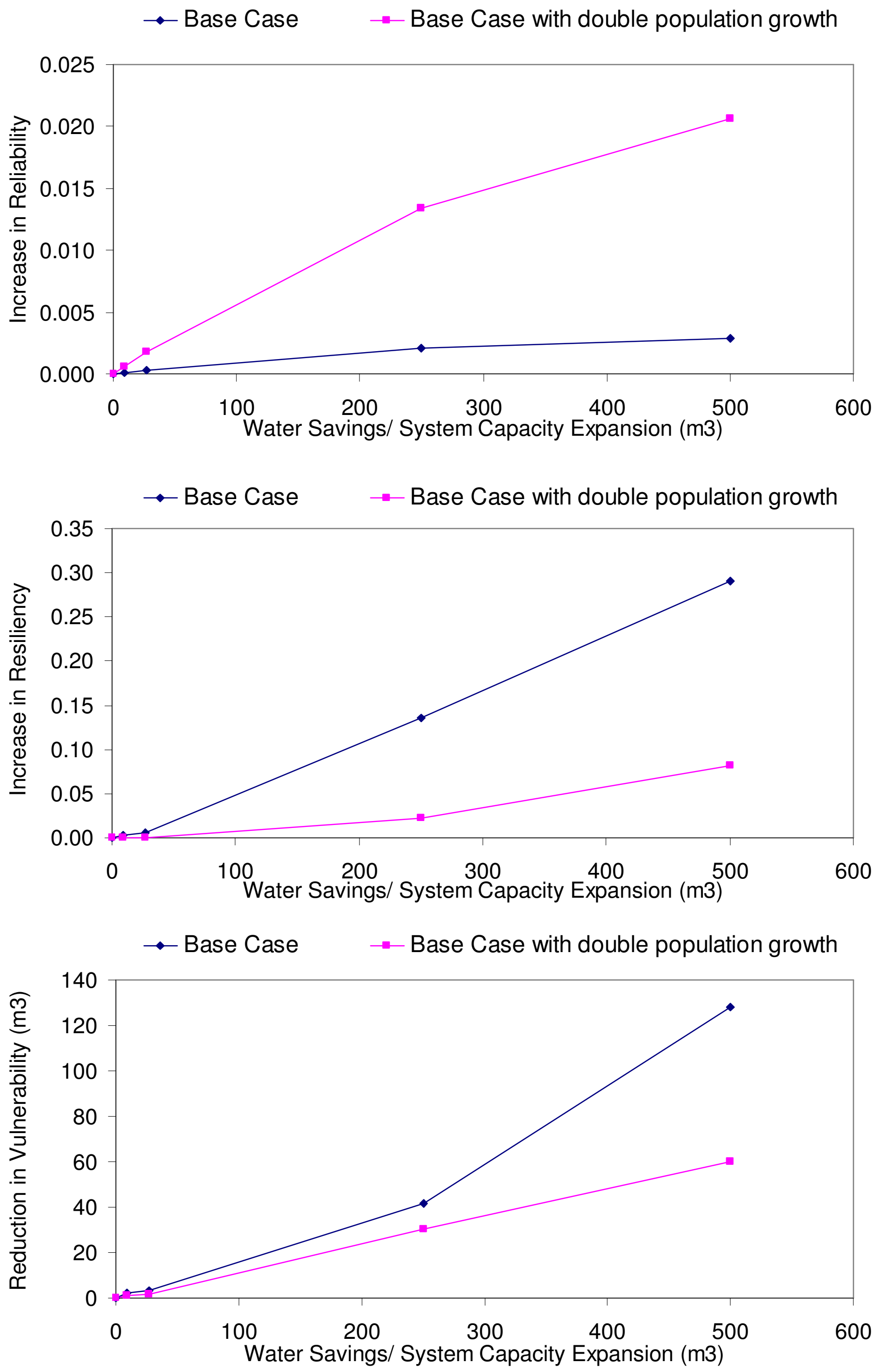


Figure 36. Reductions of Reliability, Resiliency, and Vulnerability in scenario 1b, 3b to 6b.

Table 32. Scenario 7c to 11c Failure Statistics and Performance Measures.

Scenario no.	No. of Days Failed (days)	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
7c	(381 , 470.2 , 551)	(80 , 103.1 , 123)	(23 , 46.7 , 79)	(3.7 , 4.6 , 6)	(1754 , 1834 , 1970)	(33253 , 46282 , 56404)	(180950 , 240372 , 292837)
	37.7	8.5	13.4	0.5	44.4	4121.9	24538.1
8c	(373 , 464.1 , 546)	(79 , 101.7 , 124)	(23 , 46 , 79)	(3.6 , 4.6 , 6)	(1746 , 1825 , 1961)	(33602 , 45689 , 56158)	(177935 , 236646 , 288742)
	37.6	8.7	13.1	0.5	44.4	4076.6	24317.2
9c	(364 , 452.4 , 536)	(79 , 99.3 , 124)	(20 , 45.1 , 79)	(3.7 , 4.6 , 6.2)	(1730 , 1809 , 1945)	(33335 , 44618 , 54954)	(172027 , 229329 , 280698)
	37.7	8.8	13.3	0.5	44.4	4002.6	23880.5
10c	(238 , 311.9 , 381)	(55 , 71 , 94)	(16 , 37.6 , 73)	(3.4 , 4.4 , 6)	(1507 , 1587 , 1723)	(21529 , 30317 , 39417)	(102634 , 144727 , 184331)
	32.8	7.4	12.9	0.5	44.4	3597.7	18081.3
11c	(139 , 190.6 , 252)	(32 , 48.3 , 62)	(13 , 30.3 , 62)	(2.9 , 4 , 5.1)	(1260 , 1340 , 1476)	(12275 , 19481 , 26509)	(48952 , 83510 , 108483)
	25.1	6.2	12.2	0.5	44.4	2881.9	12716.0

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
7c	(0.9246 , 0.9356 , 0.9478)	(0.1673 , 0.2203 , 0.2715)	(0.2 , 0.4 , 0.7)	(367 , 450 , 553)	(423 , 511 , 598)	(0.6639 , 0.8027 , 0.9387)
	0.0052	0.0221	0.1	37	36	0.0562
8c	(0.9253 , 0.9365 , 0.9489)	(0.1673 , 0.2202 , 0.2759)	(0.2 , 0.4 , 0.7)	(374 , 451 , 556)	(421 , 510 , 595)	(0.6604 , 0.8007 , 0.9344)
	0.0052	0.0228	0.1	37	36	0.0567
9c	(0.9266 , 0.9381 , 0.9502)	(0.1618 , 0.2207 , 0.2716)	(0.2 , 0.4 , 0.8)	(366 , 451 , 552)	(412 , 507 , 597)	(0.6468 , 0.7963 , 0.9367)
	0.0052	0.0231	0.1	40	37	0.0577
10c	(0.9478 , 0.9573 , 0.9674)	(0.1667 , 0.229 , 0.2957)	(0.3 , 0.7 , 1.8)	(334 , 429 , 539)	(349 , 465 , 545)	(0.548 , 0.7292 , 0.8555)
	0.0045	0.0260	0.3	41	39	0.0613
11c	(0.9655 , 0.9739 , 0.981)	(0.1958 , 0.2557 , 0.3425)	(0.5 , 1.5 , 3.2)	(276 , 405 , 535)	(335 , 439 , 513)	(0.5263 , 0.6887 , 0.8054)
	0.0034	0.0340	0.7	49	42	0.0663

Consequently, the reliability of the system on average decreased from 0.97926 to 0.94828, resiliency decreased from 0.30238 to 0.22918, and the average vulnerability increased from 291.4 to 437.2 m^3. The results show that a larger population and a changing climate will substantially increase the water demand and therefore lead to a substantial degradation of the system performance.

Scenario 12-16 versus Scenario 12c and 16c (CSIROMk2b B11)

Scenarios 12c to 16c have a similar arrangement as in scenarios 7c to 11c (Table 34). This scenario setting describes the worst-case scenario among all simulation scenarios. Table 33 provides a comparison of the overall average system performance in scenario 7 to 11, 7c to 11c, 12 to 16, and 12c and 16c. The base case results are also included for reference. As shown, under the combined influence of climate change and rapid population growth, the system's operation can be subjected to substantial failure. Figure 37 and Figure 38 illustrates the influences of the combined factors on the system's RRVs in scenario 7 to 11, 12 to 16 and the corresponding sensitivity analysis scenarios.

Table 33. Overall System Performance in Scenario 1, 3 to 6, 7 to 11, 7c to 11c, 12 to 16, and 12c to 16c

	Base Case	Had CM3 A23		CSIROMk2b B11	
	1,3 to 6	7 to 11	7c to 11c	12 to 16	12c to 16c
Number of failure day	14	91	378	139	462
Number of consecutive failures	7.9	26.9	84.7	40.0	100.5
Maximum failure duration	4	19	41	19	43
Maximum severity of failure	402.8	672.8	1678.8	729.5	1739.4
Reliability	0.998	0.988	0.948	0.981	0.937
Resiliency	0.635	0.302	0.229	0.304	0.223
Vulnerability	172.5	250.4	437.1	258.5	462.0

Table 34. Scenario 12c to 16c Failure Statistics and Performance Measures.

Scenario no.	No. of Days Failed (days)	No. of Consecutive Failures	Max. Failure Duration (days)	Avg. Failure Duration (days)	Max Severity of Failure (m^3)	Total Maximum Severity of Sojourn (m^3)	Total Severity of Failure (m^3)
12c	(485 , 564.4 , 657)	(99 , 119.1 , 148)	(28 , 50.7 , 87)	(3.9 , 4.8 , 6.1)	(1546 , 1894 , 1980)	(47208 , 56883 , 71777)	(235624 , 304634 , 374040)
	32.9	9.8	12.2	0.4	46.7	4475.3	26790.1
13c	(477 , 557.3 , 648)	(97 , 117.3 , 147)	(28 , 50.6 , 87)	(3.9 , 4.8 , 6.1)	(1538 , 1886 , 1971)	(46487 , 56139 , 70611)	(231726 , 300177 , 368860)
	32.6	9.9	12.1	0.4	46.7	4420.1	26604.0
14c	(463 , 544.8 , 634)	(95 , 114.6 , 145)	(28 , 49.7 , 87)	(3.9 , 4.8 , 6.1)	(1521 , 1870 , 1955)	(45277 , 54837 , 68653)	(224083 , 291419 , 358687)
	32.2	9.7	12.1	0.4	46.7	4377.0	26233.0
15c	(316 , 388.1 , 474)	(67 , 87.6 , 108)	(18 , 36.9 , 62)	(3.6 , 4.5 , 5.3)	(1299 , 1647 , 1733)	(30618 , 39857 , 49980)	(134576 , 187775 , 234530)
	30.2	7.5	9.5	0.4	46.7	3529.5	21157.6
16c	(192 , 253.9 , 319)	(46 , 63.9 , 81)	(12 , 27.4 , 53)	(3.1 , 4 , 5.7)	(1052 , 1400 , 1486)	(19111 , 26396 , 33976)	(66251 , 109481 , 146374)
	24.5	6.4	8.7	0.5	46.7	3090.2	16262.8

Scenario no.	Reliability, α	Resiliency, γ_1 F(E(Tf))	Resiliency, γ_3 1/(MD/NS*NF)	Vulnerability, ν_1 (m^3)	Average Vulnerability, ν_3 (m^3)	Normalized Average Vulnerability, ν_3'
12c	(0.9101 , 0.9227 , 0.9336)	(0.1638 , 0.2115 , 0.2548)	(0.1 , 0.3 , 0.5)	(391 , 479 , 579)	(466 , 540 , 635)	(0.7312 , 0.8472 , 0.9976)
	0.0045	0.0182	0.1	36	34	0.0532
13c	(0.9113 , 0.9237 , 0.9347)	(0.1643 , 0.211 , 0.2559)	(0.1 , 0.3 , 0.5)	(387 , 480 , 589)	(463 , 538 , 637)	(0.7264 , 0.8453 , 0.9999)
	0.0045	0.0185	0.1	37	34	0.0536
14c	(0.9132 , 0.9254 , 0.9366)	(0.1644 , 0.2109 , 0.2551)	(0.1 , 0.3 , 0.6)	(409 , 480 , 591)	(460 , 535 , 634)	(0.7219 , 0.8395 , 0.9956)
	0.0044	0.0190	0.1	37	34	0.0533
15c	(0.9351 , 0.9469 , 0.9567)	(0.1875 , 0.2264 , 0.2794)	(0.3 , 0.6 , 1.3)	(351 , 457 , 567)	(404 , 484 , 574)	(0.6336 , 0.7593 , 0.9006)
	0.0041	0.0207	0.2	37	37	0.0587
16c	(0.9563 , 0.9652 , 0.9737)	(0.1767 , 0.2529 , 0.3271)	(0.5 , 1.2 , 2.8)	(326 , 414 , 506)	(294 , 431 , 521)	(0.4622 , 0.6759 , 0.8177)
	0.0033	0.0276	0.4	39	44	0.0688

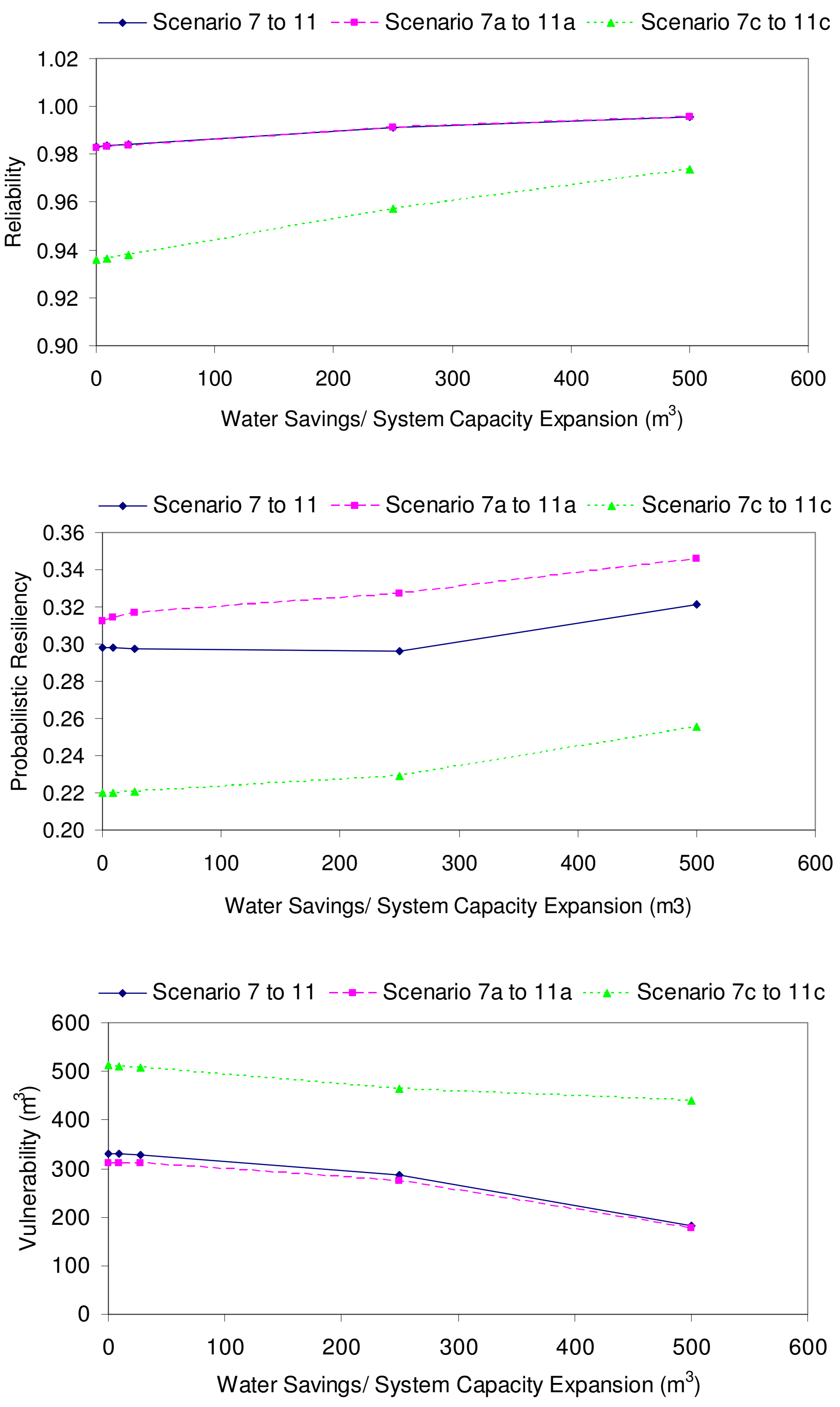


Figure 37. Reductions of Reliability, Resiliency, and Vulnerability of scenario 7 to 11, 7a to 11a and 7c to 11c.

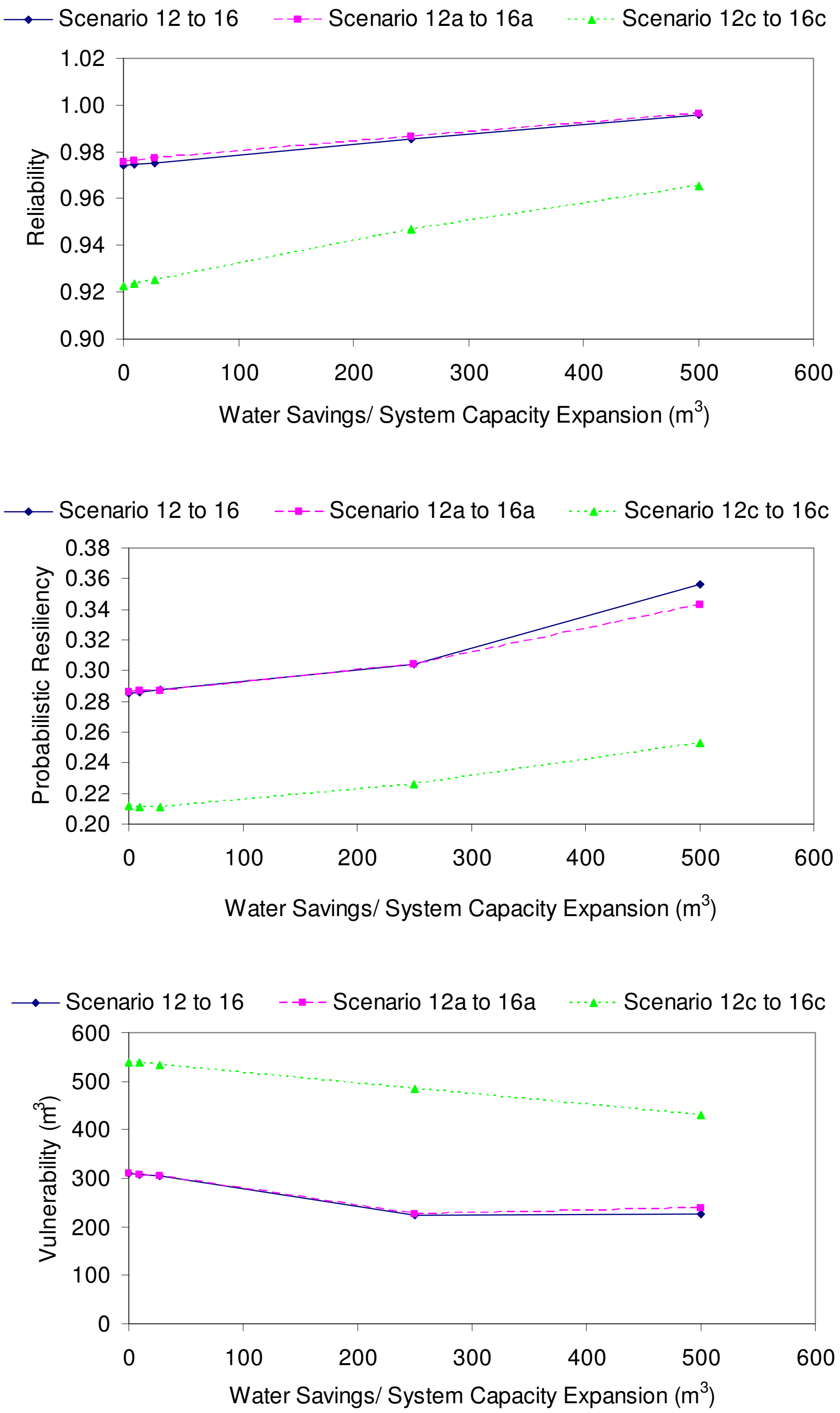


Figure 38. Reductions of Reliability, Resiliency, and Vulnerability of scenario 12 to 16, 12a to 16a and 12c to 16c.

5.4 Tradeoffs

In many municipalities, water supply systems are operating close to capacity, such that the systems must be expanded and/or conservation actions must be taken. The simulation results were used to derive tradeoff relationships between spending and risk measures with different system configurations, climatic conditions and population growth rate settings. These relationships can be used to conduct cost-benefit analysis to aid decision makers in allocating resources to prepare for future needs.

In this study, vulnerability is calculated as the expected magnitude of water shortage during a failure and is measured in m^3. To have all of three indices on the same magnitude of axis, the vulnerability measures is standardized by the existing system capacity.

Tradeoff relationships between costs and system performance are found in the simulation results and are plotted in Figure 39. In Figure 39, each point represents the average of a scenario and linear relationships are assumed between any two points in the same set of scenarios. As illustrated, more spending would lead to greater improvement. However, the tradeoffs vary under different climatic conditions. For example, to provide for the level of protection, as illustrated in the top figure, a spending of $1,100,000 is required to achieve a reliability of 0.99 in HadCM3 A23, but in CSIROMK2b B11 spending $1,460,000 is required to reach the same level of reliability.

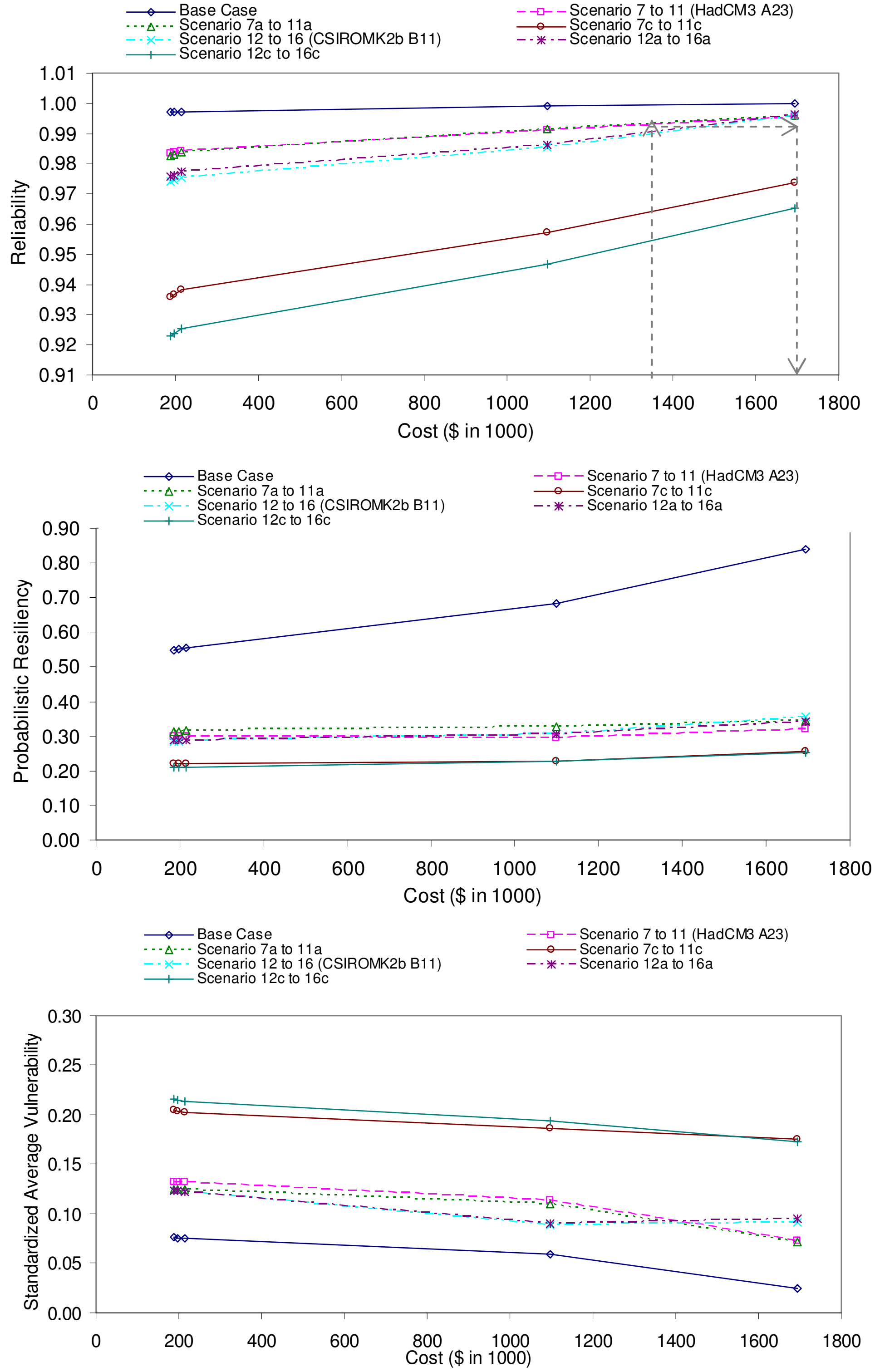


Figure 39. Performance Indices and Costs Tradeoff

5.5 Optimization

In making the decision for a water supply system expansion, many factors come into play. Upon reviewing the features of the four alternatives evaluated in the risk assessment, each alternative is assigned a number of characteristic measures to account for cost and associated performance.

Compromise programming was used to account for all of the characteristic variables and possible combinations of alternatives, to produce an objective decision aid for decision makers to reconfigure the existing water management systems.

The Euclidean distance, d_i, from the ideal point in objective space to a scenario i is calculated using

$$d_i = \sqrt{(p_1 - q_{1i})^2 + (p_2 - q_{2i})^2 + (p_3 - q_{3i})^2} \qquad \textbf{\textit{(33)}}$$

where p_1, p_2, p_3 are the ideal reliability, α^*, resiliency, $\gamma_1{}^*$, and the normalized vulnerability indices, $v_3{}'^*$ (1, 1, 0) and q_{1i}, q_{2i}, and q_{3i} are the RRV indices of scenario i. Table 35 lists the costs and performance indices of the existing conditions and the four alternatives. Note that the cost for the existing conditions is for the continuation of the toilet replacement program, the implementation of outdoor water use by-law, and other educational water efficiency management programs.

Table 35. Costs and Performance Indices of Alternatives in Base Case Scenario.

System Performance	Alternatives				
	(1) Existing Conditions	(2) 5% additional WEMPs savings	(3) 15% additional WEMPs savings	(4) 10% additional system capacity	(5) 20% additional system capacity
Reliability (maximize)	0.99695	0.99704	0.99725	0.99905	0.99981
Resiliency (maximize)	0.548	0.550	0.554	0.683	0.838
Vulnerability (minimize)	0.076	0.075	0.075	0.060	0.025
Euclidean Distance	0.458	0.456	0.452	0.322	0.164
Costs ($ in 1000)	187.02	196.371	215.073	1097.5	1695

When evaluating the use of a combination of alternatives, there are two objective functions that must be formulated to solve this problem: Cost and the Euclidean distance based on the three performance measures. Given the four possible improvement alternatives, a set of feasible solutions was generated, as below.

5.5.1 Optimization Results

In ranking the alternatives using comprise programming, it was first assumed that the two categories, cost and system performance, are of equivalent importance. Detailed results of the comprise programming are included in Appendix D. Table 36 shows the rankings of the alternatives with $\alpha_1=\alpha_2=1$, thus the two objectives are weighted equally (see equation 24 for objective function formulation).

Table 36. Ranking of Alternatives with $\alpha_1 = \alpha_2 = 1$

	s=	1	s=	2	s=	100
Alternative Implementation	$L_s(x)$	Rank	$L_s(x)$	Rank	$L_s(x)$	Rank
Alterative 1	1.000	3	1.000	4	1.00	4
Alterative 2	0.999	2	0.985	3	0.46	3
Alterative 3	0.998	1	0.960	2	0.13	2
Alterative 4	1.142	5	0.655	1	0.00	1
Alterative 5	1.000	3	1.000	4	1.00	4

For s = 1, all deviations are weighted equally. For s = 2, each deviation is weighted in proportion to its magnitude. As s becomes larger and larger, the largest deviation receives more and more weight, which shows that the decision maker's concern on the maximal deviation can be reflected on the choice of s, that is, the larger the value of s, the greater the concern. As shown in the ranking table alternative 3 is ranked first if s = 1. Interestingly if s = 2 or 100, alternative 4 becomes the best alternative.

5.6 Sensitivity Analysis

Alphas represent the relative importance of the objectives and can be adjusted to reflect the decision maker's weighting on the objectives. Two weighting assignments are selected to illustrate the nondominated set rankings with emphasis on the two objectives, as follows.

Emphasis on Cost: $\alpha_1=10$; $\alpha_2=1$;

Emphasis on System Performance: $\alpha_1=1$; $\alpha_2=10$;

The ranked alternatives with s equals to 1, 2, and 100 for the two weight assignment schemes are shown in Table 37 and Table 38. The detailed ranking results are also included in Appendix D.

Table 37. Ranking of Compromise Solutions with α_1=10 and α_2=1.

	s=	1	s=	2	s=	100
Alternative Implementation	$L_s(x)$	Rank	$L_s(x)$	Rank	$L_s(x)$	Rank
Alterative 1	1.000	1	1.000	3	1.000	4
Alterative 2	1.055	2	0.985	2	0.463	3
Alterative 3	1.166	3	0.963	1	0.126	2
Alterative 4	6.579	4	3.939	4	0.000	1
Alterative 5	10.000	5	10.000	5	10.00	5

Table 38. Ranking of Compromise Solutions with α_1=1 and α_2=10.

	s=	1	s=	2	s=	100
Alternative Implementation	$L_s(x)$	Rank	$L_s(x)$	Rank	$L_s(x)$	Rank
Alterative 1	10.000	5	10.000	5	10.00	5
Alterative 2	0.999	2	9.847	4	4.625	4
Alterative 3	0.998	1	9.594	3	1.258	3
Alterative 4	1.142	4	3.261	2	0.000	1
Alterative 5	1.000	3	1.000	1	1.000	2

The rankings show that the first three ranked implementation schemes with emphasis on cost and system performance are identical to that with the two objectives equally weighted. With emphasis on cost, the first ranked implementation scheme would be alternative 1 for s=1 and alternative 3 for s=2. Interestingly, if s =100, the first comprise solutions are identical in all three weighting schemes. Therefore, it is concluded that alternative 4 is the ultimate comprise solution. It is not a coincidence to have alternative 4 reappearing in all of the first three ranked comprise solutions. This ranking result is attributed by the performance of the alternative, which is relatively high as compared to alternatives 1, 2, and 3 and a lower cost than alternative 5.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

This study aimed to assess the impacts of population growth and fluctuating climate conditions on the performance of a municipal water supply system. A hybrid model was developed which combines a data-derived stochastic component with a deterministic artificial neural network. The simulation model takes in climatic variables and water consumption patterns derived from historical records and projects future water demands under different assumptions. The model was used to estimate the effects of water efficiency management programs and system expansion on improving the system.

The impact of future climate change was assessed in two ways and compared. First, the possible outcomes of a changing monthly mean temperature and precipitation magnitude as projected by a selection of Globe Climate Models (GCMs) is estimated. Second, the possible outcomes of a change in precipitation amount represented by a change of precipitation pattern is investigated.

The simulation results suggest that a rise in temperature and a change in precipitation magnitude will have a negative impact on the performance of the system. For example, under the worst case climate change scenario and the current water supply system, average future reliability, resilience, and vulnerability values are projected to be 0.981, 0.304, and

258.5 m^3, respectively. This compares with average future reliability, resilience, and vulnerability values of the current system with no climate change 0.998, 0.635, and 172.5 m^3. The results also suggest that a reduction of precipitation may worsen the system performance. Conversely, an increase of precipitation may lessen the impacts of a warmer climate.

A more rapid population growth will substantially increase the water demand, showing that expansion of the current system is required. For example, under more rapid growth and without expansion, the current system has an estimated reliability of 0.923 under the worst case climate scenario. With expansion option increasing system capacity by 20%, this reliability is improved to 0.965.

To complete the analysis, a multiobjective optimization problem consisting of two objectives was formulated to help identify a recommended management alternative. Four feasible system improvement alternatives were generated. By using compromise programming, the alternative to increase system capacity by 10% was ranked first. This compromise solution has emphasis on the aspects of cost and the overall performance measures.

6.2 Recommendations

It was attempted to introduce source water quality parameters into the risk assessment. Because of the lack of representative data, such analysis was not possible. It is recommended that more frequent water sampling be conducted by the Region of Waterloo to provide continuous water quality monitoring.

The effect of conservation is hard to estimate and substantial savings are difficult to achieve. However, the conservation technology is readily available and more intense water efficiency management program is recommended.

6.2.1 Direction of Future Work

Additional research could be done in a few areas, as follows:

Analysis on the required insurance capacity for fire protection was not conducted. The existing model can be modified to incorporate such analysis. By using the following equation in the National Board of Fire Underwriters, the required fire demand can be estimated.

$$F = 320\,C\sqrt{A}$$

where F is the required fire flow in m^3/d, C is a coefficient depending on the type of construction, and A is the total building floor area in the municipality (Tchobanoglous and Schroeder, 1987)

As reported in the literature, a reduction of 10 to 25 percent in water consumption can be achieved without significantly changing people's life-style (Droste, 1997). It would be interesting to see the temporal effects of an intensive water efficiency management program

on the water demand. In particular, of interest is the relative benefit on the system performance of such seasonal savings as compared to a fixed increase of capacity.
In this study, water savings are assumed to be fixed. However, there are many factors affecting water use. These factors include geographic location, type of community, economic status, water pressure, cost and need for conservation. To carry the study one step further, investigation on the actual effectiveness of water conservation is needed. Alternatively, effectiveness can be considered uncertain.

To make the optimization weighting scheme more relevant, a survey of decision makers' perceptions can be conducted.

Risk is simply defined as a product of probability of failure and the consequence of a failure. The hidden costs and loss of revenue for residences and businesses due to a water supply system shut down was not estimated. A more thorough risk management study can be conducted by building on the current risk assessment process and by incorporating study on the social, environmental, economical impacts. With sufficient data, the risk assessment can be expanded to cover risks in all basic components of the water supply system.

Of interest is to take into account the possible impacts of climate change on water infiltration as a result of a reduction in precipitation and an increase of evaporation potential. As pointed out in 2001 Groundwater Monitoring Report, the water taking rate in the Region of Waterloo is less than 25% of the recharge rate. However, with a rapid population growth and change of land use, an assessment on the risk of over-exploitation of underground water sources is needed.

In conducting the risk assessment simulation, to compromise with the time and computation constraints, 100 trials were run for each scenario. More analysis on the simulation results is needed to assess the number of simulation trials required for a particular confidence level.

The GCM precipitation scaling algorithm for a changing occurrence rate needs to be revised to reflect monthly scaling of precipitation. Currently, the scaling is done once by matching the total precipitation volume generated by frequency change to that with scaled magnitudes for the entire time horizon of interest (see section 4.3.2.1).

Uncertainties exist in the GCM projections of the temperature and precipitation change. The individual effects of an increase of average temperature, a reduction in precipitation, and the fluctuations in the GCM estimates, on the risk in the system is unclear. Additional studies are needed to if the independent influence of these two factors are desired.

6.3 Concluding Thoughts

Concerns regarding of the reliability of water supply systems to meet the future needs are growing in the Kitchener and Waterloo area in spite of the on-going research to monitor and recharging of aquifers. Further studies are needed to identify the possible shortage of water to aid the local authority in allocating their resources to the most pressing problem. In addition, the current communication between municipalities and public can be improved to give greater emphasis on the water saving strategies such as alternative landscaping techniques, recycle use of water, or reduction of leakage loss from the point of conservation. In summary, with improved management of source water, understanding of the effects of climate change on water supply demands and reduction of water uses in response to conservation efforts, and cost-effective approaches to optimize the performance of water supplies system, a sustainable reliable water supply will be available to the future public.

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Appendix A

Sample Raw Data

University of Waterloo Weather Station Daily_summary_2006

Date	Low temperat	High tempera	Precipitation
01-Jan-06	-3.6	1.8	0.5
02-Jan-06	-0.4	1.4	4.5
03-Jan-06	-0.2	1.2	0.1
04-Jan-06	0.8	4.6	3
05-Jan-06	-3.7	3.1	4.4
06-Jan-06	-9.9	-3.9	0.1
07-Jan-06	-7.1	-1.4	2.8
08-Jan-06	-4.3	0.1	0.2
09-Jan-06	-0.4	1.6	0.5
10-Jan-06	-3	0.3	0
11-Jan-06	-0.4	7.6	2.9
12-Jan-06	1.6	7	0
13-Jan-06	4.5	8.4	3.2
14-Jan-06	-7	6.1	0.8
15-Jan-06	-11.3	-5.9	0
16-Jan-06	-11.6	-5.6	0
17-Jan-06	-5.8	4.7	14.6
18-Jan-06	-4.6	4.5	7.9
19-Jan-06	-5.5	5.8	0.1
20-Jan-06	0.3	8.3	3.4
21-Jan-06	-6.4	0.2	16.6
22-Jan-06	-9.1	1.7	0
23-Jan-06	-4.8	0.2	0.1
24-Jan-06	-3.9	1.3	3.1
25-Jan-06	-10.7	-0.2	1.1
26-Jan-06	-15.5	-7.9	0
27-Jan-06	-15.6	2.9	0.2
28-Jan-06	1.6	7.5	0
29-Jan-06	2.1	7.5	20
30-Jan-06	1.7	6.9	0.2
31-Jan-06	-2.3	1.6	0
01-Feb-06	-3.5	2.6	0.2
02-Feb-06	1.1	3.1	2.4
03-Feb-06	0.2	2.3	10.1
04-Feb-06	0.2	2.7	28.1
05-Feb-06	-5.9	0.5	5.9
06-Feb-06	-7.4	-3.6	4.2
07-Feb-06	-7	-3	1.8
08-Feb-06	-15.7	-6.6	0
09-Feb-06	-17.8	-6.7	0.5
10-Feb-06	-9.2	-1.8	1
11-Feb-06	-16.7	-3.5	0
12-Feb-06	-18.3	-5.5	0
13-Feb-06	-8.8	-4.3	0.9
14-Feb-06	-5.1	2.2	0
15-Feb-06	0.4	3.9	0
16-Feb-06	-3.7	6.9	25.7
17-Feb-06	-9.2	7.5	12.8
18-Feb-06	-15	-9.8	0
19-Feb-06	-14.4	-9.8	0
20-Feb-06	-11.3	-5.3	1.2
21-Feb-06	-12.5	-1.6	0
22-Feb-06	-12.7	3.9	0
23-Feb-06	-7.1	3.2	0.3
24-Feb-06	-10.5	-2.7	0.5
25-Feb-06	-8.9	0.9	0
26-Feb-06	-17.2	-8.2	0.2
27-Feb-06	-19.7	-5.1	1.1
28-Feb-06	-18.6	-5.6	0

Date	Low temperat	High tempera	Precipitation
01-Mar-06	-13	-3.6	0
02-Mar-06	-12	-3.3	0
03-Mar-06	-14	-5.1	0
04-Mar-06	-9.1	0	0
05-Mar-06	-8.9	1.3	0
06-Mar-06	-10.3	0.4	0
07-Mar-06	-12.4	-0.1	0
08-Mar-06	-8.8	2.1	0
09-Mar-06	1.2	9.3	24
10-Mar-06	-1.1	9.5	5.6
11-Mar-06	-2.9	10.7	0
12-Mar-06	2.2	12.5	6.4
13-Mar-06	2.3	15.6	14.1
14-Mar-06	-3.4	4	2.4
15-Mar-06	-3.7	1.1	1.1
16-Mar-06	-4.8	2.5	0.2
17-Mar-06	-7.1	-1	0
18-Mar-06	-6.6	-2.6	0.1
19-Mar-06	-4.8	-1.8	1.3
20-Mar-06	-7.6	-2.6	0
21-Mar-06	-9.6	-1.1	0
22-Mar-06	-3.3	-0.3	0
23-Mar-06	-3.4	1.4	0
24-Mar-06	-1.3	2.5	0
25-Mar-06	-1.4	3.6	6.3
26-Mar-06	-1.9	6.1	0
27-Mar-06	-4.4	9.3	0
28-Mar-06	-2.5	10.5	0
29-Mar-06	-3.5	13	0
30-Mar-06	-1.3	15.9	0
31-Mar-06	2.5	19.3	2.5
01-Apr-06	0.7	12.2	3.8
02-Apr-06	-2.7	11.4	0.2
03-Apr-06	0.6	17	1.8
04-Apr-06	-3.8	4.6	0.2
05-Apr-06	-4	3.3	1.2
06-Apr-06	0.4	12.3	0
07-Apr-06	-0.5	6.4	11.8
08-Apr-06	-4.5	2.8	0
09-Apr-06	-4.9	8.2	0
10-Apr-06	-1.6	13.7	0
11-Apr-06	-0.5	18.6	0
12-Apr-06	7.8	15.3	15.4
13-Apr-06	6.2	19.7	0
14-Apr-06	9.2	15	2.4
15-Apr-06	5	14	0.2
16-Apr-06	2.9	13.9	0
17-Apr-06	2.9	13.4	0
18-Apr-06	1.4	18.6	0
19-Apr-06	3.1	21.7	0
20-Apr-06	4.6	23.5	0
21-Apr-06	10.4	18.4	0.4
22-Apr-06	7.2	11.4	6
23-Apr-06	6.4	8.5	26.6
24-Apr-06	5.8	11.6	0.6
25-Apr-06	-0.8	10.5	0.4
26-Apr-06	-1.2	15.6	0
27-Apr-06	1.5	12	0
28-Apr-06	-2.3	13.8	0
29-Apr-06	-0.5	14.7	0
30-Apr-06	7.8	18.3	0

Date	Low temperat	High tempera	Precipitation
01-May-06	7.4	19	0
02-May-06	3	19.8	0
03-May-06	3.9	23.3	0
04-May-06	7.9	21.1	0
05-May-06	4.4	15.2	1
06-May-06	0.7	9.9	2.4
07-May-06	-1.1	17.2	0
08-May-06	2.3	21.7	0
09-May-06	6.6	21.2	0
10-May-06	5.8	23.9	0
11-May-06	10.8	16.3	29.2
12-May-06	9.3	13.6	5.6
13-May-06	9.2	17.1	0.2
14-May-06	10.5	16.1	0.2
15-May-06	9.9	15.3	1.8
16-May-06	9.5	14.8	11.8
17-May-06	8.5	19	0.2
18-May-06	6.1	11.9	19.2
19-May-06	6	12.8	0.4
20-May-06	6.2	15	0.2
21-May-06	2.7	10.7	3.2
22-May-06	1.1	7.8	0
23-May-06	2.1	16.1	0
24-May-06	4	22.3	0
25-May-06	13.9	23.5	0
26-May-06	14.2	18.9	4
27-May-06	12.2	24.7	0.2
28-May-06	11.8	27.6	0
29-May-06	20.3	32.7	0
30-May-06	19.1	31.4	0
31-May-06	19.2	27.9	33.8
01-Jun-06	17.1	23.3	0
02-Jun-06	15	22.9	4.2
03-Jun-06	13.3	20.7	3.4
04-Jun-06	12.9	21.2	0
05-Jun-06	11.7	25.1	0
06-Jun-06	11	27.2	0
07-Jun-06	12.9	26.9	0
08-Jun-06	13.1	24.7	8.6
09-Jun-06	8.7	16.6	0
10-Jun-06	7.1	15.1	0
11-Jun-06	6	16.4	0
12-Jun-06	10.9	20.4	0
13-Jun-06	8.7	20.7	0
14-Jun-06	10.2	23.3	0
15-Jun-06	9.6	23.9	0
16-Jun-06	9.7	26.7	0
17-Jun-06	20.7	31.1	0
18-Jun-06	20.7	28.8	0
19-Jun-06	18.2	26.6	3.6
20-Jun-06	12.1	21.4	0.2
21-Jun-06	10.4	22.8	0
22-Jun-06	17.5	27.8	0
23-Jun-06	14.5	24.7	0
24-Jun-06	10.4	25.4	0
25-Jun-06	12.4	26	0
26-Jun-06	17.6	22.6	0
27-Jun-06	17.7	25.6	1
28-Jun-06	15.1	26.2	10.2
29-Jun-06	13.7	21.1	1.4
30-Jun-06	13.7	24.6	0.2

Date	Low temperat	High tempera	Precipitation
01-Jul-06	15.9	26.6	0.8
02-Jul-06	21.3	28	0.4
03-Jul-06	19.5	28.2	0
04-Jul-06	14.1	26.2	11.2
05-Jul-06	11.4	20.6	0
06-Jul-06	10.1	22.6	0
07-Jul-06	10.5	26.4	0
08-Jul-06	13	26.6	0
09-Jul-06	17.2	26.4	0
10-Jul-06	17.2	22.9	24
11-Jul-06	16.2	26.9	0.4
12-Jul-06	17.8	22	47
13-Jul-06	15.6	29.1	0
14-Jul-06	17	29.5	2.4
15-Jul-06	20	28.7	3
16-Jul-06	19.4	31.5	0
17-Jul-06	20	31.2	0
18-Jul-06	17.2	26.9	0
19-Jul-06	13.9	27.6	0
20-Jul-06	15.9	26.9	26.2
21-Jul-06	18.8	26.8	0
22-Jul-06	15.6	21.9	0
23-Jul-06	12.1	23	18.4
24-Jul-06	12.8	26.2	0
25-Jul-06	20.3	27.5	0.2
26-Jul-06	20.4	26.8	8
27-Jul-06	20.4	28.5	0.8
28-Jul-06	19.9	27.5	9.4
29-Jul-06	21.1	30.2	0
30-Jul-06	18.8	28.1	0
31-Jul-06	20	31.9	0
01-Aug-06	25.3	33.7	0
02-Aug-06	20.9	32.7	12.4
03-Aug-06	17.6	22.1	17
04-Aug-06	14.8	26.9	0.2
05-Aug-06	12.7	26.4	0
06-Aug-06	16.4	27.5	0
07-Aug-06	16.6	26.3	0
08-Aug-06	11.8	23.5	0
09-Aug-06	9.3	25.6	0
10-Aug-06	14.7	25.6	0
11-Aug-06	10.9	22.3	0
12-Aug-06	7.7	23.6	0
13-Aug-06	7.8	24.8	0
14-Aug-06	12.2	24.2	7
15-Aug-06	13.5	23.1	0.2
16-Aug-06	11.9	24.8	0
17-Aug-06	10.3	25.4	0
18-Aug-06	15	28.5	0
19-Aug-06	19.4	23.4	4.8
20-Aug-06	13.2	20.5	0.2
21-Aug-06	10.4	24.6	0.2
22-Aug-06	12.7	25	0
23-Aug-06	11.2	24.7	0
24-Aug-06	14.6	21.9	0
25-Aug-06	15.3	17.9	8
26-Aug-06	14.7	20.8	1
27-Aug-06	17.1	25.1	0.2
28-Aug-06	15.4	22.9	0.8
29-Aug-06	14.9	23.8	0.4
30-Aug-06	12.1	22.3	0
31-Aug-06	10.3	20.2	0

Date	Low temperat	High tempera	Precipitation
01-Sep-06	10.9	22	0
02-Sep-06	12.4	16.9	8.8
03-Sep-06	11.5	16.8	4
04-Sep-06	12.1	20.6	0.2
05-Sep-06	12.1	20.4	0
06-Sep-06	12.5	22.9	0
07-Sep-06	9.3	23.3	0
08-Sep-06	15.2	25.7	0.2
09-Sep-06	7.5	17.2	0.8
10-Sep-06	6.1	16.6	0.2
11-Sep-06	8	16.8	0
12-Sep-06	13.8	15.7	15.2
13-Sep-06	14.9	22.8	14.4
14-Sep-06	14.7	18	0.2
15-Sep-06	11.4	19.6	0.4
16-Sep-06	9.9	20.4	0
17-Sep-06	12.7	23.4	0.2
18-Sep-06	13	22.2	23
19-Sep-06	11.6	16.3	0.2
20-Sep-06	7.4	12.9	0.4
21-Sep-06	5.9	16.1	0.4
22-Sep-06	4.4	16.2	1.4
23-Sep-06	15.4	22.6	10.6
24-Sep-06	9.7	18.9	5
25-Sep-06	6.7	17.3	0.4
26-Sep-06	7.6	17.8	0.2
27-Sep-06	9.7	21.3	19.4
28-Sep-06	4.8	12.1	0
29-Sep-06	2.3	12.1	0
30-Sep-06	7.6	12.1	11.6
01-Oct-06	5.2	15.3	0.2
02-Oct-06	4.1	20.8	0
03-Oct-06	14.1	22.6	3.4
04-Oct-06	6.3	18.9	23.8
05-Oct-06	2.2	12	0
06-Oct-06	1.3	13.9	0
07-Oct-06	-0.2	17.9	0.2
08-Oct-06	1.3	21	0
09-Oct-06	9	18.4	0.2
10-Oct-06	8.4	16.5	1.4
11-Oct-06	8.4	16.7	20.8
12-Oct-06	-0.6	8.5	0.8
13-Oct-06	-0.3	4.8	1.2
14-Oct-06	2.1	7.1	1.8
15-Oct-06	1.1	10	0
16-Oct-06	-1.1	14.3	0
17-Oct-06	8.3	13.9	27.2
18-Oct-06	10	14.8	0
19-Oct-06	2.3	13.6	6.6
20-Oct-06	1.9	7.2	0.4
21-Oct-06	2.2	8.6	0
22-Oct-06	2.4	9.9	10.8
23-Oct-06	0.9	5.2	0.2
24-Oct-06	0.9	6.2	0.6
25-Oct-06	1.8	6.3	0
26-Oct-06	0	6.3	0
27-Oct-06	0	4.2	14.6
28-Oct-06	1.2	4.5	10.6
29-Oct-06	0.5	5.2	5.8
30-Oct-06	1.2	15.3	0
31-Oct-06	2.6	14.3	0.8

Date	Low temperat	High tempera	Precipitation
01-Nov-06	-1.6	6.2	0
02-Nov-06	-2.6	1.5	0
03-Nov-06	-2.5	2	0.6
04-Nov-06	-3.7	3.7	0
05-Nov-06	2.6	9.6	0
06-Nov-06	-2.1	14.1	0
07-Nov-06	6.8	9.6	10.8
08-Nov-06	7.1	12	0.4
09-Nov-06	4.6	14.9	0
10-Nov-06	3.1	6.9	0
11-Nov-06	0.9	5.4	5.6
12-Nov-06	-0.4	1.8	0
13-Nov-06	1.4	4.2	0.2
14-Nov-06	3.5	5	0
15-Nov-06	1	9	4
16-Nov-06	4.3	12	21.6
17-Nov-06	1.7	4.1	2
18-Nov-06	-1.4	3.7	0
19-Nov-06	-0.7	1.1	0
20-Nov-06	-2	0.4	0
21-Nov-06	-4.7	4.9	0
22-Nov-06	-5.4	7	0.2
23-Nov-06	-2.2	10.8	0
24-Nov-06	-3.6	10.3	0
25-Nov-06	-3.4	12.8	0
26-Nov-06	6.5	13.3	0.2
27-Nov-06	6.6	13.1	0
28-Nov-06	4.9	10.6	0
29-Nov-06	5.1	15	1.2
30-Nov-06	0.9	14.9	21.8
01-Dec-06	-1.1	4.2	35.1
02-Dec-06	-2.5	0.1	0.4
03-Dec-06	-6.3	-1.5	0.3
04-Dec-06	-7.1	-3.6	1.6
05-Dec-06	-8.7	-2.8	0.5
06-Dec-06	-4.1	2.1	5.3
07-Dec-06	-15.4	-1.6	1.5
08-Dec-06	-15.5	-3.9	1.1
09-Dec-06	-6.4	0.6	0.3
10-Dec-06	-1.5	5.9	0.2
11-Dec-06	1.7	4.1	1.1
12-Dec-06	3.1	8.6	1.7
13-Dec-06	0	7.2	6.7
14-Dec-06	1.5	9.7	0.1
15-Dec-06	0.9	7.7	0.2
16-Dec-06	-1.2	5.6	0.1
17-Dec-06	4.1	10.1	0
18-Dec-06	-0.3	4.9	0
19-Dec-06	-1.9	1.4	0
20-Dec-06	-1.4	5.5	0.1
21-Dec-06	-1	5.3	0
22-Dec-06	2	8.5	17.3
23-Dec-06	2	8.1	1.4
24-Dec-06	-0.5	4.2	0.1
25-Dec-06	-0.2	2.7	1.5
26-Dec-06	-2.1	2.8	1.7
27-Dec-06	-1.9	0.7	0.2
28-Dec-06	0.3	2.6	0.1
29-Dec-06	-2.9	0.7	0
30-Dec-06	-3.3	1.2	0.4
31-Dec-06	-3.4	4.9	7.4

Ayr Daily Water Demand

DATE	A1 Pumpage (m3)	A2 Pumpage (m3)	Ayr Tank Level (@6:00 am) (Metre)	Daily Consumption (m3)
1/1/00	0	1217	348.62	1406
1/2/00	0	967	347.13	744
1/3/00	0	1108	348.79	1263
1/4/00	685	438	347.51	1022
1/5/00	743	0	348.32	670
1/6/00	1034	0	348.8	1086
1/7/00	1144	0	348.37	1224
1/8/00	859	0	347.83	820
1/9/00	1326	0	348.1	1356
1/10/00	843	0	347.77	861
1/11/00	276	731	347.66	896
1/12/00	0	841	348.42	789
1/13/00	0	1014	348.69	1012
1/14/00	0	965	348.64	942
1/15/00	0	1145	348.89	1237
1/16/00	0	1263	348.12	1368
1/17/00	0	1076	347.37	1040
1/18/00	668	199	347.63	754
1/19/00	828	0	348.49	764
1/20/00	1000	0	348.78	985
1/21/00	1038	0	348.97	1127
1/22/00	1224	0	348.34	1364
1/23/00	1107	0	347.11	941
1/24/00	1190	0	348.47	1121
1/25/00	994	43	348.86	1059
1/26/00	1003	0	348.61	1016
1/27/00	1016	0	348.53	939
1/28/00	1001	0	348.92	1086
1/29/00	1055	0	348.23	1045
1/30/00	1224	0	348.34	1160
1/31/00	416	717	348.69	1180
2/1/00	0	943	348.27	861
2/2/00	0	1022	348.79	1008
2/3/00	0	1062	348.75	1087
2/4/00	9	922	348.53	962
2/5/00	0	1186	348.27	1099
2/6/00	0	1028	348.86	1115
2/7/00	0	1041	348.3	991
2/8/00	105	948	348.58	1007
2/9/00	0	1049	348.89	1052
2/10/00	0	1015	348.83	1001
2/11/00	0	984	348.79	982
2/12/00	0	1128	348.79	1233
2/13/00	0	1038	348.1	982
2/14/00	0	1140	348.43	1080
2/15/00	672	402	348.73	1109
2/16/00	942	0	348.42	965
2/17/00	1185	0	348.1	1163
2/18/00	977	0	348.24	1070
2/19/00	1045	0	347.57	881
2/20/00	1309	0	348.68	1466
2/21/00	1143	0	347.6	1141
2/22/00	390	757	347.42	1049
2/23/00	0	767	348.21	675
2/24/00	0	927	348.83	899
2/25/00	0	997	348.96	1149
2/26/00	0	1238	347.81	1226
2/27/00	0	830	347.83	694
2/28/00	0	960	348.83	961
2/29/00	0	929	348.86	919
3/1/00	9	972	348.86	990
3/2/00	0	1134	348.64	1239
3/3/00	0	689	347.88	545
3/4/00	0	1098	348.9	1188
3/5/00	0	1162	348.11	1285
3/6/00	0	861	347.22	724
3/7/00	11	1051	348.2	1144
3/8/00	331	611	347.44	826
3/9/00	851	0	348.38	796

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                                                                         csiromk2b_B11_2010_2039_tmax_anom_long16_lat15
Anom tmax Grid box centre at:  43.0068N  84.3750W
 Year      Jan          Feb          Mar          Apr          May          Jun          Jul          Aug          Sep          Oct          Nov          Dec
 2010  0.27986E+00  0.23762E+01 -0.10353E+02  0.15241E+01  0.12090E+01 -0.92360E+00  0.14740E+01  0.10963E+01  0.35990E+00 -0.18195E+01 -0.10057E+01  0.10561E+02
 2011  0.54850E-01  0.41842E+01  0.94659E+01  0.16100E-01  0.15200E+00  0.16540E+00  0.35370E+01  0.76930E+00  0.54209E+01  0.21355E+01  0.32683E+01 -0.18554E+01
 2012  0.71679E+01  0.67818E+00  0.25490E+00  0.65581E+01  0.39900E+00 -0.28956E+01 -0.33580E+01  0.10443E+01  0.13419E+01 -0.37105E+01  0.22233E+01  0.58046E+01
 2013  0.13447E+02  0.99152E+01  0.13253E+02  0.52261E+01  0.55150E+01  0.42084E+01  0.31090E+01  0.28283E+01  0.13709E+01  0.45325E+01  0.83523E+01  0.65276E+01
 2014  0.24289E+01  0.10780E+02  0.90149E+01  0.67481E+01  0.28090E+01  0.63884E+01  0.54180E+01  0.49023E+01 -0.27171E+01 -0.17645E+01  0.13683E+01  0.73661E+00
 2015 -0.55413E+00  0.14092E+01  0.71309E+01  0.25691E+01  0.64320E+01  0.87540E+00 -0.26000E+01  0.17930E+00  0.32569E+01 -0.43250E+00  0.23293E+01  0.35166E+01
 2016 -0.15441E+01  0.17317E+00 -0.36681E+01  0.72311E+01  0.50150E+01  0.14004E+01  0.25670E+01  0.32093E+01  0.10579E+01 -0.26275E+01 -0.26270E+00 -0.14584E+01
 2017  0.90759E+01  0.10082E+02  0.15173E+02  0.52531E+01  0.80500E+00  0.98104E+01  0.85220E+01  0.66463E+01  0.42019E+01  0.65445E+01 -0.17547E+01 -0.27244E+01
 2018  0.10848E+02  0.13692E+01  0.15724E+02  0.53431E+01  0.51660E+01  0.37114E+01  0.55030E+01  0.33943E+01  0.13659E+01  0.30765E+01 -0.58597E+01  0.83886E+01
 2019 -0.35213E+00  0.12562E+01  0.10169E+01  0.27671E+01  0.15890E+01  0.36914E+01  0.11510E+01  0.35323E+01 -0.16531E+01 -0.39255E+01  0.31633E+01  0.59286E+01
 2020 -0.49411E+01  0.17332E+01 -0.30651E+01  0.87341E+01  0.40510E+01 -0.14476E+01 -0.20330E+01  0.12123E+01  0.21499E+01  0.36750E+00  0.28923E+01  0.11376E+02
 2021  0.41299E+01  0.79102E+01  0.12353E+02  0.43561E+01  0.74900E+00  0.20994E+01  0.23090E+01 -0.24570E+00  0.29619E+01  0.65250E+00  0.23283E+01  0.29846E+01
 2022  0.83559E+01  0.66372E+01  0.11875E+02  0.22471E+01  0.16160E+01  0.49840E+00  0.33120E+01  0.31613E+01  0.48619E+01  0.10350E+00  0.20213E+01  0.38396E+01
 2023  0.86679E+01  0.81017E+00 -0.17411E+01  0.21331E+01  0.35860E+01  0.36134E+01  0.19860E+01  0.39773E+01 -0.15051E+01 -0.88150E+00 -0.15827E+01  0.23936E+01
 2024 -0.14051E+01 -0.73508E+01 -0.42941E+01  0.46551E+01  0.27620E+01  0.20144E+01  0.43610E+01  0.59430E+00  0.20579E+01 -0.31325E+01  0.23473E+01 -0.19374E+01
 2025  0.14650E+02  0.82882E+01  0.99799E+01  0.10111E+01  0.87390E+01  0.91494E+01  0.51110E+01  0.11653E+01  0.28689E+01 -0.14850E+00  0.54603E+01  0.78959E+00
 2026 -0.17714E+00 -0.28538E+01  0.12224E+02  0.75531E+01 -0.19550E+01  0.48384E+01  0.53080E+01  0.13093E+01  0.61799E+01 -0.15499E-01  0.37933E+01 -0.17234E+01
 2027 -0.25821E+01  0.48317E+00  0.75709E+01  0.35171E+01  0.21350E+01  0.37114E+01  0.32800E+01  0.32343E+01  0.39249E+01  0.21005E+01  0.36923E+01  0.39436E+01
 2028 -0.93913E+00  0.12212E+01  0.62649E+01  0.22931E+01  0.91300E+00  0.30364E+01  0.46400E+01 -0.77370E+00  0.31249E+01 -0.12165E+01  0.15683E+01  0.63146E+01
 2029  0.81079E+01 -0.33983E+00  0.63709E+01  0.30401E+01  0.15610E+01  0.35874E+01  0.53750E+01  0.53683E+01  0.95119E+01  0.32975E+01 -0.87570E+00  0.62166E+01
 2030  0.67139E+01 -0.97682E+00 -0.18451E+01  0.40601E+01  0.41500E+00  0.49344E+01  0.55490E+01  0.30493E+01  0.26509E+01  0.22450E+00  0.87930E+00  0.24806E+01
 2031  0.28679E+01  0.30932E+01  0.20619E+01  0.20310E+00  0.11410E+01 -0.67060E+00  0.49200E+01  0.26343E+01  0.61909E+01  0.45835E+01 -0.33157E+01 -0.34434E+01
 2032  0.53619E+01  0.11279E+02  0.64049E+01  0.12521E+02  0.39940E+01 -0.20686E+01 -0.19520E+01  0.12633E+01  0.69219E+01  0.47335E+01  0.56530E+00  0.44776E+01
 2033  0.18069E+01  0.34522E+01  0.10749E+01  0.22621E+01  0.46770E+01  0.24614E+01  0.47610E+01  0.39453E+01  0.57209E+01  0.21675E+01  0.33353E+01 -0.30474E+01
 2034 -0.21413E+00 -0.84883E+00  0.10411E+02  0.50361E+01  0.25600E+00 -0.14946E+01  0.26200E+00  0.92830E+00  0.57039E+01 -0.14115E+01  0.52930E+00 -0.49274E+01
 2035  0.10144E+02  0.13714E+02  0.13127E+02  0.77771E+01  0.14560E+01  0.68774E+01  0.67850E+01  0.76783E+01  0.59619E+01 -0.19425E+01  0.56030E+00 -0.17974E+01
 2036  0.39279E+01  0.75892E+01  0.11031E+02  0.70410E+00  0.27420E+01  0.38004E+01  0.15090E+01  0.78843E+01  0.78909E+01 -0.17295E+01  0.18743E+01  0.10806E+01
 2037  0.45149E+01 -0.97398E+01 -0.33811E+01  0.14231E+01  0.27600E+00  0.42944E+01  0.11490E+01 -0.93170E+00 -0.41100E-01 -0.50635E+01 -0.40267E+01  0.19406E+01
 2038  0.59749E+01  0.35562E+01  0.12123E+02 -0.39490E+00  0.12260E+01  0.54504E+01  0.73250E+01  0.42803E+01  0.45389E+01  0.20225E+01 -0.36747E+01 -0.35940E+00
 2039  0.32369E+01  0.10392E+01 -0.19711E+01  0.75251E+01  0.69100E+00  0.55399E-01  0.55620E+01 -0.11157E+01  0.57059E+01 -0.18935E+01  0.17301E-01  0.38116E+01
```

```
                                                                   csiromk2b_B11_2010_2039_prec_anom_long16_lat15
Anom prec Grid box centre at:  43.0068N  84.3750W
 Year     Jan          Feb          Mar          Apr          May          Jun          Jul          Aug          Sep          Oct          Nov          Dec
 2010  0.90635E+01 -0.15212E+02 -0.54244E+02 -0.21672E+02  0.68547E+02 -0.24760E+02  0.48993E+01  0.24046E+02 -0.60436E+02 -0.29734E+02 -0.45542E+01  0.11209E+03
 2011 -0.29266E+02  0.52412E+02  0.12010E+03  0.22891E+02  0.34170E+02 -0.47106E+02 -0.40381E+02 -0.42175E+02 -0.24147E+02  0.30367E+02 -0.46404E+02 -0.49935E+02
 2012  0.46040E+02 -0.37084E+02 -0.36653E+02  0.46284E+02  0.63352E+02  0.34720E+02 -0.16138E+02 -0.10745E+02  0.10341E+03 -0.12332E+02  0.69762E+01 -0.34572E+02
 2013  0.56550E+02  0.52218E+02 -0.31046E+02 -0.50172E+02  0.99323E+02  0.29469E+01  0.36775E+02 -0.10079E+02 -0.31987E+02 -0.54397E+02  0.29283E+02 -0.11603E+02
 2014 -0.19763E+02  0.13831E+03  0.98802E+01 -0.25337E+02 -0.29120E+02  0.28917E+01  0.25555E+02  0.27801E+02  0.53410E+02 -0.39469E+02  0.54685E+01  0.61771E+02
 2015 -0.56424E+02 -0.21920E+02  0.17494E+02 -0.15638E+02  0.77509E+02  0.32982E+01  0.78289E+02 -0.37058E+02 -0.27855E+01 -0.50359E+02 -0.61735E+01  0.27967E+02
 2016  0.95668E+01  0.30475E+02  0.94633E+02  0.12227E-01  0.31417E+02  0.44350E+02  0.58894E+02  0.38801E+01  0.45245E+02  0.24865E+02  0.11103E+03 -0.19410E+00
 2017  0.66718E+01  0.66864E+02  0.13027E+02  0.11348E+02 -0.32018E+02 -0.11396E+02 -0.37175E+02  0.22865E+02 -0.36027E+02  0.38034E+02 -0.57153E+02 -0.75890E+01
 2018  0.74771E+02 -0.13883E+02  0.61746E+02 -0.73188E+01  0.39779E+02 -0.14353E+02 -0.73139E+02 -0.34847E+02 -0.64578E+02  0.12610E+03  0.27524E+02  0.50880E+01
 2019 -0.43711E+02  0.56236E+02  0.54847E+02 -0.52478E+02 -0.90860E+01  0.31301E+02 -0.10728E+02  0.97837E+02  0.56029E+02  0.41355E+02  0.27943E+02 -0.13142E+02
 2020  0.10794E+02  0.20463E+02 -0.64208E+02  0.25629E+02  0.14423E+03  0.80671E+01  0.57933E+02 -0.12592E+02  0.60274E+02 -0.51271E+02 -0.27560E+02  0.22292E+02
 2021  0.19196E+02  0.17353E+02  0.36899E+02  0.83762E+02  0.40234E+02  0.13482E+02  0.54947E+02  0.14853E+03 -0.39416E+02 -0.10476E+02  0.18618E+02 -0.34965E+02
 2022 -0.16552E+02 -0.93469E+01 -0.35169E+02  0.33568E+02  0.34151E+01  0.78820E+01 -0.54646E+02 -0.93452E+00 -0.81259E+01 -0.40820E+02  0.16050E+02  0.13451E+01
 2023  0.36615E+02  0.52013E+01 -0.38742E+02  0.69620E+01  0.64408E+02 -0.59693E+02 -0.60657E+02  0.53337E+01  0.29977E+02 -0.83927E+01 -0.16196E+02  0.89514E+01
 2024  0.12777E+02 -0.45022E+02 -0.46369E+02  0.11482E+02  0.12902E+03  0.30578E+01 -0.63206E+01 -0.32358E+01 -0.56293E+02  0.15537E+02 -0.13083E+02  0.37866E+02
 2025  0.42326E+02  0.27207E+03  0.12788E+03 -0.16822E+02 -0.49734E+02  0.53499E+01 -0.32667E+02  0.59503E+02 -0.39837E+01 -0.39681E+02  0.13397E+02 -0.40730E+02
 2026  0.30839E+01 -0.35237E+02  0.76815E+01  0.45357E+02  0.34170E+02  0.20950E+02 -0.76144E+02  0.11208E+02 -0.42873E+02 -0.31379E+02 -0.16029E+02  0.91325E+01
 2027 -0.48494E+02  0.16445E+02 -0.21508E+02 -0.51160E+02 -0.18834E+02  0.10525E+02  0.69733E+02 -0.18163E+02 -0.64681E+02  0.34290E+02  0.65571E+01 -0.39462E+02
 2028 -0.50348E+01 -0.10902E+02  0.33147E+02 -0.13572E+01  0.17778E+02 -0.22042E+02  0.58333E+02  0.85695E+02  0.81088E+02 -0.67325E+01  0.31950E+02 -0.70153E+01
 2029  0.40533E+02 -0.46254E+02 -0.42782E+02 -0.35376E+02  0.66250E+00  0.26125E+02 -0.18382E+02 -0.55861E+02 -0.97032E+02 -0.53355E+02  0.20237E+02 -0.20955E+01
 2030  0.13280E+02  0.52989E+01  0.18272E+01 -0.82454E+01 -0.13308E+02 -0.51043E+02 -0.49537E+02 -0.28277E+02 -0.74753E+01 -0.43099E+02  0.57537E+02 -0.33607E+02
 2031  0.58643E+02  0.10030E+02 -0.20478E+02 -0.31186E+02 -0.20800E+02  0.41466E+02 -0.13333E+02 -0.58647E+02 -0.54650E+02  0.49006E+02 -0.84108E+00 -0.21020E+02
 2032 -0.26670E+02  0.25421E+02  0.76438E+02  0.42350E+02  0.83780E+02  0.27179E+02  0.25495E+02  0.11329E+02 -0.99976E+02  0.24555E+02  0.15687E+02  0.56919E+01
 2033  0.24106E+02  0.14177E+02 -0.80541E+01  0.32579E+02 -0.23263E+02 -0.70526E+01 -0.83041E+01  0.48905E+02 -0.69371E+02 -0.15230E+02 -0.32892E+02  0.34396E+02
 2034 -0.12745E+02 -0.45217E+02  0.51247E+02  0.20461E+02  0.27071E+02  0.20414E+02  0.18936E+01  0.84272E+02 -0.57286E+02  0.90256E+02 -0.60266E+02 -0.38014E+02
 2035  0.34616E+01  0.75127E+02  0.32969E+02  0.13582E+02 -0.48409E+02  0.10063E+02 -0.56890E+02  0.12675E+03  0.77151E+02 -0.36783E+02  0.69905E+02  0.22594E+02
 2036  0.11770E+02  0.12719E+02 -0.49896E+01  0.73795E+02 -0.34978E+01  0.49950E+02  0.44870E+02 -0.23281E+02  0.64964E+02  0.26020E+02  0.76550E+02 -0.30438E+02
 2037  0.10574E+02 -0.87599E+02 -0.36653E+02 -0.64793E+02 -0.50084E+01 -0.65166E+01  0.13240E+03  0.80608E+02  0.12346E+02 -0.38639E+02  0.10570E+03 -0.39070E+02
 2038 -0.39683E+02  0.89869E+02 -0.53465E+01  0.36780E+02 -0.54277E+02 -0.64924E+02  0.10449E+02  0.30011E+02 -0.59785E+02 -0.25681E+02  0.17110E+02 -0.36383E+02
 2039  0.73670E+02 -0.40907E+02  0.45997E+02 -0.37734E+02  0.56574E+02  0.95271E+01 -0.17541E+02  0.12964E+02 -0.10391E+01  0.23837E+01  0.48477E+02 -0.50237E+02
```

```
                                                                     hadcm3_A23_2010_2039_tmax_anom_long24_lat19
Anom tmax Grid box centre at:  42.5000N  82.5000W
 Year      Jan          Feb          Mar          Apr          May          Jun          Jul          Aug          Sep          Oct          Nov          Dec
 2010 -0.21177E+01 -0.61660E-01  0.27263E+01  0.33497E+01  0.26540E+01  0.39060E+01  0.79230E+00  0.69230E+00  0.25900E+01  0.33390E+01  0.16056E+01 -0.33123E+01
 2011 -0.11777E+01 -0.26167E+00 -0.22437E+01  0.14597E+01  0.35840E+01 -0.11640E+01  0.14723E+01  0.30223E+01  0.34100E+01  0.29990E+01  0.54457E+01  0.18477E+01
 2012  0.66123E+01  0.82083E+01  0.35634E+00 -0.11103E+01  0.60400E+00  0.16460E+01  0.46230E+00  0.21123E+01 -0.56000E+00  0.58900E+00  0.89566E+00 -0.77235E+00
 2013 -0.20477E+01 -0.17817E+01 -0.52437E+01  0.56970E+00  0.91400E+00  0.22260E+01 -0.42770E+00  0.19023E+01  0.50100E+01  0.16990E+01 -0.10243E+01  0.11677E+01
 2014 -0.40765E+00  0.17383E+01  0.18763E+01 -0.34203E+01 -0.17760E+01 -0.25740E+01  0.11923E+01  0.17523E+01  0.38100E+01  0.22190E+01  0.32757E+01  0.60766E+00
 2015 -0.39577E+01  0.18183E+01  0.34264E+01  0.10897E+01  0.33340E+01  0.16460E+01  0.29023E+01 -0.25177E+01 -0.19999E-01 -0.15510E+01  0.53568E+00  0.16477E+01
 2016  0.37723E+01 -0.21717E+01  0.30632E+00  0.16597E+01  0.10640E+01  0.33600E+00 -0.47699E-01  0.12723E+01  0.15400E+01 -0.95100E+00 -0.76434E+00 -0.10723E+01
 2017 -0.14577E+01  0.83499E-02 -0.39737E+01  0.11297E+01  0.36240E+01 -0.37400E+00  0.14523E+01  0.32423E+01  0.77000E+00  0.40990E+01  0.12257E+01  0.97765E+00
 2018  0.35423E+01  0.10138E+02  0.52364E+01  0.39297E+01  0.20400E+00  0.15360E+01  0.30223E+01  0.47230E+00  0.45700E+01 -0.48100E+00  0.12257E+01  0.15277E+01
 2019  0.29823E+01  0.26883E+01  0.29563E+01 -0.11203E+01  0.17240E+01 -0.99400E+00  0.49523E+01  0.40723E+01  0.48400E+01  0.24990E+01 -0.13434E+00  0.32477E+01
 2020  0.15924E+01  0.35833E+00 -0.11137E+01 -0.86030E+00  0.71400E+00 -0.21400E+00 -0.97770E+00 -0.18477E+01  0.40300E+01  0.16390E+01  0.41957E+01  0.21767E+00
 2021 -0.17977E+01  0.28835E+00  0.76263E+01  0.26197E+01  0.12540E+01  0.59600E+00 -0.39770E+00  0.72923E+01  0.36800E+01  0.25390E+01  0.98566E+00 -0.64234E+00
 2022 -0.19377E+01 -0.51167E+00  0.15763E+01  0.31697E+01  0.20140E+01  0.37600E+00  0.93230E+00  0.65230E+00  0.66300E+01  0.56290E+01 -0.37433E+00  0.32977E+01
 2023  0.48233E+00  0.53783E+01  0.72163E+01  0.76897E+01 -0.57600E+00 -0.10340E+01  0.21523E+01  0.22423E+01 -0.12000E+01  0.31790E+01  0.31657E+01  0.62477E+01
 2024  0.72623E+01  0.62083E+01  0.70963E+01  0.18997E+01  0.27540E+01  0.10460E+01  0.67230E+00  0.87523E+01  0.79400E+01  0.19990E+01 -0.98434E+00 -0.16023E+01
 2025 -0.23177E+01 -0.22017E+01 -0.25937E+01 -0.15203E+01 -0.67600E+00  0.33960E+01  0.92300E-01 -0.57699E-01  0.13700E+01  0.11990E+01 -0.22843E+01 -0.72330E-01
 2026 -0.11377E+01 -0.42167E+00  0.46463E+01  0.16997E+01  0.12940E+01  0.96001E-01  0.80230E+00 -0.12877E+01  0.31100E+01  0.15390E+01 -0.14143E+01 -0.35233E+00
 2027 -0.18777E+01  0.17283E+01  0.29663E+01  0.71970E+00  0.61400E+00  0.57600E+00  0.56423E+01  0.43023E+01  0.49000E+01  0.22390E+01  0.11657E+01  0.77660E-01
 2028 -0.76604E-02 -0.81166E+00 -0.20037E+01 -0.16703E+01  0.25440E+01  0.31560E+01  0.28423E+01  0.45823E+01  0.13000E+01  0.30900E+00  0.24157E+01 -0.50233E+00
 2029  0.43234E+00  0.39983E+01  0.46663E+01  0.38497E+01  0.29740E+01  0.36160E+01  0.14023E+01  0.23223E+01  0.41900E+01  0.21990E+01  0.21457E+01  0.91766E+00
 2030  0.18723E+01  0.17783E+01  0.32763E+01 -0.21903E+01  0.81400E+00  0.15060E+01  0.14723E+01  0.26223E+01  0.50100E+01  0.33190E+01  0.28057E+01  0.20377E+01
 2031  0.47224E+01  0.47483E+01  0.49663E+01 -0.26603E+01  0.19340E+01  0.30760E+01  0.20623E+01  0.31123E+01  0.85100E+01  0.90008E-02  0.31056E+01  0.75677E+01
 2032  0.42623E+01 -0.10717E+01  0.17635E+00  0.29497E+01  0.12240E+01  0.40060E+01  0.54230E+00  0.33623E+01  0.30100E+01  0.46900E+00 -0.10743E+01 -0.32223E+01
 2033  0.15023E+01  0.76833E+00  0.87363E+01  0.54097E+01  0.17340E+01  0.22760E+01 -0.28770E+00  0.19523E+01  0.30000E+01 -0.55100E+00 -0.84320E-01  0.23766E+00
 2034  0.19023E+01 -0.22217E+01 -0.28737E+01 -0.16303E+01  0.27240E+01  0.50600E+00  0.26623E+01  0.24923E+01  0.43800E+01  0.49790E+01  0.36356E+01  0.40277E+01
 2035  0.78523E+01  0.54183E+01  0.36764E+01  0.55097E+01  0.33540E+01  0.17360E+01  0.19223E+01  0.35823E+01  0.29000E+00 -0.61100E+00  0.39657E+01  0.23877E+01
 2036 -0.18765E+00 -0.12166E+00  0.54634E+00  0.21697E+01  0.18440E+01  0.11760E+01  0.37823E+01  0.70523E+01  0.69400E+01  0.27790E+01  0.25557E+01 -0.65232E+00
 2037  0.47235E+00 -0.10317E+01  0.34963E+01 -0.42030E+00 -0.21600E+00  0.22960E+01  0.33223E+01  0.16923E+01  0.11000E+00  0.33190E+01  0.17057E+01  0.22077E+01
 2038  0.26323E+01  0.33183E+01  0.32463E+01 -0.18030E+00  0.32740E+01  0.94600E+00  0.36523E+01  0.90923E+01  0.37000E+01  0.75290E+01  0.11757E+01  0.40877E+01
 2039  0.53523E+01  0.84283E+01  0.38163E+01  0.22797E+01  0.42840E+01  0.55960E+01  0.35523E+01  0.53023E+01  0.32200E+01  0.42190E+01 -0.93433E+00 -0.18423E+01
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                                                                                  hadcm3_A23_2010_2039_prec_anom_long24_lat19
Anom prec Grid box centre at:  42.5000N  82.5000W
 Year     Jan          Feb          Mar          Apr          May          Jun          Jul          Aug          Sep          Oct          Nov          Dec
 2010  0.74877E+01 -0.20263E+01  0.51609E+02  0.10884E+03  0.53647E+02 -0.75503E+00 -0.27800E+02 -0.52637E+02 -0.83586E+02 -0.17520E+02 -0.23316E+02 -0.42835E+02
 2011 -0.56127E+02  0.21588E+02 -0.67391E+02  0.47455E+02  0.96357E+02 -0.55976E+02 -0.12166E+02 -0.29438E+02  0.39331E+02 -0.35714E+02  0.20642E+02  0.37431E+02
 2012  0.23721E+02  0.25105E+02 -0.57227E+02 -0.13625E+02 -0.62587E+01 -0.39690E+02 -0.33542E+01 -0.44260E+02 -0.61064E+02  0.13208E+02 -0.21070E+02  0.37588E+01
 2013  0.66103E+01 -0.35336E+01 -0.68662E+02  0.23702E+02  0.10551E+03 -0.76258E+01 -0.17283E+02 -0.72066E+01 -0.52666E+02 -0.38949E+02 -0.36792E+02 -0.52623E+02
 2014 -0.83064E+01 -0.20114E+02  0.79983E+02  0.13213E+02 -0.44532E+02 -0.30020E+02 -0.30074E+02 -0.11073E+02  0.74449E+02 -0.30862E+02 -0.36792E+02  0.15505E+02
 2015 -0.56566E+02  0.80223E+01  0.18154E+02  0.12905E+02 -0.20986E+01 -0.33582E+02  0.11143E+02 -0.72613E+02 -0.49612E+02  0.24528E+02  0.94117E+01 -0.48551E+01
 2016  0.29863E+02 -0.55786E+02 -0.33089E+02 -0.77636E+01  0.53647E+02 -0.23912E+02 -0.15577E+02  0.57878E+02  0.62998E+02 -0.67251E+02 -0.65348E+02 -0.48551E+01
 2017 -0.46475E+02 -0.34684E+02 -0.61462E+02 -0.22571E+02  0.44217E+02  0.29782E+02  0.13985E+02  0.72923E+01  0.25588E+02  0.50405E+02 -0.18824E+02 -0.14644E+02
 2018  0.90684E+00 -0.10065E+02 -0.46640E+02  0.27403E+02  0.95212E+00  0.15277E+02  0.28994E+01 -0.19128E+02  0.35132E+02  0.89623E+02 -0.10802E+02 -0.14252E+02
 2019 -0.14887E+02 -0.27148E+02 -0.25889E+02  0.86324E+02  0.46159E+02 -0.37145E+02 -0.82945E+02 -0.25250E+02  0.27497E+02 -0.57143E+02  0.20000E+02  0.81676E+02
 2020  0.11875E+02  0.71831E+02  0.37551E+01 -0.38920E+02  0.43108E+02  0.36907E+02  0.85901E+02 -0.50381E+02  0.48110E+02 -0.34501E+02 -0.14332E+02  0.24902E+02
 2021 -0.29804E+02  0.31134E+02  0.92605E+01  0.10699E+03 -0.43459E+00 -0.44779E+02 -0.41444E+02 -0.54248E+02  0.12596E-01 -0.16711E+02 -0.30374E+02 -0.27173E+02
 2022 -0.61392E+02 -0.55433E+01 -0.68322E+01  0.64113E+02  0.13987E+02  0.40800E+01 -0.13872E+02  0.21791E+02  0.87923E+01 -0.23989E+02  0.10374E+02 -0.57322E+02
 2023 -0.67973E+02  0.15559E+02 -0.76791E+01  0.11902E+03  0.30073E+02 -0.28493E+02 -0.29221E+02 -0.14939E+02 -0.27090E+02 -0.98382E+01  0.44064E+02  0.46829E+02
 2024  0.96110E+02  0.97957E+02  0.24846E+01 -0.46788E+01 -0.59786E+02  0.26287E+00  0.15691E+02 -0.75191E+02  0.25207E+02  0.58895E+02 -0.11444E+02 -0.68285E+02
 2025 -0.19713E+02 -0.38201E+02  0.46021E+01 -0.48792E+02 -0.20403E+02 -0.35542E+01  0.21660E+02  0.72377E+02  0.31314E+02 -0.10647E+02 -0.24278E+02  0.62882E+02
 2026 -0.49547E+02  0.10534E+02 -0.38594E+02 -0.40463E+02  0.27577E+02 -0.86437E+01  0.65947E+01 -0.64880E+02 -0.12584E+02 -0.45418E+02 -0.47059E+02  0.43305E+02
 2027  0.46096E+02  0.43695E+02  0.67279E+02  0.55012E+01  0.69455E+02  0.22987E+01 -0.30699E+01 -0.72066E+01 -0.44268E+02 -0.41375E+02 -0.13690E+02  0.88489E+01
 2028  0.11436E+02  0.20081E+02  0.16376E+01 -0.49717E+02  0.23139E+02 -0.13224E+02 -0.63047E+02 -0.25894E+02  0.56508E+02 -0.68059E+02  0.10694E+01 -0.48316E+02
 2029 -0.35946E+02  0.44700E+02 -0.89496E+01 -0.68535E+02 -0.40400E+01  0.23420E+02  0.33030E+02 -0.20417E+02 -0.89312E+02 -0.13073E+02  0.94759E+02 -0.21143E+01
 2030  0.33811E+02 -0.11070E+02 -0.93731E+01 -0.66992E+02 -0.12083E+02 -0.41216E+02  0.23650E+02 -0.43937E+02  0.35895E+02  0.35041E+02 -0.14973E+02 -0.33438E+02
 2031 -0.21468E+02 -0.15592E+02  0.59656E+02 -0.44165E+02  0.25358E+02 -0.17296E+02 -0.52246E+02 -0.47159E+02 -0.66026E+02  0.67790E+02 -0.18183E+01  0.58575E+02
 2032 -0.26733E+02 -0.32172E+02  0.33399E+02  0.58097E+01  0.29796E+02  0.38255E+01 -0.26663E+02 -0.39846E+01  0.34368E+02 -0.40162E+02 -0.15615E+02 -0.40486E+02
 2033 -0.54811E+02  0.40029E+01  0.71514E+02  0.14447E+02  0.16292E+03  0.45050E+02  0.15975E+02 -0.38782E+02 -0.13348E+02  0.17655E+02 -0.36471E+02  0.37040E+02
 2034  0.83652E+01 -0.33177E+02  0.25353E+02 -0.67301E+02  0.56669E+01  0.56068E+01  0.97214E+01 -0.69069E+02 -0.30144E+02  0.13895E+03  0.30909E+02 -0.36179E+02
 2035  0.62328E+02  0.43192E+02 -0.18690E+02  0.41285E+02  0.12409E+03 -0.75503E+00 -0.47129E+02 -0.33402E+01  0.13373E+02  0.70216E+02  0.47914E+02 -0.25998E+02
 2036 -0.48230E+02  0.14554E+02 -0.67391E+02  0.45295E+02  0.51122E+01 -0.52922E+02 -0.51677E+02 -0.97842E+01 -0.35106E+02  0.25741E+02  0.37326E+02  0.16680E+02
 2037 -0.36824E+02 -0.29157E+02 -0.28430E+02  0.33265E+02  0.19534E+02 -0.48342E+02  0.47243E+02 -0.29438E+02  0.24061E+02 -0.74933E+02 -0.24920E+02 -0.53406E+02
 2038 -0.40333E+02  0.75199E+01 -0.16572E+02 -0.29357E+02 -0.15688E+02 -0.11443E+02 -0.58499E+02  0.60035E+01 -0.47703E+02 -0.77358E+02 -0.40963E+02  0.47220E+02
 2039 -0.53934E+02 -0.59303E+02  0.38058E+02  0.58252E+02  0.15929E+02 -0.13479E+02 -0.11882E+02 -0.10106E+02  0.16809E+02 -0.57143E+02 -0.18182E+02 -0.11903E+02
```

Appendix B

Artificial Neural Network Input Variable Selection Experiment Results

		Purpose
Training 1	Initial Training	Set up training tags, and see relative importance of variables.
Training 2	Insert Random Variable	
Training 3	Relative importance of Max Temp (t-n) and Total Prec (t-n)	
Training 4	Delete Max Temp (t-1) to (t-3), Precp (t-1) to (t-3)	
Training 5-2	Avg. Max Temp (t-1 to t-3) and Total Prec (t-1 to t-3) to see if it perfer one or another	

Average of Training Trials Performance

Number of Trials in each Training: 6	Training					
	1(i)	2(i)	3(i)	4(i)	5(i)	6(i)
Training						
% Bad Predictions (20% Tolerance)	13.2%	12.4%	22.4%	13.1%	12.1%	11.5%
Root Mean Square Error	0.0461	0.0451	0.0624	0.0462	0.0449	0.0444
Mean Absolute Error	0.0310	0.0302	0.0459	0.0320	0.0304	0.0299
Change of Mean Abs. Err. as compared to 1(i)		-3%	33%	3%	-2%	-4%
Std. Deviation of Abs. Error	0.0340	0.0334	0.0421	0.0333	0.0330	0.0327
Testing						
% Bad Predictions (20% Tolerance)	24.6%	22.6%	26.0%	25.6%	25.3%	26.9%
Root Mean Square Error	0.0683	0.0684	0.0685	0.0705	0.0698	0.0694
Mean Absolute Error	0.0486	0.0483	0.0492	0.0498	0.0494	0.0489
Change of Mean Abs. Err. as compared to 1(i)		-1%	2%	2%	2%	1%
Std. Deviation of Abs. Error	0.0479	0.0483	0.0476	0.0498	0.0494	0.0491

Number of Trials in each Training: 6	Training					
	1(ii)	2(ii)	3(ii)	4(ii)	5(ii)	6(ii)
Training						
% Bad Predictions (20% Tolerance)	11.8%	10.5%	19.2%	11.4%	10.5%	10.9%
Root Mean Square Error	0.0440	0.0422	0.0567	0.0456	0.0427	0.0436
Mean Absolute Error	0.0295	0.0275	0.0400	0.0303	0.0288	0.0287
Change of Mean Abs. Err. as compared to 1(ii)		-7%	26%	3%	-2%	-3%
Std. Deviation of Abs. Error	0.0325	0.0319	0.0402	0.0341	0.0314	0.0327
Testing						
% Bad Predictions (20% Tolerance)	23.3%	22.9%	23.5%	24.7%	23.8%	22.9%
Root Mean Square Error	0.0667	0.0668	0.0644	0.0669	0.0658	0.0659
Mean Absolute Error	0.0469	0.0474	0.0475	0.0476	0.0468	0.0463
Change of Mean Abs. Err. as compared to 1(ii)		1%	0%	2%	0%	-1%
Std. Deviation of Abs. Error	0.0473	0.0469	0.0434	0.0470	0.0462	0.0467

Note: A decrease of Mean Abs Err indicates that there is an improvement of model prediction.

Comparisons made to 1(i):
2(i) There is a small decrease of Mean Abs Err in training, which is odd. However, this may have be caused by the selection of training and testing points.
3(i) There is a significant increase of Mean Abs Err from 1(i) to 3(i), which illustrates that an elimination of the variables of precipitation would significantly degraded the net.
4(i) Eliminating Max Temp (t-4) to Max Temp (t-7) would induce a small increase of Mean Abs Err. It shows that Max Temp (t-4) to Max Temp (t-7) has some relevancy in the net, but not a lot.
5(i) Taking average of Max Temp [(t-1) to (t-3)] would decrease the Mean Abs. Err. in training, but it would increase the Mean Abs. Err. in testing.
6(i) Taking average of Max Temp [(t-1) to (t-3)] and total of Precp [(t-1) to (t-3)] would decrease the Mean Abs. Err. in training and increase the Mean Abs. Err. in testing.

Comparisons made to 1(ii):
2(ii) There is a decrease of Mean Abs Err in training but an small increase of Mean Abs Err in testing.
3(ii) There is a significant increase of Mean Abs Err from 1(i) to 3(i), which illustrates that an elimination of the variables of precipitation would significantly degraded the net.
4(ii) Eliminating Precp (t-4) to Precp (t-7) would induce a small increase of Mean Abs Err. It shows that Max Temp (t-4) to Max Temp (t-7) has some relevancy in the net, but not a lot.
5(ii) Totaling Precp[(t-1) to (t-3)] would decrease the Mean Abs. Err in training and would leave the Mean Abs. Err. in testing unchange.
6(ii) Totaling Precp[(t-1) to (t-3)] would decrease the Mean Abs. Err in training and testing. It will result in the best configurations.

Final note: If one takes the average of the results of 6(i) and 6(ii), the Change of Mean Abs. Err. From 1(i) and 1(ii) is -3.5% and 0% for training and testing respectively.
This illustrates that the pruning of the input variables indeed improved the prediction of the training set a bit and leaving the prediction on the testing set unchange.
Therefore, it can be concluded that the pruned input variable set is just as good, if not slightly better than the orginial set.
However, it dimensions on which the neural network need to train on has reduced significantly, and therefore would benefit the efficiency of the computation time.

	1(i) Max	2(i) Max	3(i) Max	4(i) Max	5(i) Max	6(i) Max
% Bad Predictions (20% Tolerance)	18.3%	18.3%	24.5%	19.0%	14.6%	13.0%
Root Mean Square Error	0.0527	0.0541	0.0647	0.0520	0.0501	0.0475
Mean Absolute Error	0.0363	0.0376	0.0475	0.0375	0.0340	0.0330
Std. Deviation of Abs. Error	0.0383	0.0390	0.0443	0.0371	0.0368	0.0342
% Bad Predictions (20% Tolerance)	31.1%	27.3%	29.5%	32.3%	29.3%	33.3%
Root Mean Square Error	0.0794	0.0818	0.0750	0.0715	0.0727	0.0767
Mean Absolute Error	0.0556	0.0554	0.0521	0.0516	0.0518	0.0524
Std. Deviation of Abs. Error	0.0567	0.0602	0.0545	0.0527	0.0520	0.0560

1(ii) Max	2(ii) Max	3(ii) Max	4(ii) Max	5(ii) Max	6(ii) Max
20.8%	19.1%	21.2%	14.8%	14.8%	16.7%
0.0547	0.0529	0.0594	0.0496	0.0482	0.0514
0.0396	0.0377	0.0430	0.0335	0.0325	0.0355
0.0378	0.0371	0.0414	0.0368	0.0356	0.0373
27.7%	28.4%	29.3%	31.4%	29.7%	27.7%
0.0732	0.0739	0.0713	0.0732	0.0701	0.0694
0.0520	0.0540	0.0510	0.0519	0.0508	0.0495
0.0515	0.0517	0.0499	0.0536	0.0512	0.0513

a. this slightly increase, because of the addition of an random variable
b. comparing 3(i) and 4(i), it shows that the general quality of training and testing improved

Average of Training Trials performance
Number of Trials in each Training: 6

Training no.	1(i)	2(i)	3(i)	4(i)	5(i)	6(i)
Training						
% Bad Predictions (20% Tolerance)	13.2%	12.4%	22.4%	13.1%	12.1%	11.5%
Root Mean Square Error	0.0461	0.0451	0.0624	0.0462	0.0449	0.0444
Mean Absolute Error	0.0310	0.0302	0.0459	0.0320	0.0304	0.0299
Std. Deviation of Abs. Error	0.0340	0.0334	0.0421	0.0333	0.0330	0.0327
Testing						
% Bad Predictions (20% Tolerance)	24.6%	22.6%	26.0%	25.6%	25.3%	26.9%
Root Mean Square Error	0.0683	0.0684	0.0685	0.0705	0.0698	0.0694
Mean Absolute Error	0.0486	0.0483	0.0492	0.0498	0.0494	0.0489
Std. Deviation of Abs. Error	0.0479	0.0483	0.0476	0.0498	0.0494	0.0491

c.

Training no.	1(i)	2(i)	3(i)	4(i)	5(i)	6(i)
Training						
% Bad Predictions (20% Tolerance)	11.8%	10.5%	19.2%	11.4%	10.5%	10.9%
Root Mean Square Error	0.0440	0.0422	0.0567	0.0456	0.0427	0.0436
Mean Absolute Error	0.0295	0.0275	0.0400	0.0303	0.0288	0.0287
Std. Deviation of Abs. Error	0.0325	0.0319	0.0402	0.0341	0.0314	0.0327
Testing						
% Bad Predictions (20% Tolerance)	23.3%	22.9%	23.5%	24.7%	23.8%	22.9%
Root Mean Square Error	0.0667	0.0668	0.0644	0.0669	0.0658	0.0659
Mean Absolute Error	0.0469	0.0474	0.0475	0.0476	0.0468	0.0463
Std. Deviation of Abs. Error	0.0473	0.0469	0.0434	0.0470	0.0462	0.0467

a. this slightly increased
b. % of Bad Prediction of Training increased
This is not an identical comparsion. Just to illustrate
relative importance and show that by removing some variables,
the RMS and % Bad Prediction would increase.
c. slightly decreased

	1 Min	1(i) Min	2 Min	2(i) Min	3(all) Min	3(i) Min	4(all) Min	4(i) Min	5(i) Min	6(i) Min
% Bad Predictions (20	2.7%	5.7%	4.0%	4.7%	15.6%	21.4%	6.4%	6.4%	7.9%	8.4%
Root Mean Square Er	0.0269	0.0336	0.0294	0.0303	0.0517	0.0589	0.0360	0.0360	0.0383	0.0403
Mean Absolute Error	0.0161	0.0195	0.0171	0.0172	0.0352	0.0441	0.0240	0.0240	0.0237	0.0246
Std. Deviation of Abs.	0.0216	0.0273	0.0238	0.0250	0.0380	0.0390	0.0268	0.0268	0.0300	0.0291
% Bad Predictions (20	15.8%	15.8%	16.1%	17.8%	18.0%	22.5%	18.4%	20.5%	19.8%	21.4%
Root Mean Square Er	0.0572	0.0578	0.0602	0.0602	0.0564	0.0630	0.0580	0.0686	0.063376	0.0638
Mean Absolute Error	0.0397	0.0437	0.0433	0.0449	0.0423	0.0452	0.0411	0.0483	0.045323	0.0462
Std. Deviation of Abs.	0.0379	0.0379	0.0391	0.0391	0.0373	0.0440	0.0410	0.0465	0.044298	0.0430

1(ii) Min	2(i) Min	3(ii) Min	4(ii) Min	5(ii) Min	6(ii) Min
2.7%	4.0%	16%	7.7%	6.7%	5.7%
0.0269	0.0294	0.0517	0.0419	0.0363	0.0355
0.0161	0.0171	0.0352	0.0258	0.0237	0.0218
0.0216	0.0238	0.0380	0.0321	0.0275	0.0281
19.5%	16.1%	18.0%	18.4%	16%	15.0%
0.05716	0.0604	0.0564	0.0580	0.0556	0.0558
0.03969	0.0433	0.0423	0.0411	0.0390	0.0394
0.04071	0.0398	0.0373	0.0410	0.0396	0.0395

	1 Stdev	1(i) Stdev	2 Stdev	2(i) Stdev	3(i) Stdev	4(all) Stdev	4(i) Stdev	5(i) Stdev	6(i) Stdev
% Bad Predictions (20	5.3%	4.8%	4.9%	4.6%	1%	3%	4.2%	2.3%	1.63%
Root Mean Square Er	0.0082	0.0072	0.0080	0.0081	0.002	0.0045	0.0060	0.0039	0.003
Mean Absolute Error	0.0071	0.0066	0.0070	0.0071	0.002	0.0038	0.0046	0.0035	0.003
Std. Deviation of Abs.	0.0048	0.0039	0.0046	0.0046	0.0018	0.0031	0.0041	0.0026	0.002
% Bad Predictions (20	5%	6%	4.0%	4.1%	2%	4%	4.6%	3.9%	4.35%
Root Mean Square Er	0.0064	0.0075	0.0061	0.0076	0.004	0.0042	0.001	0.0036	0.005
Mean Absolute Error	0.0041	0.0042	0.0036	0.0038	0.003	0.0029	0.001	0.0024	0.002
Std. Deviation of Abs.	0.0057	0.0067	0.0059	0.0071	0.0040	0.0042	0.002	0.0031	0.005

 Stdev	2(ii) Stdev	3(ii) Stdev	4(ii) Stdev	5(ii) Stdev	6(ii) Stdev
6.1%	5.4%	0.0222	2.5%	3.2%	4.74%
0.0097	0.0084	0.0030	0.0031	0.0042	0.006
0.0082	0.0073	0.0032	0.0030	0.0036	0.005
0.0059	0.0049	0.0013	0.0021	0.0026	0.004
3.6%	4.4%	4.3%	4.8%	5.3%	5.84%
0.0057	0.0049	0.0053	0.0054	0.0052	0.005
0.0041	0.0036	0.0030	0.0037	0.0044	0.004
0.0052	0.0050	0.0049	0.0053	0.0042	0.004

Appendix C

Simulation Results

Scenario no.	Corresponding trial no.	No. of Days Failed
1	87	6
	82	53
2	4, 38	21
	99	84
3	87	6
	82	53
4	87	5
	82	50
5	87	0
	82	23
6	more than 1	0
	34	10
1b	40	139
	82	243
3b	40	137
	82	238
4b	40	130
	43	224
5b	4	61
	82	141
6b	4	21
	99	88

Scenario no.	Corresponding trial no.	No. of Days Failed
7	7	79
	99	170
8	7	78
	99	168
9	7	73
	99	155
10	7	35
	9	92
11	7, 70	15
	30, 78	52
7a	7	73
	99	172
8a	7	70
	99	165
9a	7	65
	99	159
10a	7	35
	56	89
11a	70	12
	56	48
7c	54	381
	35	551
8c	54	373
	35	546
9c	54	364
	78	536
10c	54	238
	99	381
11c	19	139
	61	252

Scenario no.	Corresponding trial no.	No. of Days Failed
12	4	135
	85	244
13	4	134
	85	240
14	4	129
	85	231
15	4	59
	45	146
16	40	3
	99	54
12a	56	129
	89	242
13a	56	127
	89	240
14a	41	121
	89	232
15a	4	54
	75	149
16a	40	2
	37	53
12c	41	485
	85	657
13c	41	477
	85	648
14c	41	463
	85	634
15c	93	316
	85	474
16c	41	192
	77	319

Scenario no.	Corresponding trial no.	No. of Days Failed
17	40	67
	62	148
18	40	64
	85	144
19	40	58
	85	139
20	76	18
	85	86
21	76	2
	85	40
22	16	29
	75	88
23	87	27
	75	86
24	16	24
	75	82
25	16	6
	75	46
26	27	0
	34	20

Scenerio N Scenario 1 Base Case
Date: 11/10/2007
Simulation 11:18:59 PM
Simulation 1:01:29 AM
Elapsed Ti -1337.5 Minutes

		ΣZ_t	ΣW_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Avg S_i	Σ si	Σ sjej				v= $\Sigma s_j e_j$	v= Σ si	no. of days with Demand						
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Avg. Severity of a Failure	Total Severity of Failure	Total Maximum Severity of Sojourn	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	Vulnerability 1	Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance
1	7305	21	12	6	1	1.8	461	19	173	3639	2510	0.9971	0.5714	58	209	173	0	526	5531	1058	170	20	0.3894
2	7305	19	13	3	1	1.5	384	11	142	2690	2138	0.9974	0.6842	128	164	142	0	550	5405	1174	162	14	0.5050
3	7305	28	13	5	1	2.2	532	30	203	5695	2982	0.9962	0.4643	52	229	203	0	561	5426	1148	145	25	0.3399
4	7305	7	4	2	1	1.8	479	23	152	1065	928	0.9990	0.5714	522	232	152	0	537	5518	1126	118	6	0.5388
5	7305	17	11	3	1	1.5	296	24	115	1959	1442	0.9977	0.6471	143	131	115	0	534	5437	1158	160	16	0.4689
6	7305	24	15	4	1	1.6	644	17	149	3567	2725	0.9967	0.6250	76	182	149	0	551	5469	1090	175	20	0.6164
7	7305	13	6	4	1	2.2	558	2	219	2850	1652	0.9982	0.4615	140	275	219	0	575	5428	1130	159	13	0.6314
8	7305	13	10	2	1	1.3	419	14	191	2480	2021	0.9982	0.7692	281	202	191	0	542	5470	1146	137	10	0.4554
9	7305	31	19	5	1	1.6	489	13	190	5900	3776	0.9958	0.6129	47	199	190	0	548	5436	1103	193	25	0.5034
10	7305	29	16	5	1	1.8	525	6	130	3756	1923	0.9960	0.5517	50	120	130	0	547	5509	1090	134	25	0.3409
11	7305	22	11	4	1	2.0	487	4	212	4661	2576	0.9970	0.5000	83	234	212	0	561	5412	1158	153	21	0.4638
12	7305	30	15	6	1	2.0	425	3	194	5818	3248	0.9959	0.5000	41	217	194	0	542	5490	1062	184	27	0.3559
13	7305	28	10	10	1	2.8	876	11	314	8801	2826	0.9962	0.3571	26	283	314	0	514	5449	1140	174	28	0.3953
14	7305	17	11	3	1	1.5	506	2	202	3433	2371	0.9977	0.6471	143	216	202	0	552	5453	1076	208	16	0.3945
15	7305	30	15	4	1	2.0	517	5	176	5292	3377	0.9959	0.5000	61	225	176	0	539	5422	1128	189	27	0.3570
16	7305	9	4	4	1	2.3	507	2	223	2004	993	0.9988	0.4444	203	248	223	0	537	5491	1129	142	6	0.7063
17	7305	27	12	6	1	2.3	711	9	209	5654	2728	0.9963	0.4444	45	227	209	0	522	5419	1130	213	21	0.4728
18	7305	18	12	4	1	1.5	519	12	237	4262	2590	0.9975	0.6667	101	216	237	0	551	5532	1055	152	15	0.5419
19	7305	12	6	4	1	2.0	423	2	147	1763	1170	0.9984	0.5000	152	195	147	0	543	5528	1100	123	11	0.6045
20	7305	16	8	5	1	2.0	733	19	265	4237	2133	0.9978	0.5000	91	267	265	0	571	5474	1110	135	15	0.5060
21	7305	23	14	2	1	1.6	508	9	158	3626	2715	0.9969	0.6087	159	194	158	0	549	5508	1068	157	23	0.2921
22	7305	23	11	8	1	2.1	561	34	192	4406	2146	0.9969	0.4783	40	195	192	0	551	5453	1106	172	23	0.5111
23	7305	17	11	4	1	1.5	440	3	209	3549	2108	0.9977	0.6471	107	192	209	0	529	5539	1066	155	16	0.5522
24	7305	24	15	5	1	1.6	532	0	140	3366	2113	0.9967	0.6250	61	141	140	0	559	5455	1105	165	21	0.3465
25	7305	35	15	5	1	2.3	565	5	225	7886	3639	0.9952	0.4286	42	243	225	0	558	5458	1104	154	31	0.3900
26	7305	17	9	3	1	1.9	417	13	176	2992	2304	0.9977	0.5294	143	256	176	0	556	5484	1110	140	15	0.4852
27	7305	9	7	3	1	1.3	507	14	182	1642	1172	0.9988	0.7778	271	167	182	0	542	5438	1202	116	7	0.5935
28	7305	30	16	5	1	1.9	627	3	202	6054	3651	0.9959	0.5333	49	228	202	0	531	5422	1152	174	26	0.4758
29	7305	30	12	8	1	2.5	487	14	185	5535	2069	0.9959	0.4000	30	172	185	0	541	5456	1101	182	25	0.4183
30	7305	18	12	3	1	1.5	478	0	166	2994	2374	0.9975	0.6667	135	198	166	0	524	5505	1077	183	16	0.6180
31	7305	30	20	4	1	1.5	589	1	128	3854	2854	0.9959	0.6667	61	143	128	0	551	5468	1082	177	27	0.3621
32	7305	16	6	5	1	2.7	846	2	273	4366	1757	0.9978	0.3750	91	293	273	0	549	5489	1135	117	15	0.5318
33	7305	20	11	4	1	1.8	519	22	231	4628	2663	0.9973	0.5500	91	242	231	0	546	5461	1103	176	19	0.4114
34	7305	35	14	7	1	2.5	888	13	341	11925	4864	0.9952	0.4000	30	347	341	0	525	5477	1080	193	30	0.5627
35	7305	25	15	4	1	1.7	418	18	164	4090	2395	0.9966	0.6000	73	160	164	0	542	5493	1116	130	24	0.4151
36	7305	18	7	4	1	2.6	517	41	202	3637	1988	0.9975	0.3889	101	284	202	0	526	5542	1056	163	18	0.4507
37	7305	26	14	6	1	1.9	615	13	207	5389	2489	0.9964	0.5385	47	178	207	0	553	5373	1169	186	24	0.4462
38	7305	10	3	7	1	3.3	303	73	173	1726	858	0.9986	0.3000	104	286	173	0	556	5443	1145	151	10	0.6550
39	7305	16	11	3	1	1.5	317	9	106	1700	1153	0.9978	0.6875	152	105	106	0	552	5423	1127	191	12	0.3503
40	7305	10	7	2	1	1.4	415	35	196	1959	1621	0.9986	0.7000	365	232	196	0	570	5484	1122	119	10	0.4789
41	7305	19	7	10	1	2.7	882	4	224	4250	1583	0.9974	0.3684	38	226	224	0	535	5556	1083	113	18	0.3853
42	7305	24	14	5	1	1.7	490	20	179	4286	2184	0.9967	0.5833	61	156	179	0	551	5484	1114	135	21	0.7034
43	7305	23	13	3	1	1.8	479	9	166	3816	2617	0.9969	0.5652	106	201	166	0	531	5499	1071	185	19	0.6345
44	7305	36	19	7	1	1.9	571	16	198	7134	4213	0.9951	0.5278	29	222	198	0	577	5458	1078	162	30	0.2431
45	7305	22	14	4	1	1.6	529	17	179	3948	2747	0.9970	0.6364	83	196	179	0	561	5477	1091	157	19	0.6303
46	7305	29	18	4	1	1.6	474	2	169	4894	3330	0.9960	0.6207	63	185	169	0	532	5485	1125	141	22	0.3162
47	7305	33	10	9	1	3.3	544	11	285	9410	2762	0.9955	0.3030	25	276	285	0	545	5448	1120	160	32	0.2362
48	7305	24	13	5	1	1.8	449	2	130	3114	1890	0.9967	0.5417	61	145	130	0	552	5435	1176	123	19	0.4398
49	7305	21	15	4	1	1.4	727	2	152	3198	2366	0.9971	0.7143	87	158	152	0	550	5404	1173	159	19	0.4409
50	7305	36	17	5	1	2.1	658	6	163	5855	3409	0.9951	0.4722	41	201	163	0	571	5465	1099	139	31	0.3101
51	7305	18	8	5	1	2.3	682	14	224	4025	1805	0.9975	0.4444	81	226	224	0	560	5462	1092	176	15	0.6391
52	7305	16	10	4	1	1.6	312	3	127	2029	1500	0.9978	0.6250	114	150	127	0	565	5397	1161	169	13	0.5785
53	7305	23	12	3	1	1.9	572	4	192	4423	3029	0.9969	0.5217	106	252	192	0	533	5420	1164	166	22	0.4594
54	7305	25	13	6	1	1.9	507	17	177	4433	2577	0.9966	0.5200	49	198	177	0	549	5402	1197	134	23	0.4176
55	7305	16	9	4	1	1.8	496	9	219	3508	2153	0.9978	0.5625	114	239	219	0	547	5459	1145	141	13	0.5229
56	7305	10	6	2	1	1.7	467	46	217	2168	1557	0.9986	0.6000	365	260	217	0	544	5516	1080	155	10	0.6153
57	7305	32	12	7	1	2.7	749	1	224	7182	3248	0.9956	0.3750	33	271	224	0	550	5450	1099	178	28	0.3179
58	7305	17	11	3	1	1.5	610	4	134	2275	1787	0.9977	0.6471	143	162	134	0	553	5503	1053	181	15	0.5678
59	7305	18	12	3	1	1.5	513	0	131	2351	1777	0.9975	0.6667	135	148	131	0	544	5457	1120	170	14	0.4341
60	7305	31	17	7	1	1.8	432	4	146	4521	2755	0.9958	0.5484	34	162	146	0	564	5442	1102	169	28	0.3154

61	7305	27	15	5	1	1.8	566	4	186	5029	2782	0.9963	0.5556	54	185	186	0	579	5389	1161	152	24	0.3208
62	7305	16	11	3	1	1.5	536	9	145	2323	1915	0.9978	0.6875	152	174	145	0	544	5449	1145	154	13	0.5618
63	7305	24	10	4	1	2.4	535	11	233	5593	3252	0.9967	0.4167	76	325	233	0	545	5469	1102	170	19	0.4844
64	7305	19	7	7	1	2.7	609	22	244	4634	2103	0.9974	0.3684	55	300	244	0	536	5472	1153	126	18	0.3875
65	7305	22	12	4	1	1.8	568	15	195	4299	2256	0.9970	0.5455	83	188	195	0	554	5460	1097	178	16	0.5907
66	7305	33	15	6	1	2.2	591	36	241	7941	3588	0.9955	0.4545	37	239	241	0	551	5497	1054	170	33	0.4659
67	7305	21	13	5	1	1.6	596	8	202	4233	3017	0.9971	0.6190	70	232	202	0	560	5429	1135	161	20	0.4053
68	7305	27	13	6	1	2.1	582	2	168	4538	2368	0.9963	0.4815	45	182	168	0	533	5462	1080	207	23	0.3374
69	7305	22	12	4	1	1.8	710	24	224	4917	3117	0.9970	0.5455	83	260	224	0	554	5425	1136	170	20	0.5627
70	7305	13	9	4	1	1.4	517	37	182	2370	1987	0.9982	0.6923	140	221	182	0	532	5516	1120	124	13	0.5628
71	7305	23	9	6	1	2.6	786	30	266	6126	3009	0.9969	0.3913	53	334	266	0	553	5405	1143	184	20	0.3428
72	7305	18	11	3	1	1.6	490	20	177	3185	2351	0.9975	0.6111	135	214	177	0	525	5514	1080	171	15	0.4613
73	7305	22	13	3	1	1.7	518	20	176	3862	2806	0.9970	0.5909	111	216	176	0	547	5492	1089	157	20	0.3707
74	7305	21	12	5	1	1.8	520	13	259	5432	2849	0.9971	0.5714	70	237	259	0	548	5456	1108	177	16	0.3797
75	7305	27	16	4	1	1.7	637	9	142	3833	2772	0.9963	0.5926	68	173	142	0	555	5440	1110	178	22	0.3394
76	7305	13	8	3	1	1.6	569	1	161	2095	1548	0.9982	0.6154	187	193	161	0	513	5489	1112	183	8	0.5539
77	7305	36	16	6	1	2.3	657	6	225	8093	3483	0.9951	0.4444	34	218	225	0	557	5459	1095	160	34	0.4093
78	7305	19	8	10	1	2.4	720	3	119	2270	1368	0.9974	0.4211	38	171	119	0	550	5494	1108	137	16	0.4141
79	7305	13	10	3	1	1.3	555	2	126	1634	1326	0.9982	0.7692	187	133	126	0	555	5463	1124	152	11	0.5708
80	7305	18	12	3	1	1.5	455	8	159	2870	2186	0.9975	0.6667	135	182	159	0	553	5431	1106	198	17	0.3792
81	7305	15	8	4	1	1.9	558	3	190	2844	1718	0.9979	0.5333	122	215	190	0	541	5453	1142	158	11	0.5273
82	7305	53	25	8	1	2.1	624	8	221	11716	5695	0.9927	0.4717	17	228	221	0	561	5396	1119	180	49	0.1702
83	7305	24	13	4	1	1.8	455	16	177	4253	3018	0.9967	0.5417	76	232	177	0	548	5443	1120	174	20	0.3627
84	7305	17	10	3	1	1.7	588	12	184	3135	2156	0.9977	0.5882	143	216	184	0	546	5554	1069	124	12	0.4736
85	7305	35	23	5	1	1.5	528	3	179	6262	3973	0.9952	0.6571	42	173	179	0	539	5447	1096	194	29	0.2339
86	7305	17	8	4	1	2.1	563	28	265	4503	2512	0.9977	0.4706	107	314	265	0	527	5513	1099	153	13	0.4513
87	7305	6	5	2	1	1.2	210	11	86	515	450	0.9992	0.8400	609	90	86	0	575	5493	1076	157	4	0.5357
88	7305	18	12	4	1	1.5	510	3	200	3592	2128	0.9975	0.6667	101	177	200	0	570	5428	1145	145	17	0.4228
89	7305	29	18	4	1	1.6	612	4	197	5725	4139	0.9960	0.6207	63	230	197	0	566	5444	1108	164	23	0.5456
90	7305	25	11	6	1	2.3	569	1	234	5839	2415	0.9966	0.4400	49	220	234	0	565	5399	1153	167	21	0.3784
91	7305	24	9	4	1	2.7	767	11	203	4872	2810	0.9967	0.3750	76	312	203	0	557	5524	1070	131	23	0.5399
92	7305	13	7	3	1	1.9	652	13	159	2073	1235	0.9982	0.5385	187	176	159	0	548	5509	1052	187	9	0.5809
93	7305	29	12	10	1	2.4	861	5	232	6721	2707	0.9960	0.4138	25	226	232	0	552	5546	1039	144	24	0.3979
94	7305	18	12	3	1	1.5	412	2	178	3210	2132	0.9975	0.6667	135	178	178	0	571	5408	1130	180	16	0.3373
95	7305	13	8	4	1	1.6	492	79	255	3318	1627	0.9982	0.6154	140	203	255	0	548	5489	1074	182	12	0.6379
96	7305	22	10	7	1	2.2	748	21	214	4717	2483	0.9970	0.4545	47	248	214	0	544	5507	1058	175	21	0.4612
97	7305	22	13	3	1	1.7	452	22	209	4603	3268	0.9970	0.5909	111	251	209	0	535	5484	1123	142	21	0.5071
98	7305	32	14	6	1	2.3	552	32	242	7731	3837	0.9956	0.4375	38	274	242	0	533	5496	1063	181	32	0.3964
99	7305	41	19	8	1	2.2	613	3	120	4918	2769	0.9944	0.4634	22	146	120	0	566	5475	1059	174	31	0.4329
100	7305	22	13	5	1	1.7	619	15	161	3542	2449	0.9970	0.5909	66	188	161	0	540	5478	1119	147	21	0.4633
Minimum		6	3	2	1	1.2	210	0	86	515	450	0.9927	0.300	17	90	86	0	513	5373	1039	113	4	0.1702
Average		22	12	5	1	1.9	553	13	191	4310	2459	0.9970	0.548	104	212	191	0	548	5466	1111	161	20	0.4590
Maximum		53	25	10	1	3.3	888	79	341	11925	5695	0.9992	0.840	609	347	341	0	579	5556	1202	213	49	0.7063
Std.dev		8	4	2	0	0.4	127	14	45	2044	863	0.0011	0.111	92.7	50.1	44.9	0	13.8	40.3	35.2	22.5	7.4	0.1106

Scenerio Name: Scenario 2 Base Case if no WEMPs were implemented
Date: 12/10/2007
Simulation Start Time: 12:16:26 PM
Simulation End Time: 2:17:03 PM
Elapsed Time: 120.62 Minutes

		ΣZ_t	ΣW_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Avg S_i	Σ si	Σ sjej	$e_j = 1/\Sigma Z_t$				$v = \Sigma s_j e_j$	v= Σ si	no. of days with Demand							
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Avg. Severity of a Failure	Total Severity of Failure	Total Maximum Severity of Sojourn	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	Vulnerability	Vulnerability	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance	Total Severity/no. of days with failure
87	7305	24	14	7	1	1.7	364	19	121	2896	2034	0.0417	0.9967	0.5833	43	145	121	0	0	4870	2161	252	22	0.4195	121
4	7305	21	14	3	1	1.5	632	3	152	3197	2411	0.0476	0.9971	0.6667	116	172	152	0	0	4895	2171	221	18	0.3389	152
27	7305	29	16	5	1	1.8	658	1	136	3941	2544	0.0345	0.9960	0.5517	50	159	136	0	2	4828	2214	241	20	0.4516	136
38	7305	21	10	7	1	2.1	454	0	197	4133	1789	0.0476	0.9971	0.4762	50	179	197	0	2	4838	2154	292	19	0.5297	197
16	7305	22	13	4	1	1.7	660	9	197	4328	2324	0.0455	0.9970	0.5909	83	179	197	0	0	4826	2199	261	19	0.4166	197
40	7305	26	16	4	1	1.6	567	9	169	4398	3047	0.0385	0.9964	0.6154	70	190	169	0	0	4823	2230	231	21	0.3905	169
92	7305	29	15	3	1	1.9	807	4	165	4781	2839	0.0345	0.9960	0.5172	84	189	165	0	1	4821	2188	274	21	0.4873	165
19	7305	28	9	9	1	3.1	578	8	172	4806	1910	0.0357	0.9962	0.3214	29	212	172	0	2	4865	2169	244	25	0.6820	172
56	7305	33	20	4	1	1.7	618	2	164	5407	3426	0.0303	0.9955	0.6061	55	171	164	0	0	4816	2181	277	31	0.3994	164
7	7305	24	15	4	1	1.6	710	12	228	5468	3112	0.0417	0.9967	0.6250	76	207	228	0	3	4783	2239	260	20	0.3859	228
79	7305	40	22	6	1	1.8	708	11	138	5537	3592	0.0250	0.9945	0.5500	30	163	138	0	2	4839	2127	301	36	0.4534	138
70	7305	31	23	6	1	1.3	669	8	182	5654	4389	0.0323	0.9958	0.7419	39	191	182	0	1	4851	2142	285	26	0.2682	182
39	7305	35	20	4	1	1.8	471	4	165	5780	3414	0.0286	0.9952	0.5714	52	171	165	0	0	4823	2212	237	33	0.4337	165
58	7305	35	18	4	1	1.9	765	4	168	5879	3863	0.0286	0.9952	0.5143	52	215	168	0	2	4845	2191	239	28	0.4904	168
5	7305	36	24	4	1	1.5	449	12	170	6113	4207	0.0278	0.9951	0.6667	51	175	170	0	2	4867	2144	259	33	0.3402	170
76	7305	40	21	5	1	1.9	723	0	153	6115	3764	0.0250	0.9945	0.5250	37	179	153	0	1	4863	2123	283	35	0.4790	153
62	7305	36	21	4	1	1.7	689	7	174	6264	4315	0.0278	0.9951	0.5833	51	205	174	0	2	4848	2138	284	33	0.4225	174
8	7305	40	24	7	1	1.7	571	6	160	6420	4578	0.0250	0.9945	0.6000	26	191	160	0	0	4860	2121	289	35	0.4052	160
95	7305	33	17	7	1	1.9	644	15	196	6479	3193	0.0303	0.9955	0.5152	32	188	196	0	2	4841	2210	224	28	0.4912	196
52	7305	46	24	5	1	1.9	467	2	141	6492	3881	0.0217	0.9937	0.5217	32	162	141	0	0	4824	2143	298	40	0.4816	141
81	7305	35	18	5	1	1.9	710	0	189	6604	3655	0.0286	0.9952	0.5143	42	203	189	0	2	4843	2147	283	30	0.4916	189
72	7305	33	20	3	1	1.7	644	2	201	6636	4518	0.0303	0.9955	0.6061	74	226	201	0	0	4875	2140	262	28	0.4021	201
78	7305	47	21	13	1	2.2	875	0	146	6839	3332	0.0213	0.9936	0.4468	12	159	146	0	0	4816	2168	282	39	0.5563	146
2	7305	35	18	6	1	1.9	538	9	200	7008	4469	0.0286	0.9952	0.5143	35	248	200	0	1	4835	2196	239	34	0.4923	200
14	7305	35	20	4	1	1.8	658	2	201	7032	4346	0.0286	0.9952	0.5714	52	217	201	0	3	4794	2237	242	29	0.4361	201
94	7305	40	20	5	1	2.0	563	2	182	7265	4036	0.0250	0.9945	0.5000	37	202	182	0	0	4811	2161	301	32	0.5053	182
59	7305	50	24	5	1	2.1	665	5	145	7267	4551	0.0200	0.9932	0.4800	29	190	145	0	1	4873	2105	282	44	0.5233	145
26	7305	42	23	4	1	1.8	569	0	175	7338	4769	0.0238	0.9943	0.5476	43	207	175	0	1	4881	2078	309	36	0.4578	175
84	7305	43	23	6	1	1.9	740	3	174	7503	4670	0.0233	0.9941	0.5349	28	203	174	0	1	4883	2164	220	37	0.4704	174
32	7305	29	14	6	1	2.1	1001	1	266	7721	3261	0.0345	0.9960	0.4828	42	233	266	0	1	4839	2203	237	25	0.5281	266
80	7305	53	26	5	1	2.0	606	0	146	7731	5057	0.0189	0.9927	0.4906	28	195	146	0	2	4847	2127	283	46	0.5128	146
36	7305	38	19	5	1	2.0	670	14	205	7774	3925	0.0263	0.9948	0.5000	38	207	205	0	0	4870	2132	270	33	0.5067	205
55	7305	45	23	6	1	2.0	648	4	174	7837	4438	0.0222	0.9938	0.5111	27	193	174	0	1	4809	2182	276	37	0.4939	174
23	7305	43	28	4	1	1.5	592	1	185	7952	4945	0.0233	0.9941	0.6512	42	177	185	0	0	4849	2131	286	39	0.3566	185
20	7305	38	19	5	1	2.0	887	1	211	8029	3989	0.0263	0.9948	0.5000	38	210	211	0	1	4806	2226	240	32	0.5071	211
30	7305	54	29	5	1	1.9	630	1	149	8044	5058	0.0185	0.9926	0.5370	27	174	149	0	1	4846	2106	308	44	0.4668	149
41	7305	34	12	13	1	2.8	1037	10	239	8142	2753	0.0294	0.9953	0.3529	17	229	239	0	0	4923	2141	211	30	0.6541	239
88	7305	46	23	5	1	2.0	661	1	178	8167	4590	0.0217	0.9937	0.5000	32	200	178	0	0	4874	2112	280	39	0.5051	178
86	7305	33	18	5	1	1.8	715	4	248	8178	4477	0.0303	0.9955	0.5455	44	249	248	0	3	4861	2086	326	29	0.4653	248
51	7305	40	18	8	1	2.2	837	3	206	8238	3770	0.0250	0.9945	0.4500	23	209	206	0	1	4885	2147	239	33	0.5562	206
100	7305	45	23	5	1	2.0	774	3	183	8240	5054	0.0222	0.9938	0.5111	32	220	183	0	1	4851	2133	282	38	0.4944	183
64	7305	32	17	9	1	1.9	764	14	261	8359	3212	0.0313	0.9956	0.5313	25	189	261	0	1	4785	2234	255	30	0.4803	261
1	7305	38	17	8	1	2.2	612	6	220	8372	4743	0.0263	0.9948	0.4474	24	279	220	0	0	4849	2149	271	36	0.5596	220
49	7305	50	24	14	1	2.1	881	5	169	8434	4569	0.0200	0.9932	0.4800	10	190	169	0	2	4824	2157	278	44	0.5244	169
18	7305	38	18	5	1	2.1	671	1	223	8460	4830	0.0263	0.9948	0.4737	38	268	223	0	1	4862	2104	308	30	0.5338	223
24	7305	48	29	7	1	1.7	687	0	177	8511	4879	0.0208	0.9934	0.6042	22	168	177	0	2	4827	2149	288	39	0.4022	177
6	7305	40	20	7	1	2.0	799	6	216	8655	5416	0.0250	0.9945	0.5000	26	271	216	0	1	4836	2194	237	37	0.5075	216
22	7305	38	17	8	1	2.2	714	0	230	8728	4025	0.0263	0.9948	0.4474	24	237	230	0	0	4867	2129	276	33	0.5602	230
73	7305	46	24	7	1	1.9	673	4	190	8761	5262	0.0217	0.9937	0.5217	23	219	190	0	1	4845	2172	248	39	0.4843	190
43	7305	43	18	6	1	2.4	631	13	206	8871	4880	0.0233	0.9941	0.4186	28	271	206	0	1	4880	2091	292	41	0.5873	206
21	7305	50	25	5	1	2.0	663	5	177	8872	5620	0.0200	0.9932	0.5000	29	225	177	0	1	4823	2143	295	43	0.5051	177
33	7305	44	23	4	1	1.9	672	4	202	8893	5052	0.0227	0.9940	0.5227	42	220	202	0	4	4872	2102	293	34	0.4841	202
48	7305	59	27	12	1	2.2	601	0	151	8899	4532	0.0169	0.9919	0.4576	10	168	151	0	0	4890	2125	240	50	0.5458	151
96	7305	43	22	8	1	2.0	902	6	216	9285	4640	0.0233	0.9941	0.5116	21	211	216	0	0	4832	2170	267	36	0.4960	216
65	7305	51	27	7	1	1.9	721	1	184	9366	4896	0.0196	0.9930	0.5294	20	181	184	0	1	4866	2118	280	40	0.4763	184
83	7305	42	18	6	1	2.3	608	6	225	9447	5055	0.0238	0.9943	0.4286	29	281	225	0	1	4812	2188	265	39	0.5785	225
42	7305	44	17	7	1	2.6	642	1	215	9463	4300	0.0227	0.9940	0.3864	24	253	215	0	1	4862	2161	241	40	0.6197	215
53	7305	43	22	4	1	2.0	724	10	224	9637	5830	0.0233	0.9941	0.5116	42	265	224	0	0	4768	2208	290	39	0.4966	224
11	7305	44	24	5	1	1.8	639	1	220	9662	5153	0.0227	0.9940	0.5455	33	215	220	0	0	4836	2148	280	41	0.4630	220
67	7305	46	23	6	1	2.0	750	20	211	9705	5698	0.0217	0.9937	0.5000	26	248	211	0	0	4822	2177	261	45	0.5071	211
97	7305	48	24	5	1	2.0	603	2	203	9756	5899	0.0208	0.9934	0.5000	30	246	203	0	0	4809	2200	253	43	0.5066	203
10	7305	54	22	6	1	2.5	677	2	183	9907	4564	0.0185	0.9926	0.4074	23	207	183	0	0	4884	2127	247	47	0.5972	183
35	7305	54	27	10	1	2.0	570	1	184	9912	5318	0.0185	0.9926	0.5000	14	197	184	0	1	4788	2191	276	49	0.5054	184
91	7305	47	21	7	1	2.2	922	1	212	9973	4710	0.0213	0.9936	0.4468	22	224	212	0	1	4853	2094	316	41	0.5597	212
75	7305	56	28	6	1	2.0	792	2	178	9988	5873	0.0179	0.9923	0.5000	22	210	178	0	2	4829	2121	308	45	0.5051	178
45	7305	59	23	11	1	2.6	681	6	170	10014	5381	0.0169	0.9919	0.3898	11	234	170	0	1	4782	2197	273	52	0.6140	170
54	7305	51	18	11	1	2.8	662	4	200	10211	4650	0.0196	0.9930	0.3529	13	258	200	0	0	4841	2198	221	45	0.6520	200
68	7305	52	24	7	1	2.2	737	2	200	10377	5013	0.0192	0.9929	0.4615	20	209	200	0	0	4793	2142	325	45	0.5444	200
31	7305	57	28	4	1	2.0	744	8	183	10408	6757	0.0175	0.9922	0.4912	32	241	183	0	1	4833	2159	260	52	0.5140	183
90	7305	40	22	7	1	1.8	721	0	263	10538	4615	0.0250	0.9945	0.5500	26	210	263	0	1	4784	2228	258	34	0.4622	263
69	7305	53	21	11	1	2.5	865	11	201	10644	5482	0.0189	0.9927	0.3962	13	261	201	0	0	4878	2096	283	48	0.6091	201
74	7305	50	28	6	1	1.8	673	4	216	10803	5573	0.0200	0.9932	0.5600	24	199	216	0	1	4856	2136	268	44	0.4485	216
71	7305	47	19	6	1	2.5	940	3	231	10844	4840	0.0213	0.9936	0.4043	26	255	231	0	1	4815	2172	280	37	0.6029	231
46	7305	60	33	6	1	1.8	626	2	183	10952	6812	0.0167	0.9918	0.5500	20	206	183	0	0	4893	2080	284	48	0.4560	183
61	7305	58	31	5	1	1.9	718	1	192	11136	6098	0.0172	0.9921	0.5345	25	197	192	0	1	4825	2117	313	49	0.4719	192
37	7305	54	28	7	1	1.9	768	0	207	11189	5757	0.0185	0.9926	0.5185	19	206	207	0	1	4768	2175	315	46	0.4886	207
63	7305	49	15	10	1	3.3	688	6	229	11245	4684	0.0204	0.9933	0.3061	15	312	229	0	0	4841	2201	219	44	0.7000	229
60	7305	58	25	7	1	2.3	586	2	195	11282	5962	0.0172	0.9921	0.4310	18	238	195	0	0	4819	2117	316	53	0.5743	195
12	7305	52	21	6	1	2.5	580	6	223	11590	5866	0.0192	0.9929	0.4038	23	279	223	0	1	4787	2155	317	45	0.6028	223
89	7305	52	26	5	1	2.0	767	1	226	11745	7458	0.0192	0.9929	0.5000	28	287	226	0	1	4884	2132	241	47	0.5081	226
17	7305	51	21	9	1	2.4	866	0	233	11900	4919	0.0196	0.9930	0.4118	16	234	233	0	4	4791	2191	272	47	0.5956	233
15	7305	62	25	5	1	2.5	672	3	193	11981	6408	0.0161	0.9915	0.4032	24	256	193	0	1	4821	2153	277	53	0.6018	193
29	7305	61	26	8	1	2.3	638	0	198	12063	4746	0.0164	0.9916	0.4262	15	183	198	0	2	4869	2101	282	51	0.5793	198
3	7305	61	26	7	1	2.3	683	9	202	12298	5839	0.0164	0.9916	0.4262	17	225	202	0	2	4799	2151	298	55	0.5795	202
9	7305	58	29	5	1	2.0	642	0	217	12611	7459	0.0172	0.9921	0.5000	25	257	217	0	2	4846	2102	304	51	0.5076	217

93	7305	51	22	11	1	2.3	1016	1	249	12714	5318	0.0196	0.9930	0.4314	13	242	249	0	1	4890	2156	213	45	0.5773	249	
28	7305	60	27	6	1	2.2	781	1	219	13128	7267	0.0167	0.9918	0.4500	20	269	219	0	1	4793	2155	302	54	0.5570	219	
85	7305	69	37	5	1	1.9	680	2	204	14093	8223	0.0145	0.9906	0.5362	21	222	204	0	1	4827	2114	303	60	0.4710	204	
50	7305	66	23	10	1	2.9	812	2	214	14108	6088	0.0152	0.9910	0.3485	11	265	214	0	1	4873	2106	263	62	0.6572	214	
44	7305	61	25	7	1	2.4	723	5	235	14357	7225	0.0164	0.9916	0.4098	17	289	235	0	0	4898	2096	255	56	0.5977	235	
57	7305	65	29	7	1	2.2	904	12	221	14380	6184	0.0154	0.9911	0.4462	16	213	221	0	1	4833	2135	278	58	0.5609	221	
98	7305	62	29	6	1	2.1	707	8	236	14620	7020	0.0161	0.9915	0.4677	20	242	236	0	3	4867	2095	285	55	0.5406	236	
99	7305	84	28	14	1	3.0	768	4	175	14727	5815	0.0119	0.9885	0.3333	6	208	175	0	0	4885	2097	247	76	0.6704	175	
13	7305	48	18	13	1	2.7	1031	9	309	14820	5109	0.0208	0.9934	0.3750	12	284	309	0	0	4801	2196	265	43	0.6371	309	
66	7305	61	27	7	1	2.3	746	1	244	14881	6712	0.0164	0.9916	0.4426	17	249	244	0	4	4849	2143	255	54	0.5659	244	
77	7305	60	27	7	1	2.2	811	3	255	15291	6440	0.0167	0.9918	0.4500	17	239	255	0	1	4849	2152	250	53	0.5594	255	
25	7305	71	31	8	1	2.3	718	2	221	15675	6802	0.0141	0.9903	0.4366	13	219	221	0	0	4812	2135	295	63	0.5703	221	
47	7305	55	19	11	1	2.9	697	7	291	16013	4739	0.0182	0.9925	0.3455	12	249	291	0	0	4781	2206	270	48	0.6649	291	
34	7305	60	26	8	1	2.3	1043	0	313	18807	7775	0.0167	0.9918	0.4333	15	299	313	0	0	4831	2152	272	50	0.5804	313	🟥
82	7305	81	34	8	1	2.4	779	5	272	22033	10224	0.0123	0.9889	0.4198	11	301	272	0	1	4788	2133	306	77	0.5905	272	
Minimum		21	9	3	1	1.3	364	0	121	2896	1789	0.0119	0.9885	0.3061	6	145	121	0	0	4768	2078	211	18	0.2682	121	
Average		46	22	7	1	2.1	706	4	200	9370	4885	0.0235	0.9937	0.4911	30	220	200	0	1	4839	2153	271	40	0.5155	200	
Maximum		84	37	14	1	3.3	1043	20	313	22033	10224	0.0476	0.9971	0.7419	116	312	313	0	4	4923	2239	326	77	0.7000	313	
Std.dev		12.5	5.2	2.5	0	0.4	127.9	4.3	36.4	3380.4	1423.8	0.0074	0.0017	0.0801	18.2	36.9	36.4	0.0	1.0	33.2	39.6	27.2	11.6	0.0800	36	

Scenerio Na Scenario 3 Base Case with 5% additional WEMPs savings
Date: 12/10/2007
Simulation S 1:23:17 AM
Simulation E 2:51:56 AM
Elapsed Tim 88.65 Minutes

		ΣZ_t	ΣW_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Avg S_i	Σ sj		$e_j = 1/\Sigma Z_t$				v=Σsjej	v= Σsiei	no. of days with Demand						
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Avg. Severity of a Failure	Total Maximum Severity of Sojourn	Total Severity of Failure	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	Vulnerability 1	Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance
87	7305	6	5	2	1	1.2	202	4	78	412	469	0.1667	0.9992	0.8333	609	82	78	0	622	5493	1035	151	4	0.1696
4	7305	7	4	2	1	1.8	471	16	145	898	1012	0.1429	0.9990	0.5714	522	224	145	0	589	5518	1075	118	5	0.4325
79	7305	10	8	2	1	1.3	548	1	155	1259	1549	0.1000	0.9986	0.8000	365	157	155	0	569	5473	1077	178	8	0.2094
27	7305	9	7	3	1	1.3	499	7	175	1119	1574	0.1111	0.9988	0.7778	271	160	175	0	601	5427	1158	113	6	0.2330
39	7305	16	11	3	1	1.5	309	2	99	1069	1577	0.0625	0.9978	0.6875	152	97	99	0	592	5442	1125	134	12	0.3150
38	7305	10	3	7	1	3.3	295	65	165	835	1649	0.1000	0.9986	0.3000	104	278	165	0	616	5428	1107	144	10	0.7031
19	7305	11	5	4	1	2.2	415	39	152	1130	1677	0.0909	0.9985	0.4545	166	226	152	0	602	5516	1059	117	11	0.5489
5	7305	17	11	3	1	1.5	289	16	108	1358	1829	0.0588	0.9977	0.6471	143	123	108	0	587	5529	1022	153	14	0.3556
40	7305	10	7	2	1	1.4	407	27	188	1568	1883	0.1000	0.9986	0.7000	365	224	188	0	618	5474	1087	117	9	0.3093
52	7305	14	11	4	1	1.3	304	6	137	1442	1915	0.0714	0.9981	0.7857	130	131	137	0	611	5396	1096	190	12	0.2212
16	7305	8	3	4	2	2.7	499	6	243	968	1941	0.1250	0.9989	0.3750	228	323	243	0	591	5485	1091	132	6	0.6325
92	7305	13	7	3	1	1.9	644	5	152	1182	1974	0.0769	0.9982	0.5385	187	169	152	0	613	5449	1083	149	11	0.4655
76	7305	12	7	3	1	1.7	561	2	167	1493	2003	0.0833	0.9984	0.5833	203	213	167	0	605	5495	1020	176	9	0.4220
56	7305	10	6	2	1	1.7	459	39	209	1512	2093	0.1000	0.9986	0.6000	365	252	209	0	592	5522	1029	152	10	0.4087
78	7305	16	8	8	1	2.0	713	20	133	1330	2130	0.0625	0.9978	0.5000	57	166	133	0	617	5386	1129	160	13	0.5028
58	7305	16	11	3	1	1.5	603	16	134	1703	2148	0.0625	0.9978	0.6875	152	155	134	0	603	5478	1071	138	15	0.3171
62	7305	16	11	3	1	1.5	528	1	138	1832	2202	0.0625	0.9978	0.6875	152	167	138	0	615	5421	1104	153	12	0.3173
59	7305	17	11	3	1	1.5	506	14	131	1693	2220	0.0588	0.9977	0.6471	143	154	131	0	603	5440	1080	168	14	0.3568
70	7305	13	9	4	1	1.4	509	29	175	1919	2271	0.0769	0.9982	0.6923	140	213	175	0	622	5419	1097	155	12	0.3155
8	7305	13	10	2	1	1.3	411	7	183	1944	2381	0.0769	0.9982	0.7692	281	194	183	0	600	5472	1044	177	12	0.2421
2	7305	19	13	3	1	1.5	376	4	134	2039	2545	0.0526	0.9974	0.6842	128	157	134	0	623	5461	1072	134	15	0.3203
80	7305	18	12	3	1	1.5	447	0	152	2095	2733	0.0556	0.9975	0.6667	135	175	152	0	582	5499	1042	168	14	0.3388
81	7305	13	7	4	1	1.9	550	0	211	1661	2738	0.0769	0.9982	0.5385	140	237	211	0	593	5446	1101	154	11	0.4692
7	7305	12	6	4	1	2.0	550	0	230	1606	2757	0.0833	0.9984	0.5000	152	268	230	0	618	5432	1112	133	10	0.5084
26	7305	17	9	3	1	1.9	410	5	168	2236	2862	0.0588	0.9977	0.5294	143	248	168	0	615	5481	1016	178	15	0.4754
30	7305	17	11	3	1	1.5	470	25	169	2291	2865	0.0588	0.9977	0.6471	143	208	169	0	616	5420	1056	197	16	0.3593
48	7305	23	13	4	1	1.8	441	4	128	1791	2937	0.0435	0.9969	0.5652	79	138	128	0	620	5437	1061	169	18	0.4378
84	7305	17	10	3	1	1.7	580	4	177	2080	3005	0.0588	0.9977	0.5882	143	208	177	0	599	5534	1039	121	12	0.4178
72	7305	18	11	3	1	1.6	482	13	169	2267	3048	0.0556	0.9975	0.6111	135	206	169	0	620	5426	1103	141	15	0.3948
49	7305	18	13	3	1	1.4	719	13	170	2262	3054	0.0556	0.9975	0.7222	135	174	170	0	597	5456	1064	174	14	0.2860
94	7305	16	11	3	1	1.5	404	37	192	2041	3079	0.0625	0.9978	0.6875	152	186	192	0	623	5395	1096	175	16	0.3218
24	7305	22	13	5	1	1.7	524	16	145	2014	3197	0.0455	0.9970	0.5909	66	155	145	0	609	5437	1079	160	20	0.4132
95	7305	13	8	4	1	1.6	484	71	248	1566	3219	0.0769	0.9982	0.6154	140	196	248	0	579	5517	1078	118	13	0.3972
14	7305	16	11	2	1	1.5	499	3	207	2287	3309	0.0625	0.9978	0.6875	228	208	207	0	580	5514	1049	150	12	0.3233
100	7305	22	13	5	1	1.7	611	7	153	2350	3374	0.0455	0.9970	0.5909	66	181	153	0	627	5446	1066	147	19	0.4137
6	7305	24	15	4	1	1.6	636	9	141	2610	3383	0.0417	0.9967	0.6250	76	174	141	0	615	5411	1141	119	19	0.3792
55	7305	16	9	4	1	1.8	489	1	212	2084	3386	0.0625	0.9978	0.5625	114	232	212	0	631	5376	1123	163	12	0.4456
23	7305	16	10	4	1	1.6	433	37	214	2029	3425	0.0625	0.9978	0.6250	114	203	214	0	587	5437	1107	158	16	0.3847
21	7305	23	14	2	1	1.6	501	1	150	2608	3450	0.0435	0.9969	0.6087	159	186	150	0	610	5397	1096	183	19	0.3959
88	7305	17	11	4	1	1.5	502	11	203	2041	3459	0.0588	0.9977	0.6471	107	186	203	0	588	5476	1045	182	14	0.3622
1	7305	21	12	6	1	1.8	454	11	166	2419	3480	0.0476	0.9971	0.5714	58	202	166	0	585	5510	1026	165	19	0.4337
36	7305	18	7	4	1	2.6	510	33	194	1935	3500	0.0556	0.9975	0.3889	101	276	194	0	578	5529	1019	161	18	0.6160
10	7305	27	14	5	1	1.9	517	2	131	1803	3536	0.0370	0.9963	0.5185	54	129	131	0	598	5475	1074	139	19	0.4843
75	7305	27	16	4	1	1.7	629	2	134	2650	3626	0.0370	0.9963	0.5926	68	166	134	0	607	5431	1076	170	21	0.4110
43	7305	23	13	3	1	1.8	472	1	158	2519	3641	0.0435	0.9969	0.5652	106	194	158	0	587	5486	1031	183	18	0.4394
31	7305	27	18	3	1	1.5	581	13	135	2711	3642	0.0370	0.9963	0.6667	90	151	135	0	593	5454	1054	180	24	0.3377
73	7305	22	13	3	1	1.7	510	13	168	2706	3693	0.0455	0.9970	0.5909	111	208	168	0	593	5474	1080	137	21	0.4146
45	7305	22	14	4	1	1.6	522	10	172	2640	3779	0.0455	0.9970	0.6364	83	189	172	0	613	5450	1051	176	15	0.3701
51	7305	18	8	5	1	2.3	674	7	216	1744	3887	0.0556	0.9975	0.4444	81	218	216	0	609	5503	1035	143	15	0.5622
35	7305	25	15	4	1	1.7	411	10	156	2281	3900	0.0400	0.9966	0.6000	73	152	156	0	619	5378	1124	164	20	0.4049
83	7305	24	13	4	1	1.8	448	8	170	2919	4070	0.0417	0.9967	0.5417	76	225	170	0	591	5462	1071	163	18	0.4633
67	7305	21	13	5	1	1.6	588	0	194	2918	4072	0.0476	0.9971	0.6190	70	224	194	0	609	5388	1135	155	18	0.3888
42	7305	24	14	5	1	1.7	482	12	171	2077	4103	0.0417	0.9967	0.5833	61	148	171	0	608	5475	1069	132	21	0.4223
41	7305	18	7	10	1	2.6	875	27	228	1530	4107	0.0556	0.9975	0.3889	41	219	228	0	583	5564	1029	112	17	0.6179
20	7305	16	8	5	1	2.0	725	11	257	2072	4115	0.0625	0.9978	0.5000	91	259	257	0	623	5455	1081	131	15	0.5105
18	7305	18	12	4	1	1.5	511	5	229	2499	4125	0.0556	0.9975	0.6667	101	208	229	0	628	5437	1055	171	14	0.3457
65	7305	22	12	4	1	1.8	561	8	188	2165	4132	0.0455	0.9970	0.5455	83	180	188	0	607	5410	1104	165	19	0.4607
22	7305	23	11	8	1	2.1	554	26	184	2063	4230	0.0435	0.9969	0.4783	40	188	184	0	611	5495	1023	154	22	0.5269
54	7305	25	13	6	1	1.9	499	10	170	2478	4241	0.0400	0.9966	0.5200	49	191	170	0	591	5491	1072	127	24	0.4848
32	7305	15	5	5	1	3.0	838	25	283	1716	4250	0.0667	0.9979	0.3333	97	343	283	0	602	5483	1093	113	14	0.6762
53	7305	22	12	3	1	1.8	564	26	193	2937	4251	0.0455	0.9970	0.5455	111	245	193	0	593	5407	1121	163	21	0.4611
60	7305	29	16	7	1	1.8	424	2	148	2629	4291	0.0345	0.9960	0.5517	36	164	148	0	601	5431	1062	189	22	0.4522
68	7305	24	11	6	1	2.2	575	0	181	2277	4343	0.0417	0.9967	0.4583	51	207	181	0	578	5417	1081	209	20	0.5465
86	7305	17	8	4	1	2.1	555	20	257	2451	4373	0.0588	0.9977	0.4706	107	306	257	0	616	5426	1050	197	16	0.5393

97	7305	22	13	3	1	1.7	444	15	202	3169	4436	0.0455	0.9970	0.5909	111	244	202	0	591	5465	1084	145	20	0.4170
33	7305	20	11	4	1	1.8	511	15	224	2579	4476	0.0500	0.9973	0.5500	91	234	224	0	604	5442	1067	173	19	0.4588
64	7305	19	7	7	1	2.7	601	14	236	2050	4489	0.0526	0.9974	0.3684	55	293	236	0	591	5468	1108	120	18	0.6386
11	7305	21	11	4	1	1.9	480	4	214	2492	4497	0.0476	0.9971	0.5238	87	227	214	0	610	5469	1054	152	20	0.4838
96	7305	22	10	7	1	2.2	741	14	207	2407	4549	0.0455	0.9970	0.4545	47	241	207	0	609	5417	1109	150	20	0.5517
99	7305	39	19	8	1	2.1	605	2	118	2623	4609	0.0256	0.9947	0.4872	23	138	118	0	621	5469	1016	169	30	0.5150
46	7305	28	18	4	1	1.6	466	3	167	3193	4678	0.0357	0.9962	0.6429	65	177	167	0	626	5425	1069	163	22	0.3634
91	7305	24	9	4	1	2.7	759	4	195	2741	4688	0.0417	0.9967	0.3750	76	305	195	0	621	5414	1081	171	18	0.6299
69	7305	22	12	4	1	1.8	703	17	216	3025	4749	0.0455	0.9970	0.5455	83	252	216	0	603	5478	1034	169	21	0.4627
61	7305	26	14	5	1	1.9	558	0	186	2672	4827	0.0385	0.9964	0.5385	56	191	186	0	593	5437	1051	201	23	0.4675
15	7305	29	15	4	1	1.9	510	3	175	3263	5067	0.0345	0.9960	0.5172	63	218	175	0	613	5454	1038	174	26	0.4878
37	7305	26	14	6	1	1.9	607	5	200	2383	5191	0.0385	0.9964	0.5385	47	170	200	0	605	5368	1129	182	21	0.4684
74	7305	21	12	5	1	1.8	512	5	251	2758	5273	0.0476	0.9971	0.5714	70	230	251	0	599	5444	1090	152	20	0.4402
29	7305	30	12	8	1	2.5	479	6	177	1977	5306	0.0333	0.9959	0.4000	30	165	177	0	601	5460	1038	182	24	0.6042
63	7305	24	10	4	1	2.4	527	4	225	3175	5409	0.0417	0.9967	0.4167	76	318	225	0	616	5503	1036	127	23	0.5903
17	7305	27	12	6	1	2.3	703	2	202	2637	5448	0.0370	0.9963	0.4444	45	220	202	0	630	5388	1115	148	24	0.5614
3	7305	28	13	5	1	2.2	524	23	196	2884	5483	0.0357	0.9962	0.4643	52	222	196	0	574	5430	1104	170	27	0.5414
89	7305	26	17	4	1	1.5	604	14	212	4006	5513	0.0385	0.9964	0.6538	70	236	212	0	604	5535	1002	140	24	0.3564
50	7305	35	16	5	1	2.2	650	12	159	3281	5581	0.0286	0.9952	0.4571	42	205	159	0	625	5446	1047	157	30	0.5466
12	7305	29	15	5	1	1.9	417	7	193	3134	5594	0.0345	0.9960	0.5172	50	209	193	0	612	5388	1096	182	27	0.4889
90	7305	24	11	6	1	2.2	561	13	236	2331	5657	0.0417	0.9967	0.4583	51	212	236	0	601	5381	1170	130	23	0.5498
9	7305	31	19	5	1	1.6	481	6	183	3631	5664	0.0323	0.9958	0.6129	47	191	183	0	622	5422	1068	165	28	0.3940
28	7305	28	15	5	1	1.9	619	14	208	3532	5834	0.0357	0.9962	0.5357	52	235	208	0	590	5399	1123	168	25	0.4717
71	7305	23	9	6	1	2.6	779	23	259	2940	5950	0.0435	0.9969	0.3913	53	327	259	0	605	5440	1073	166	21	0.6174
85	7305	34	23	5	1	1.5	520	0	176	3798	6001	0.0294	0.9953	0.6765	43	165	176	0	588	5456	1049	182	30	0.3312
93	7305	27	11	10	1	2.5	853	4	241	2618	6501	0.0370	0.9963	0.4074	27	238	241	0	608	5492	1049	131	25	0.6004
44	7305	36	19	7	1	1.9	563	8	191	4068	6858	0.0278	0.9951	0.5278	29	214	191	0	623	5460	1030	164	28	0.4784
57	7305	30	11	7	1	2.7	742	5	232	3162	6949	0.0333	0.9959	0.3667	35	287	232	0	606	5429	1069	173	28	0.6401
98	7305	32	14	6	1	2.3	544	24	234	3731	7486	0.0313	0.9956	0.4375	38	266	234	0	594	5467	1036	177	31	0.5702
25	7305	33	14	5	1	2.4	558	4	231	3528	7623	0.0303	0.9955	0.4242	44	252	231	0	595	5427	1063	193	27	0.5831
66	7305	33	15	6	1	2.2	583	28	233	3474	7689	0.0303	0.9955	0.4545	37	232	233	0	600	5505	1003	165	32	0.5534
77	7305	35	15	6	1	2.3	649	2	223	3362	7818	0.0286	0.9952	0.4286	35	224	223	0	618	5453	1066	137	31	0.5784
13	7305	28	10	10	1	2.8	868	3	307	2750	8586	0.0357	0.9962	0.3571	26	275	307	0	627	5400	1116	138	24	0.6545
47	7305	33	10	9	1	3.3	537	4	278	2686	9158	0.0303	0.9955	0.3030	25	269	278	0	597	5434	1092	150	32	0.7058
82	7305	53	25	8	1	2.1	617	1	213	5504	11312	0.0189	0.9927	0.4717	17	220	213	0	613	5385	1081	178	48	0.5352
34	7305	35	14	7	1	2.5	880	6	333	4756	11655	0.0286	0.9952	0.4000	30	340	333	0	613	5439	1069	153	31	0.6146
Minimum		6	3	2	1	1.2	202	0	78	412	469	0.0189	0.9927	0.3000	17	82	78	0	569	5368	1002	112	4	0
Average		22	12	5	1	1.9	545	12	189	2371	4143	0.0539	0.9970	0.5502	110	211	189	0	605	5452	1073	157	19	0
Maximum		53	25	10	2	3	880	71	333	5504	11655	0	1	1	609	343	333	0	631	5564	1170	209	48	1
Std.dev		7.9	3.9	1.9	0.1	0.4	127.2	12.7	44.3	839.2	1991.6	0.0248	0.0011	0.1151	96.8	51.3	44.3	0.0	14.2	41.8	34.8	22.3	7.2	0.1

Scenerio N Scenario 4 Base Case with 15% additional WEMPs savings
Date: 12/10/2007
Simulation 4:32:21 PM
Simulation 5:40:37 PM
Elapsed Tii 68.27 Minutes

		ΣZ_t	ΣW_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Avg S_i	Σ sj		$e_j = 1/\Sigma Z_t$				v=Ssjej	v= Ssiei	no. of days with Demand						
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Avg. Severity of a Failure	Total Maximum Severity of Sojourn	Total Severity of Failure	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	Vulnerability 1	Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance
87	7305	5	4	2	1	1.3	187	1	78	347	388	0.2000	0.9993	0.8000	731	87	78	0	731	5470	962	138	4	0.2024
4	7305	7	4	2	1	1.8	456	0	129	837	905	0.1429	0.9990	0.5714	522	209	129	0	719	5473	1005	103	5	0.4317
39	7305	13	8	3	1	1.6	293	8	104	920	1352	0.0769	0.9982	0.6154	187	115	104	0	716	5403	1051	125	10	0.3869
79	7305	8	6	2	1	1.3	533	34	178	1165	1424	0.1250	0.9989	0.7500	457	194	178	0	691	5438	997	171	8	0.2599
27	7305	7	5	3	1	1.4	484	12	207	1024	1449	0.1429	0.9990	0.7143	348	205	207	0	713	5405	1077	104	6	0.2975
38	7305	10	3	7	1	3.3	280	50	149	789	1495	0.1000	0.9986	0.3000	104	263	149	0	740	5369	1052	134	10	0.7026
19	7305	11	5	4	1	2.2	400	23	137	1053	1507	0.0909	0.9985	0.4545	166	211	137	0	704	5478	1007	107	9	0.5482
5	7305	17	11	3	1	1.5	274	1	92	1190	1570	0.0588	0.9977	0.6471	143	108	92	0	704	5486	955	147	13	0.3549
52	7305	13	10	4	1	1.3	289	2	132	1284	1710	0.0769	0.9982	0.7692	140	128	132	0	722	5366	1030	176	11	0.2367
40	7305	10	7	2	1	1.4	392	12	173	1461	1731	0.1000	0.9986	0.7000	365	209	173	0	736	5423	1025	112	9	0.3079
92	7305	11	7	3	1	1.6	629	34	162	1134	1787	0.0909	0.9985	0.6364	221	162	162	0	720	5424	1012	138	11	0.3694
16	7305	6	3	3	1	2.0	484	23	306	922	1834	0.1667	0.9992	0.5000	406	307	306	0	721	5438	1019	122	5	0.5147
76	7305	9	5	3	1	1.8	546	16	206	1410	1856	0.1111	0.9988	0.5556	271	282	206	0	705	5472	957	163	8	0.4520
78	7305	16	8	8	1	2.0	697	5	118	1207	1884	0.0625	0.9978	0.5000	57	151	118	0	726	5346	1065	157	11	0.5022
58	7305	16	11	3	1	1.5	587	0	119	1536	1903	0.0625	0.9978	0.6875	152	140	119	0	738	5429	990	134	14	0.3161
56	7305	10	6	2	1	1.7	444	24	194	1422	1942	0.1000	0.9986	0.6000	365	237	194	0	703	5479	971	144	8	0.4075
59	7305	15	10	3	1	1.5	491	0	131	1526	1962	0.0667	0.9979	0.6667	162	153	131	0	699	5417	1018	159	12	0.3374
62	7305	13	9	3	1	1.4	513	11	152	1673	1980	0.0769	0.9982	0.6923	187	186	152	0	728	5379	1041	147	10	0.3137
70	7305	13	9	4	1	1.4	494	13	159	1782	2072	0.0769	0.9982	0.6923	140	198	159	0	731	5392	1030	141	11	0.3142
8	7305	12	9	2	1	1.3	396	27	183	1799	2190	0.0833	0.9984	0.7500	304	200	183	0	716	5432	975	172	10	0.2604
2	7305	18	13	3	1	1.4	361	0	126	1840	2267	0.0556	0.9975	0.7222	135	142	126	0	753	5405	1001	132	14	0.2823
80	7305	17	12	3	1	1.4	432	0	146	1912	2474	0.0588	0.9977	0.7059	143	159	146	0	704	5467	966	156	12	0.2998
81	7305	12	6	4	1	2.0	535	3	213	1570	2555	0.0833	0.9984	0.5000	152	262	213	0	718	5390	1042	145	10	0.5072
7	7305	10	5	4	1	2.0	535	67	259	1530	2591	0.1000	0.9986	0.5000	183	306	259	0	730	5420	1021	124	10	0.5106
30	7305	17	11	3	1	1.5	455	9	153	2124	2607	0.0588	0.9977	0.6471	143	193	153	0	733	5385	985	187	15	0.3582
48	7305	20	10	4	1	2.0	426	11	130	1617	2609	0.0500	0.9973	0.5000	91	162	130	0	735	5398	992	165	15	0.5027
26	7305	16	9	3	1	1.8	395	7	163	2098	2613	0.0625	0.9978	0.5625	152	233	163	0	728	5433	964	165	15	0.4424
84	7305	15	9	3	1	1.7	565	1	184	1938	2760	0.0667	0.9979	0.6000	162	215	184	0	713	5496	968	116	12	0.4067
72	7305	17	11	2	1	1.5	467	12	163	2101	2777	0.0588	0.9977	0.6471	215	191	163	0	732	5385	1044	131	13	0.3589
49	7305	16	12	3	1	1.3	704	10	174	2066	2782	0.0625	0.9978	0.7500	152	172	174	0	720	5413	995	164	13	0.2595
94	7305	16	11	3	1	1.5	389	22	177	1874	2836	0.0625	0.9978	0.6875	152	170	177	0	749	5352	1024	167	13	0.3205
24	7305	22	13	5	1	1.7	509	0	130	1815	2861	0.0455	0.9970	0.5909	66	140	130	0	738	5397	994	161	15	0.4124
95	7305	13	8	4	1	1.6	469	56	232	1444	3022	0.0769	0.9982	0.6154	140	180	232	0	701	5478	1002	111	13	0.3957
6	7305	20	13	3	1	1.5	621	2	152	2387	3031	0.0500	0.9973	0.6500	122	184	152	0	726	5384	1065	114	16	0.3552
100	7305	21	12	5	1	1.8	596	4	145	2159	3047	0.0476	0.9971	0.5714	70	180	145	0	743	5408	996	140	18	0.4325
14	7305	13	8	2	1	1.6	484	8	238	2146	3091	0.0769	0.9982	0.6154	281	268	238	0	702	5495	951	145	12	0.3962
21	7305	21	14	2	1	1.5	485	5	149	2395	3121	0.0476	0.9971	0.6667	174	171	149	0	712	5364	1038	172	19	0.3386
10	7305	23	11	5	1	2.1	502	6	137	1627	3162	0.0435	0.9969	0.4783	64	148	137	0	716	5421	1020	133	15	0.5246
1	7305	20	11	6	1	1.8	438	9	158	2240	3165	0.0500	0.9973	0.5500	61	204	158	0	717	5460	957	152	19	0.4544
55	7305	13	8	4	1	1.6	474	11	244	1953	3166	0.0769	0.9982	0.6154	140	244	244	0	738	5353	1050	152	12	0.3968
23	7305	16	10	4	1	1.6	417	22	199	1877	3181	0.0625	0.9978	0.6250	114	188	199	0	698	5406	1033	153	15	0.3833
88	7305	16	10	4	1	1.6	487	10	200	1877	3204	0.0625	0.9978	0.6250	114	188	200	0	698	5449	971	173	14	0.3835
36	7305	18	7	4	1	2.6	494	18	179	1829	3227	0.0556	0.9975	0.3889	101	261	179	0	680	5496	956	157	16	0.6153
31	7305	26	18	3	1	1.4	565	2	124	2435	3232	0.0385	0.9964	0.6923	94	135	124	0	716	5395	1005	167	22	0.3117
75	7305	24	15	4	1	1.6	614	2	136	2419	3253	0.0417	0.9967	0.6250	76	161	136	0	710	5414	1006	156	19	0.3789
43	7305	20	12	3	1	1.7	456	5	166	2335	3328	0.0500	0.9973	0.6000	122	195	166	0	707	5440	964	176	18	0.4055
73	7305	21	13	3	1	1.6	495	16	160	2508	3359	0.0476	0.9971	0.6190	116	193	160	0	706	5455	995	131	18	0.3863
45	7305	20	12	4	1	1.7	507	3	173	2434	3451	0.0500	0.9973	0.6000	91	203	173	0	726	5398	999	171	11	0.4059
35	7305	23	14	4	1	1.6	396	3	153	2057	3526	0.0435	0.9969	0.6087	79	147	153	0	726	5334	1070	157	18	0.3961
51	7305	16	8	5	1	2.0	658	2	227	1622	3627	0.0625	0.9978	0.5000	91	203	227	0	724	5460	971	137	13	0.5082
83	7305	23	14	3	1	1.6	432	0	161	2769	3711	0.0435	0.9969	0.6087	106	198	161	0	724	5420	990	155	16	0.3966
42	7305	23	13	5	1	1.8	467	2	163	1866	3740	0.0435	0.9969	0.5652	64	144	163	0	710	5440	1007	130	18	0.4396
67	7305	19	13	3	1	1.5	573	9	199	2742	3773	0.0526	0.9974	0.6842	128	211	199	0	717	5363	1059	149	17	0.3256
65	7305	21	12	4	1	1.8	546	5	181	1983	3804	0.0476	0.9971	0.5714	87	165	181	0	724	5377	1029	158	17	0.4347
41	7305	18	7	10	1	2.6	859	11	213	1422	3830	0.0556	0.9975	0.3889	41	203	213	0	689	5526	964	109	17	0.6170
54	7305	24	12	6	1	2.0	484	15	161	2285	3863	0.0417	0.9967	0.5000	51	190	161	0	701	5454	1003	126	21	0.5041
18	7305	16	10	4	1	1.6	496	3	242	2331	3867	0.0625	0.9978	0.6250	114	233	242	0	730	5411	987	164	13	0.3873
20	7305	15	7	5	1	2.1	710	15	258	1953	3874	0.0667	0.9979	0.4667	97	279	258	0	735	5420	1012	126	12	0.5433
22	7305	23	11	8	1	2.1	539	11	169	1895	3878	0.0435	0.9969	0.4783	40	172	169	0	742	5444	951	146	22	0.5261
60	7305	26	14	7	1	1.9	408	2	149	2403	3879	0.0385	0.9964	0.5385	40	172	149	0	715	5395	995	179	21	0.4654
53	7305	22	12	3	1	1.8	549	11	178	2753	3914	0.0455	0.9970	0.5455	111	229	178	0	723	5350	1064	147	21	0.4601
68	7305	21	10	5	1	2.1	559	7	191	2124	4007	0.0476	0.9971	0.4762	70	212	191	0	692	5368	1033	192	20	0.5293
32	7305	15	5	5	1	3.0	823	10	268	1640	4020	0.0667	0.9979	0.3333	97	328	268	0	711	5446	1027	108	13	0.6752

99	7305	33	17	5	1	1.9	590	3	123	2504	4064	0.0303	0.9955	0.5152	44	147	123	0	736	5416	962	164	27	0.4874
97	7305	21	13	3	1	1.6	429	11	195	2971	4101	0.0476	0.9971	0.6190	116	229	195	0	717	5407	1021	141	19	0.3889
86	7305	17	8	4	1	2.1	540	5	242	2329	4115	0.0588	0.9977	0.4706	107	291	242	0	741	5358	1003	187	16	0.5382
33	7305	19	10	4	1	1.9	496	28	220	2412	4171	0.0526	0.9974	0.5263	96	241	220	0	724	5395	999	169	18	0.4818
11	7305	20	11	4	1	1.8	465	27	209	2325	4189	0.0500	0.9973	0.5500	91	211	209	0	732	5422	989	143	19	0.4577
64	7305	18	7	7	1	2.6	585	31	233	1943	4199	0.0556	0.9975	0.3889	58	278	233	0	717	5419	1041	110	18	0.6182
96	7305	21	9	7	1	2.3	725	12	201	2255	4213	0.0476	0.9971	0.4286	50	251	201	0	715	5399	1026	146	19	0.5770
46	7305	25	16	4	1	1.6	451	3	171	2932	4273	0.0400	0.9966	0.6400	73	183	171	0	741	5381	1014	148	21	0.3665
91	7305	20	8	4	1	2.5	744	7	218	2614	4358	0.0500	0.9973	0.4000	91	327	218	0	745	5365	1017	162	16	0.6063
69	7305	22	12	4	1	1.8	687	1	201	2841	4411	0.0455	0.9970	0.5455	83	237	201	0	714	5455	953	163	20	0.4616
61	7305	24	14	5	1	1.7	543	6	186	2460	4457	0.0417	0.9967	0.5833	61	176	186	0	707	5402	976	201	19	0.4232
15	7305	27	15	4	1	1.8	494	13	172	3035	4643	0.0370	0.9963	0.5556	68	202	172	0	720	5415	974	172	24	0.4498
37	7305	24	12	6	1	2.0	592	7	200	2185	4810	0.0417	0.9967	0.5000	51	182	200	0	735	5324	1046	180	20	0.5064
29	7305	28	11	8	1	2.5	464	2	174	1801	4862	0.0357	0.9962	0.3929	33	164	174	0	726	5401	986	170	22	0.6111
74	7305	20	12	5	1	1.7	497	16	248	2576	4964	0.0500	0.9973	0.6000	73	215	248	0	720	5404	1018	145	18	0.4121
50	7305	34	15	5	1	2.3	634	14	148	3041	5048	0.0294	0.9953	0.4412	43	203	148	0	736	5412	977	150	30	0.5620
63	7305	23	10	4	1	2.3	512	20	220	3022	5053	0.0435	0.9969	0.4348	79	302	220	0	727	5474	960	122	22	0.5720
17	7305	24	11	6	1	2.2	688	17	211	2455	5054	0.0417	0.9967	0.4583	51	223	211	0	739	5356	1047	142	21	0.5482
3	7305	28	13	5	1	2.2	509	8	181	2688	5060	0.0357	0.9962	0.4643	52	207	181	0	698	5381	1038	162	26	0.5406
89	7305	25	17	4	1	1.5	589	7	205	3747	5119	0.0400	0.9966	0.6800	73	220	205	0	719	5501	926	136	23	0.3303
12	7305	28	14	5	1	2.0	402	1	184	2914	5160	0.0357	0.9962	0.5000	52	208	184	0	723	5354	1032	171	25	0.5054
9	7305	29	17	5	1	1.7	466	5	179	3354	5203	0.0345	0.9960	0.5862	50	197	179	0	753	5371	999	158	24	0.4200
90	7305	23	10	6	1	2.3	546	23	230	2166	5295	0.0435	0.9969	0.4348	53	217	230	0	723	5343	1098	119	22	0.5727
28	7305	27	14	5	1	1.9	603	7	200	3306	5407	0.0370	0.9963	0.5185	54	236	200	0	709	5357	1056	160	23	0.4881
85	7305	30	21	5	1	1.4	505	17	184	3452	5509	0.0333	0.9959	0.7000	49	164	184	0	704	5416	977	180	28	0.3089
71	7305	23	9	6	1	2.6	763	8	243	2803	5597	0.0435	0.9969	0.3913	53	311	243	0	722	5410	996	157	20	0.6164
93	7305	26	10	10	1	2.6	838	5	235	2461	6099	0.0385	0.9964	0.3846	28	246	235	0	723	5443	985	131	23	0.6225
44	7305	32	18	4	1	1.8	548	3	198	3857	6326	0.0313	0.9956	0.5625	57	214	198	0	737	5422	961	158	27	0.4446
57	7305	29	11	7	1	2.6	726	5	224	2994	6498	0.0345	0.9960	0.3793	36	272	224	0	717	5387	1008	168	25	0.6271
98	7305	32	14	6	1	2.3	529	9	219	3518	6997	0.0313	0.9956	0.4375	38	251	219	0	718	5419	968	169	31	0.5693
25	7305	29	13	4	1	2.2	543	8	246	3423	7147	0.0345	0.9960	0.4483	63	263	246	0	725	5396	975	182	27	0.5605
66	7305	33	15	6	1	2.2	568	13	218	3246	7186	0.0303	0.9955	0.4545	37	216	218	0	715	5466	935	159	30	0.5524
77	7305	31	14	6	1	2.2	634	25	236	3191	7309	0.0323	0.9958	0.4516	39	228	236	0	740	5404	1005	126	30	0.5565
13	7305	25	9	10	1	2.8	853	13	327	2602	8177	0.0400	0.9966	0.3600	29	289	327	0	746	5351	1053	133	22	0.6532
47	7305	32	9	9	1	3.6	522	19	271	2545	8666	0.0313	0.9956	0.2813	25	283	271	0	697	5431	1008	138	31	0.7269
82	7305	50	24	8	1	2.1	601	6	211	5137	10529	0.0200	0.9932	0.4800	18	214	211	0	729	5361	1000	170	45	0.5268
34	7305	31	12	7	1	2.6	865	43	359	4554	11135	0.0323	0.9958	0.3871	34	379	359	0	722	5404	1006	142	31	0.6295
Minimum		5	3	2	1	1.3	187	0	78	347	388	0.0200	0.9932	0.2813	18	87	78	0	680	5324	926	103	4	0.2024
Average		20	11	5	1	1.9	530	12	188	2205	3824	0.0587	0.9972	0.5540	124	210	188	0	721	5413	1004	149	17	0.4527
Maximum		50	24	10	1	3.6	865	67	359	5137	11135	0.2000	0.9993	0.8000	731	379	359	0	753	5526	1098	201	45	0.7269
Std.dev		7.4	3.7	1.9	0	0.4	127.2	12.0	48.1	797.0	1891.2	0.0295	0.0010	0.1135	112.5	52.5	48.1	0	15	42	35	22	7	0.1135

Scenerio N Scenario 5 Base Case with 10% additional system capacity
Date: 12/10/2007
Simulation 6:28:51 PM
Simulation 7:05:09 PM
Elapsed Ti 36.3 Minutes

Trial No.	Total no. of Days	ΣZ_t No. of Days Failed	ΣW_t No. of Consecutive Failures	Max T_f Max. Failure Duration	Min T_f Min. Failure Duration	$E[T_f]$ Avg. Failure Duration	Max S_i Max Severity of Failure	Min S_i Min Severity of Failure	Avg S_i Avg. Severity of a Failure	Σ sj Total Maximum Severity of Sojourn	Total Severity of Failure	$e_j = 1/\Sigma Z_t$ Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS* NF)	v=Ssjej Vulnerability 1	v= Ssiei Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance	Total Severity/no. of days with failure
87	7305	0	0	0	0	0.0	0	0	0	0	0	0.0000	1.0000	1.0000	-	0	0	0	575	5493	1076	157	4	0.0000	-
39	7305	1	1	1	1	1.0	70	70	70	70	70	1.0000	0.9999	1.0000	7305	70	70	0	547	5459	1145	141	13	0.0278	70
5	7305	2	2	1	1	1.0	49	49	49	98	98	0.5000	0.9997	1.0000	3653	49	49	0	529	5539	1066	155	16	0.0197	49
52	7305	3	2	2	1	1.5	65	8	33	93	100	0.3333	0.9996	0.6667	1218	46	33	0	552	5423	1127	191	12	0.3336	33
38	7305	4	3	2	1	1.3	56	15	33	117	132	0.2500	0.9995	0.7500	913	39	33	0	556	5443	1145	151	10	0.2503	33
4	7305	2	2	1	1	1.0	232	4	118	236	236	0.5000	0.9997	1.0000	3653	118	118	0	537	5518	1126	118	6	0.0472	118
8	7305	3	3	1	1	1.0	172	45	99	297	297	0.3333	0.9996	1.0000	2435	99	99	0	548	5489	1074	182	12	0.0396	99
40	7305	4	4	1	1	1.0	168	11	78	313	313	0.2500	0.9995	1.0000	1826	78	78	0	570	5484	1122	119	10	0.0313	78
19	7305	3	3	1	1	1.0	176	54	104	313	313	0.3333	0.9996	1.0000	2435	104	104	0	543	5528	1100	123	11	0.0418	104
1	7305	4	3	2	1	1.3	214	2	91	362	364	0.2500	0.9995	0.7500	913	121	91	0	526	5531	1058	170	20	0.2526	91
58	7305	2	2	1	1	1.0	363	2	183	366	366	0.5000	0.9997	1.0000	3653	183	183	0	556	5484	1110	140	15	0.0732	183
79	7305	2	2	1	1	1.0	308	64	186	373	373	0.5000	0.9997	1.0000	3653	186	186	0	513	5489	1112	183	8	0.0746	186
2	7305	4	4	1	1	1.0	137	58	98	394	394	0.2500	0.9995	1.0000	1826	98	98	0	550	5494	1108	137	16	0.0394	98
59	7305	3	3	1	1	1.0	266	12	134	401	401	0.3333	0.9996	1.0000	2435	134	134	0	544	5457	1120	170	14	0.0534	134
27	7305	3	2	2	1	1.5	260	34	137	294	411	0.3333	0.9996	0.6667	1218	147	137	0	542	5438	1202	116	7	0.3378	137
70	7305	3	3	1	1	1.0	270	13	142	425	425	0.3333	0.9996	1.0000	2435	142	142	0	575	5428	1130	159	13	0.0566	142
76	7305	4	4	1	1	1.0	322	4	108	433	433	0.2500	0.9995	1.0000	1826	108	108	0	548	5509	1052	187	9	0.0433	108
30	7305	5	5	1	1	1.0	231	2	88	440	440	0.2000	0.9993	1.0000	1461	88	88	0	553	5431	1106	198	17	0.0352	88
94	7305	4	2	3	1	2.0	165	20	111	185	443	0.2500	0.9995	0.5000	609	92	111	0	571	5408	1130	180	16	0.5020	111
31	7305	3	2	2	1	1.5	342	49	155	416	464	0.3333	0.9996	0.6667	1218	208	155	0	541	5456	1101	182	25	0.3390	155
80	7305	6	6	1	1	1.0	208	16	77	464	464	0.1667	0.9992	1.0000	1218	77	77	0	525	5514	1080	171	15	0.0310	77
56	7305	4	3	2	1	1.3	220	28	121	452	486	0.2500	0.9995	0.7500	913	151	121	0	544	5516	1080	155	10	0.2547	121
48	7305	4	3	2	1	1.3	202	46	123	302	490	0.2500	0.9995	0.7500	913	101	123	0	551	5469	1090	175	20	0.2548	123
35	7305	5	3	2	1	1.7	171	9	98	372	490	0.2000	0.9993	0.6000	731	124	98	0	565	5399	1153	167	21	0.4019	98
78	7305	3	2	2	1	1.5	473	14	177	517	531	0.3333	0.9996	0.6667	1218	259	177	0	550	5405	1174	162	14	0.3408	177
24	7305	4	3	2	1	1.3	285	7	134	426	536	0.2500	0.9995	0.7500	913	142	134	0	559	5455	1105	165	21	0.2557	134
92	7305	3	1	3	3	3.0	405	30	181	405	543	0.3333	0.9996	0.3333	812	405	181	0	555	5463	1124	152	11	0.6706	181
100	7305	4	3	2	1	1.3	372	45	137	503	548	0.2500	0.9995	0.7500	913	168	137	0	561	5477	1091	157	19	0.2559	137
21	7305	6	5	2	1	1.2	261	13	92	538	551	0.1667	0.9992	0.8333	609	108	92	0	553	5405	1143	184	20	0.1707	92
62	7305	3	3	1	1	1.0	289	42	187	562	562	0.3333	0.9996	1.0000	2435	187	187	0	544	5449	1145	154	13	0.0749	187
60	7305	8	7	2	1	1.1	185	3	71	552	565	0.1250	0.9989	0.8750	457	79	71	0	548	5436	1103	193	25	0.1282	71
26	7305	4	4	1	1	1.0	170	115	143	571	571	0.2500	0.9995	1.0000	1826	143	143	0	553	5503	1053	181	15	0.0571	143
36	7305	5	4	2	1	1.3	270	31	123	544	617	0.2000	0.9993	0.8000	731	136	123	0	526	5542	1056	163	18	0.2060	123
10	7305	6	3	4	1	2.0	278	7	109	311	655	0.1667	0.9992	0.5000	304	104	109	0	532	5485	1125	141	22	0.5019	109
75	7305	6	5	2	1	1.2	390	18	113	619	677	0.1667	0.9992	0.8333	609	124	113	0	555	5440	1110	178	22	0.1727	113
16	7305	5	2	3	2	2.5	260	30	138	451	690	0.2000	0.9993	0.4000	487	225	138	0	537	5491	1129	142	6	0.6025	138
72	7305	3	3	1	1	1.0	243	231	236	707	707	0.3333	0.9996	1.0000	2435	236	236	0	570	5428	1145	145	17	0.0942	236
97	7305	9	7	2	1	1.3	205	3	79	638	711	0.1111	0.9988	0.7778	406	91	79	0	540	5478	1119	147	21	0.2245	79
14	7305	7	5	2	1	1.4	259	32	103	529	720	0.1429	0.9990	0.7143	522	106	103	0	527	5513	1099	153	13	0.2887	103
73	7305	6	5	2	1	1.2	271	9	125	744	753	0.1667	0.9992	0.8333	609	149	125	0	535	5484	1123	142	21	0.1741	125
6	7305	5	5	1	1	1.0	397	63	155	774	774	0.2000	0.9993	1.0000	1461	155	155	0	552	5435	1176	123	19	0.0619	155
43	7305	7	6	2	1	1.2	232	59	114	733	795	0.1429	0.9990	0.8571	522	122	114	0	531	5499	1071	185	19	0.1499	114
23	7305	7	4	4	1	1.8	193	50	116	472	814	0.1429	0.9990	0.5714	261	118	116	0	534	5437	1158	160	16	0.4311	116
7	7305	6	3	3	1	2.0	311	34	136	621	818	0.1667	0.9992	0.5000	406	207	136	0	542	5470	1146	137	10	0.5030	136
67	7305	6	5	2	1	1.2	349	5	140	832	838	0.1667	0.9992	0.8333	609	166	140	0	550	5404	1173	159	19	0.1758	140
12	7305	9	5	5	1	1.8	178	34	93	420	840	0.1111	0.9988	0.5556	162	84	93	0	539	5422	1128	189	27	0.4460	93
53	7305	8	7	2	1	1.1	325	2	105	837	842	0.1250	0.9989	0.8750	457	120	105	0	533	5420	1164	166	22	0.1319	105
54	7305	8	5	4	1	1.6	260	28	107	574	853	0.1250	0.9989	0.6250	228	115	107	0	542	5493	1116	130	24	0.3774	107
81	7305	4	3	2	1	1.3	311	63	216	800	863	0.2500	0.9995	0.7500	913	267	216	0	541	5453	1142	158	11	0.2645	216
15	7305	9	6	3	1	1.5	270	3	98	649	881	0.1111	0.9988	0.6667	271	108	98	0	551	5468	1082	177	27	0.3356	98
95	7305	5	2	4	1	2.5	245	9	177	254	883	0.2000	0.9993	0.4000	365	127	177	0	532	5516	1120	124	13	0.6041	177
49	7305	4	3	2	1	1.3	480	100	224	688	895	0.2500	0.9995	0.7500	913	229	224	0	548	5456	1108	177	16	0.2655	224
84	7305	6	5	2	1	1.2	341	20	157	714	944	0.1667	0.9992	0.8333	609	143	157	0	546	5554	1069	124	12	0.1782	157
68	7305	9	4	3	1	2.3	335	23	107	653	964	0.1111	0.9988	0.4444	271	163	107	0	522	5419	1130	213	21	0.5572	107
99	7305	5	3	3	1	1.7	366	66	195	619	973	0.2000	0.9993	0.6000	487	206	195	0	566	5475	1059	174	31	0.4075	195
22	7305	6	4	3	1	1.5	314	10	169	443	1013	0.1667	0.9992	0.6667	406	111	169	0	549	5508	1068	157	23	0.3401	169
83	7305	9	7	2	1	1.3	208	42	113	899	1014	0.1111	0.9988	0.7778	406	128	113	0	545	5469	1102	170	19	0.2267	113
45	7305	8	6	3	1	1.3	282	6	134	651	1074	0.1250	0.9989	0.7500	304	108	134	0	554	5460	1097	178	16	0.2557	134
42	7305	7	3	4	1	2.3	243	60	154	439	1081	0.1429	0.9990	0.4286	261	146	154	0	551	5484	1114	135	21	0.5748	154
33	7305	9	6	2	1	1.5	272	8	123	726	1104	0.1111	0.9988	0.6667	406	121	123	0	546	5461	1103	176	19	0.3369	123
88	7305	6	3	3	1	2.0	263	20	186	642	1118	0.1667	0.9992	0.5000	406	214	186	0	524	5505	1077	183	16	0.5055	186
55	7305	7	4	3	1	1.8	249	16	163	688	1141	0.1429	0.9990	0.5714	348	172	163	0	565	5397	1161	169	13	0.4335	163
86	7305	8	5	2	1	1.6	316	41	144	870	1148	0.1250	0.9989	0.6250	457	174	144	0	552	5453	1076	208	16	0.3794	144
65	7305	6	2	4	2	3.0	321	41	192	475	1150	0.1667	0.9992	0.3333	304	237	192	0	554	5425	1136	170	20	0.6711	192
11	7305	7	4	4	1	1.8	240	37	165	718	1153	0.1429	0.9990	0.5714	261	180	165	0	547	5492	1089	157	20	0.4336	165
3	7305	9	6	2	1	1.5	285	19	130	795	1166	0.1111	0.9988	0.6667	406	133	130	0	514	5449	1140	174	28	0.3373	130
46	7305	8	5	3	1	1.6	227	4	147	771	1175	0.1250	0.9989	0.6250	304	154	147	0	566	5444	1108	164	23	0.3796	147
9	7305	9	6	3	1	1.5	242	20	132	782	1191	0.1111	0.9988	0.6667	271	130	132	0	564	5442	1102	169	28	0.3375	132
61	7305	10	6	3	1	1.7	319	31	124	727	1241	0.1000	0.9986	0.6000	244	121	124	0	533	5462	1080	207	23	0.4031	124
18	7305	10	5	3	1	2.0	272	46	127	859	1269	0.1000	0.9986	0.5000	244	172	127	0	560	5462	1092	176	15	0.5026	127

89	7305	9	7	2	1	1.3	365	48	145	1129	1306	0.1111	0.9988	0.7778	406	161	145	0	552	5546	1039	144	24	0.2297	145
85	7305	10	6	5	1	1.7	281	3	135	755	1347	0.1000	0.9986	0.6000	146	126	135	0	525	5477	1080	193	30	0.4036	135
96	7305	6	4	2	1	1.5	501	29	228	872	1368	0.1667	0.9992	0.6667	609	218	228	0	561	5412	1158	153	21	0.3456	228
50	7305	8	6	2	1	1.3	411	3	172	1125	1376	0.1250	0.9989	0.7500	457	187	172	0	557	5459	1095	160	34	0.2593	172
51	7305	8	3	4	1	2.7	435	12	174	717	1393	0.1250	0.9989	0.3750	228	239	174	0	551	5532	1055	152	15	0.6289	174
29	7305	9	5	5	1	1.8	240	13	156	512	1401	0.1111	0.9988	0.5556	162	102	156	0	542	5490	1062	184	27	0.4488	156
32	7305	6	3	3	1	2.0	599	6	241	822	1443	0.1667	0.9992	0.5000	406	274	241	0	549	5489	1135	117	15	0.5092	241
91	7305	8	5	3	1	1.6	520	13	182	1241	1453	0.1250	0.9989	0.6250	304	248	182	0	548	5443	1120	174	20	0.3820	182
69	7305	7	4	3	1	1.8	463	63	208	998	1457	0.1429	0.9990	0.5714	348	250	208	0	544	5507	1058	175	21	0.4366	208
63	7305	10	8	2	1	1.3	288	35	147	1282	1468	0.1000	0.9986	0.8000	365	160	147	0	557	5524	1070	131	23	0.2084	147
64	7305	7	3	4	1	2.3	362	40	214	826	1498	0.1429	0.9990	0.4286	261	275	214	0	536	5472	1153	126	18	0.5778	214
20	7305	7	4	3	1	1.8	486	36	220	789	1543	0.1429	0.9990	0.5714	348	197	220	0	571	5474	1110	135	15	0.4376	220
41	7305	6	3	4	1	2.0	635	6	257	790	1544	0.1667	0.9992	0.5000	304	263	257	0	535	5556	1083	113	18	0.5105	257
74	7305	10	5	5	1	2.0	273	14	166	702	1656	0.1000	0.9986	0.5000	146	140	166	0	560	5429	1135	161	20	0.5044	166
28	7305	10	6	3	1	1.7	380	18	167	1242	1672	0.1000	0.9986	0.6000	244	207	167	0	531	5422	1152	174	26	0.4056	167
17	7305	9	4	5	1	2.3	464	34	205	1038	1847	0.1111	0.9988	0.4444	162	260	205	0	579	5389	1161	152	24	0.5616	205
37	7305	7	3	5	1	2.3	368	58	265	575	1852	0.1429	0.9990	0.4286	209	192	265	0	553	5373	1169	186	24	0.5811	265
44	7305	12	8	3	1	1.5	324	15	162	1329	1942	0.0833	0.9984	0.6667	203	166	162	0	577	5458	1078	162	30	0.3396	162
71	7305	10	5	4	1	2.0	539	27	196	1246	1964	0.1000	0.9986	0.5000	183	249	196	0	551	5453	1106	172	23	0.5061	196
57	7305	11	7	3	1	1.6	502	4	180	1264	1976	0.0909	0.9985	0.6364	221	181	180	0	550	5450	1099	178	28	0.3707	180
90	7305	9	3	6	1	3.0	322	111	239	757	2148	0.1111	0.9988	0.3333	135	252	239	0	549	5402	1197	134	23	0.6735	239
93	7305	10	5	5	1	2.0	614	3	237	1048	2373	0.1000	0.9986	0.5000	146	210	237	0	547	5509	1090	134	25	0.5089	237
98	7305	13	7	4	1	1.9	305	46	183	1407	2381	0.0769	0.9982	0.5385	140	201	183	0	533	5496	1063	181	32	0.4673	183
25	7305	15	8	3	1	1.9	318	10	162	1312	2425	0.0667	0.9979	0.5333	162	164	162	0	539	5447	1096	194	29	0.4711	162
77	7305	13	7	6	1	1.9	410	0	192	1100	2490	0.0769	0.9982	0.5385	94	157	192	0	571	5465	1099	139	31	0.4679	192
66	7305	13	6	5	1	2.2	344	33	202	1247	2629	0.0769	0.9982	0.4615	112	208	202	0	551	5497	1054	170	33	0.5445	202
82	7305	23	11	6	1	2.1	377	10	137	1791	3144	0.0435	0.9969	0.4783	53	163	137	0	561	5396	1119	180	49	0.5246	137
47	7305	17	6	9	1	2.8	297	25	206	1065	3507	0.0588	0.9977	0.3529	48	177	206	0	545	5448	1120	160	32	0.6523	206
13	7305	13	4	9	1	3.3	629	59	326	1099	4240	0.0769	0.9982	0.3077	62	275	326	0	561	5426	1148	145	25	0.7045	326
34	7305	20	8	6	1	2.5	641	33	278	2337	5554	0.0500	0.9973	0.4000	61	292	278	0	558	5458	1104	154	31	0.6102	278
Minimum		0	0	0	0	0.0	0	0	0	0	0	0.0000	0.9969	0.3077	48	0	0	0	513	5373	1039	113	4	0.0000	33
Average		7	4	3	1	1.6	306	30	149	684	1104	0.1904	0.9991	0.6832	843	161	149	0	548	5466	1111	161	20	0.3304	151
Maximum		23	11	9	3	3.3	641	231	326	2337	5554	1.0000	1.0000	1.0000	7305	405	326	0	579	5556	1202	213	49	0.7045	326
Std.dev		3.8	1.9	1.6	0.3	0.6	126.3	31.5	55.3	373.5	869.6	0.1312	0.0005	0.2041	1077.2	65.2	55.3	0.0	13.8	40.3	35.2	22.5	7.3505	0.1920	53

Scenerio N Scenario 6 Base Case with 20% additional system capacity
Date: 12/10/2007
Simulation 8:20:51 PM
Simulation 8:58:16 PM
Elapsed Tii 37.42 Minutes

		Σ Z_t	Σ W_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Avg S_i	Σ sj		$e_j = 1/\Sigma Z_t$				v=Ssjej	v= Ssiei	no. of days with Demand							
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Avg. Severity of a Failure	Total Maximum Severity of Sojourn	Total Severity of Failure	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	Vulnerability 1	Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance	Total Severity/no. of days with failure
1	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	526	5531	1058	170	20	0.0000	0
2	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	550	5494	1108	137	16	0.0000	0
4	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	537	5518	1126	118	6	0.0000	0
5	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	529	5539	1066	155	16	0.0000	0
8	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	548	5489	1074	182	12	0.0000	0
9	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	564	5442	1102	169	28	0.0000	0
11	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	547	5492	1089	157	20	0.0000	0
12	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	539	5422	1128	189	27	0.0000	0
19	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	543	5528	1100	123	11	0.0000	0
23	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	534	5437	1158	160	16	0.0000	0
26	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	553	5503	1053	181	15	0.0000	0
29	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	542	5490	1062	184	27	0.0000	0
30	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	553	5431	1106	198	17	0.0000	0
35	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	565	5399	1153	167	21	0.0000	0
38	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	556	5443	1145	151	10	0.0000	0
39	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	547	5459	1145	141	13	0.0000	0
40	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	570	5484	1122	119	10	0.0000	0
42	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	551	5484	1114	135	21	0.0000	0
43	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	531	5499	1071	185	19	0.0000	0
46	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	566	5444	1108	164	23	0.0000	0
48	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	551	5469	1090	175	20	0.0000	0
52	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	552	5423	1127	191	12	0.0000	0
56	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	544	5516	1080	155	10	0.0000	0
60	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	548	5436	1103	193	25	0.0000	0
72	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	570	5428	1145	145	17	0.0000	0
80	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	525	5514	1080	171	15	0.0000	0
83	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	545	5469	1102	170	19	0.0000	0
87	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	575	5493	1076	157	4	0.0000	0
94	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	571	5408	1130	180	16	0.0000	0
95	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	532	5516	1120	124	13	0.0000	0
97	7305	0	0	0	0	0	0	0	0	0	0	0.0000	1.0000	-	-	0	0	0	540	5478	1119	147	21	0.0000	0
55	7305	1	1	1	1	1.0	2	2	2	2	2	1.0000	0.9999	1.0000	7305	2	2	0	565	5397	1161	169	13	0.0010	2
14	7305	1	1	1	1	1.0	12	12	12	12	12	1.0000	0.9999	1.0000	7305	12	12	0	527	5513	1099	153	13	0.0049	12
27	7305	1	1	1	1	1.0	13	13	13	13	13	1.0000	0.9999	1.0000	7305	13	13	0	542	5438	1202	116	7	0.0051	13
54	7305	1	1	1	1	1.0	13	13	13	13	13	1.0000	0.9999	1.0000	7305	13	13	0	542	5493	1116	130	24	0.0052	13
16	7305	1	1	1	1	1.0	13	13	13	13	13	1.0000	0.9999	1.0000	7305	13	13	0	537	5491	1129	142	6	0.0052	13
21	7305	1	1	1	1	1.0	14	14	14	14	14	1.0000	0.9999	1.0000	7305	14	14	0	553	5405	1143	184	20	0.0057	14
88	7305	1	1	1	1	1.0	16	16	16	16	16	1.0000	0.9999	1.0000	7305	16	16	0	524	5505	1077	183	16	0.0063	16
59	7305	1	1	1	1	1.0	19	19	19	19	19	1.0000	0.9999	1.0000	7305	19	19	0	544	5457	1120	170	14	0.0078	19
70	7305	1	1	1	1	1.0	23	23	23	23	23	1.0000	0.9999	1.0000	7305	23	23	0	575	5428	1130	159	13	0.0090	23
36	7305	1	1	1	1	1.0	23	23	23	23	23	1.0000	0.9999	1.0000	7305	23	23	0	526	5542	1056	163	18	0.0093	23
15	7305	1	1	1	1	1.0	23	23	23	23	23	1.0000	0.9999	1.0000	7305	23	23	0	551	5468	1082	177	27	0.0094	23
73	7305	1	1	1	1	1.0	24	24	24	24	24	1.0000	0.9999	1.0000	7305	24	24	0	535	5484	1123	142	21	0.0097	24
74	7305	1	1	1	1	1.0	26	26	26	26	26	1.0000	0.9999	1.0000	7305	26	26	0	560	5429	1135	161	20	0.0104	26
33	7305	2	1	2	2	2.0	25	4	14	25	29	0.5000	0.9997	0.5000	1826	25	14	0	546	5461	1103	176	19	0.5000	14
10	7305	1	1	1	1	1.0	31	31	31	31	31	1.0000	0.9999	1.0000	7305	31	0	0	532	5485	1125	141	22	0.0123	31
3	7305	1	1	1	1	1.0	38	38	38	38	38	1.0000	0.9999	1.0000	7305	38	38	0	514	5449	1140	174	28	0.0151	38
24	7305	1	1	1	1	1.0	38	38	38	38	38	1.0000	0.9999	1.0000	7305	38	38	0	559	5455	1105	165	21	0.0152	38
63	7305	1	1	1	1	1.0	41	41	41	41	41	1.0000	0.9999	1.0000	7305	41	41	0	557	5524	1070	131	23	0.0164	41
62	7305	1	1	1	1	1.0	42	42	42	42	42	1.0000	0.9999	1.0000	7305	42	42	0	544	5449	1145	154	13	0.0168	42
18	7305	2	2	1	1	1.0	25	21	23	46	46	0.5000	0.9997	1.0000	3653	23	23	0	560	5462	1092	176	15	0.0091	23
45	7305	2	1	2	2	2.0	35	16	26	35	51	0.5000	0.9997	0.5000	1826	35	26	0	554	5460	1097	178	16	0.5001	26
47	7305	3	3	1	1	1.0	50	1	19	56	56	0.3333	0.9996	1.0000	2435	19	19	0	545	5448	1120	160	32	0.0074	19
79	7305	1	1	1	1	1.0	61	61	61	61	61	1.0000	0.9999	1.0000	7305	61	61	0	513	5489	1112	183	8	0.0246	61
7	7305	1	1	1	1	1.0	64	64	64	64	64	1.0000	0.9999	1.0000	7305	64	64	0	542	5470	1146	137	10	0.0255	64
85	7305	2	2	1	1	1.0	34	32	33	66	66	0.5000	0.9997	1.0000	3653	33	33	0	525	5477	1080	193	30	0.0132	33
86	7305	1	1	1	1	1.0	69	69	69	69	69	1.0000	0.9999	1.0000	7305	69	69	0	552	5453	1076	208	16	0.0275	69
61	7305	1	1	1	1	1.0	72	72	72	72	72	1.0000	0.9999	1.0000	7305	72	72	0	533	5462	1080	207	23	0.0287	72
76	7305	1	1	1	1	1.0	75	75	75	75	75	1.0000	0.9999	1.0000	7305	75	75	0	548	5509	1052	187	9	0.0299	75
98	7305	4	4	1	1	1.0	58	1	20	82	82	0.2500	0.9995	1.0000	1826	20	20	0	533	5496	1063	181	32	0.0082	20
68	7305	1	1	1	1	1.0	88	88	88	88	88	1.0000	0.9999	1.0000	7305	88	88	0	522	5419	1130	213	21	0.0353	88
53	7305	2	2	1	1	1.0	78	11	44	89	89	0.5000	0.9997	1.0000	3653	44	44	0	533	5420	1164	166	22	0.0177	44
84	7305	1	1	1	1	1.0	94	94	94	94	94	1.0000	0.9999	1.0000	7305	94	94	0	546	5554	1069	124	12	0.0375	94
31	7305	1	1	1	1	1.0	95	95	95	95	95	1.0000	0.9999	1.0000	7305	95	95	0	541	5456	1101	182	25	0.0378	95

67	7305	1	1	1	1	1.0	102	102	102	102	102	1.0000	0.9999	1.0000	7305	102	102	0	550	5404	1173	159	19	0.0407	102
81	7305	2	2	1	1	1.0	64	39	52	103	103	0.5000	0.9997	1.0000	3653	52	52	0	541	5453	1142	158	11	0.0206	52
58	7305	1	1	1	1	1.0	116	116	116	116	116	1.0000	0.9999	1.0000	7305	116	116	0	556	5484	1110	140	15	0.0466	116
89	7305	1	1	1	1	1.0	118	118	118	118	118	1.0000	0.9999	1.0000	7305	118	118	0	552	5546	1039	144	24	0.0471	118
65	7305	2	1	2	2	2.0	74	47	61	74	121	0.5000	0.9997	0.5000	1826	74	61	0	554	5425	1136	170	20	0.5006	61
100	7305	1	1	1	1	1.0	125	125	125	125	125	1.0000	0.9999	1.0000	7305	125	125	0	561	5477	1091	157	19	0.0500	125
28	7305	2	2	1	1	1.0	133	5	69	137	137	0.5000	0.9997	1.0000	3653	69	69	0	531	5422	1152	174	26	0.0275	69
75	7305	1	1	1	1	1.0	143	143	143	143	143	1.0000	0.9999	1.0000	7305	143	143	0	555	5440	1110	178	22	0.0571	143
22	7305	3	1	3	3	3.0	67	16	48	67	143	0.3333	0.9996	0.3333	812	67	48	0	549	5508	1068	157	23	0.6669	48
6	7305	1	1	1	1	1.0	150	150	150	150	150	1.0000	0.9999	1.0000	7305	150	150	0	552	5435	1176	123	19	0.0599	150
44	7305	2	1	2	2	2.0	77	73	75	77	150	0.5000	0.9997	0.5000	1826	77	75	0	577	5458	1078	162	30	0.5009	75
92	7305	1	1	1	1	1.0	158	158	158	158	158	1.0000	0.9999	1.0000	7305	158	158	0	555	5463	1124	152	11	0.0632	158
99	7305	2	2	1	1	1.0	119	41	80	160	160	0.5000	0.9997	1.0000	3653	80	80	0	566	5475	1059	174	31	0.0319	80
50	7305	2	2	1	1	1.0	164	28	96	192	192	0.5000	0.9997	1.0000	3653	96	96	0	557	5459	1095	160	34	0.0383	96
25	7305	3	2	2	1	1.5	71	66	69	140	206	0.3333	0.9996	0.6667	1218	70	69	0	539	5447	1096	194	29	0.3345	69
17	7305	1	1	1	1	1.0	217	217	217	217	217	1.0000	0.9999	1.0000	7305	217	217	0	579	5389	1161	152	24	0.0869	217
78	7305	1	1	1	1	1.0	226	226	226	226	226	1.0000	0.9999	1.0000	7305	226	226	0	550	5405	1174	162	14	0.0906	226
49	7305	1	1	1	1	1.0	233	233	233	233	233	1.0000	0.9999	1.0000	7305	233	233	0	548	5456	1108	177	16	0.0931	233
64	7305	4	2	3	1	2.0	115	17	59	176	237	0.2500	0.9995	0.5000	609	88	59	0	536	5472	1153	126	18	0.5006	59
69	7305	3	2	2	1	1.5	216	9	80	225	240	0.3333	0.9996	0.6667	1218	113	80	0	544	5507	1058	175	21	0.3349	80
90	7305	5	2	4	1	2.5	75	43	58	125	289	0.2000	0.9993	0.4000	365	62	58	0	549	5402	1197	134	23	0.6004	58
82	7305	5	4	2	1	1.3	130	30	66	261	332	0.2000	0.9993	0.8000	731	65	66	0	561	5396	1119	180	49	0.2018	66
71	7305	2	2	1	1	1.0	292	51	172	343	343	0.5000	0.9997	1.0000	3653	172	172	0	551	5453	1106	172	23	0.0687	172
66	7305	5	2	4	1	2.5	97	55	70	166	349	0.2000	0.9993	0.4000	365	83	70	0	551	5497	1054	170	33	0.6006	70
57	7305	2	2	1	1	1.0	255	112	184	367	367	0.5000	0.9997	1.0000	3653	184	184	0	550	5450	1099	178	28	0.0734	184
20	7305	2	1	2	2	2.0	239	134	187	239	373	0.5000	0.9997	0.5000	1826	239	187	0	571	5474	1110	135	15	0.5055	187
51	7305	3	2	2	1	1.5	188	23	126	211	377	0.3333	0.9996	0.6667	1218	105	126	0	551	5532	1055	152	15	0.3371	126
37	7305	4	1	4	4	4.0	121	107	113	121	451	0.2500	0.9995	0.2500	457	121	113	0	553	5373	1169	186	24	0.7514	113
96	7305	2	1	2	2	2.0	254	221	238	254	475	0.5000	0.9997	0.5000	1826	254	238	0	561	5412	1158	153	21	0.5090	238
91	7305	2	2	1	1	1.0	273	228	251	501	501	0.5000	0.9997	1.0000	3653	251	251	0	548	5443	1120	174	20	0.1002	251
77	7305	7	3	5	1	2.3	163	7	74	240	519	0.1429	0.9990	0.4286	209	80	74	0	571	5465	1099	139	31	0.5722	74
32	7305	2	1	2	2	2.0	352	242	297	352	594	0.5000	0.9997	0.5000	1826	352	297	0	549	5489	1135	117	15	0.5139	297
41	7305	3	1	3	3	3.0	388	93	210	388	629	0.3333	0.9996	0.3333	812	388	210	0	535	5556	1083	113	18	0.6719	210
93	7305	3	1	3	3	3.0	367	203	280	367	840	0.3333	0.9996	0.3333	812	367	280	0	547	5509	1090	134	25	0.6760	280
13	7305	7	1	7	7	7.0	382	72	251	382	1755	0.1429	0.9990	0.1429	149	382	251	0	561	5426	1148	145	25	0.8630	251
34	7305	10	4	5	1	2.5	394	1	223	899	2228	0.1000	0.9986	0.4000	146	225	223	0	558	5458	1104	154	31	0.6066	223
Minimum		0	0	0	0	0.0	0	0	0	0	0	0.0000	0.9986	0.1429	146	0	0	0	513	5373	1039	113	4	0.0000	0
Average		1	1	1	1	1.0	80	47	63	96	151	0.4857	0.9998	0.8380	4720	69	62	0	548	5466	1111	161	20	0.1271	63
Maximum		10	4	7	7	7.0	394	242	297	899	2228	1.0000	1.0000	1.0000	7305	388	297	0	579	5556	1202	213	49	0.8630	297
Std.dev		1.7	0.9	1.2	1.0	1.0	101.5	63.6	76.6	137.4	312.5	0.4240	0.0002	0.2601	2864.3	91.3	76.8	0.0	13.8	40.3	35.2	22.5	7	0.2236	77

Scenerio N Scenario 12 CSIROMk2b B11 with base case settings
Date: 13/10/2007
Simulation 12:54:32 PM
Simulation 1:31:44 PM
Elapsed Ti 37.2 Minutes

		ΣZ_t	ΣW_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Avg S_i	Ssj	Ssi	$e_j = 1/\Sigma Z_t$				v=Ssjej	v= Ssiei	no. of days with Demand						
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Avg. Severity of a Failure	Total Maximum Severity of Sojourn	Total Severity of Failure	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS *NF)	Vulnerability 1	Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance
40	7305	153	50	17	1	3.1	613	2	220	11475	33725	0.0065	0.9791	0.3268	3	230	220	0	471	5018	1282	400	134	0.6793
4	7305	135	46	23	1	2.9	876	1	258	12346	34847	0.0074	0.9815	0.3407	2	268	258	0	493	5026	1244	418	124	0.6676
7	7305	164	51	33	1	3.2	772	3	251	12669	41240	0.0061	0.9775	0.3110	1	248	251	0	469	4978	1270	442	146	0.6967
2	7305	156	57	18	1	2.7	865	1	266	13499	41543	0.0064	0.9786	0.3654	3	237	266	0	475	5002	1239	448	141	0.6438
38	7305	150	48	12	1	3.1	874	1	286	13566	42879	0.0067	0.9795	0.3200	4	283	286	0	485	4971	1256	458	135	0.6899
76	7305	178	59	13	1	3.0	869	2	249	16427	44258	0.0056	0.9756	0.3315	3	278	249	0	484	5029	1220	408	164	0.6763
81	7305	178	57	17	1	3.1	866	0	254	16888	45137	0.0056	0.9756	0.3202	2	296	254	0	474	5008	1215	446	162	0.6877
84	7305	169	56	20	1	3.0	872	1	269	15235	45389	0.0059	0.9769	0.3314	2	272	269	0	468	4998	1217	466	156	0.6776
26	7305	186	52	21	1	3.6	864	3	254	13370	47231	0.0054	0.9745	0.2796	2	257	254	0	480	4989	1221	448	167	0.7280
41	7305	147	51	17	1	2.9	901	1	322	13826	47318	0.0068	0.9799	0.3469	3	271	322	0	470	5007	1319	378	131	0.6659
16	7305	176	51	16	1	3.5	910	3	270	13099	47586	0.0057	0.9759	0.2898	3	257	270	0	470	4997	1254	419	165	0.7188
58	7305	181	57	31	1	3.2	863	0	267	14775	48340	0.0055	0.9752	0.3149	1	259	267	0	479	5001	1259	395	171	0.6938
17	7305	175	57	14	1	3.1	874	4	276	16237	48358	0.0057	0.9760	0.3257	3	285	276	0	487	4972	1255	435	156	0.6837
72	7305	173	63	18	1	2.7	871	0	280	15513	48447	0.0058	0.9763	0.3642	2	246	280	0	497	4963	1220	469	156	0.6461
27	7305	161	49	28	1	3.3	873	0	302	12958	48587	0.0062	0.9780	0.3043	2	264	302	0	481	5046	1216	409	153	0.7064
18	7305	178	57	13	1	3.1	881	2	273	15523	48606	0.0056	0.9756	0.3202	3	272	273	0	476	5027	1197	441	164	0.6889
71	7305	183	55	16	1	3.3	865	0	277	14095	50725	0.0055	0.9749	0.3005	2	256	277	0	468	4961	1254	457	165	0.7086
93	7305	170	55	30	1	3.1	891	5	299	16237	50761	0.0059	0.9767	0.3235	1	295	299	0	485	4978	1312	369	161	0.6873
55	7305	160	49	17	1	3.3	894	0	319	14039	51033	0.0063	0.9781	0.3063	3	287	319	0	501	4950	1256	450	148	0.7057
36	7305	175	50	24	1	3.5	869	3	292	13983	51110	0.0057	0.9760	0.2857	2	280	292	0	455	5007	1232	450	161	0.7242
88	7305	175	48	18	1	3.6	873	3	292	14132	51117	0.0057	0.9760	0.2743	2	294	292	0	474	5060	1184	421	166	0.7354
56	7305	174	54	26	1	3.2	907	1	294	13938	51166	0.0057	0.9762	0.3103	2	258	294	0	465	5026	1216	441	157	0.7000
100	7305	180	54	12	1	3.3	897	0	285	16212	51311	0.0056	0.9754	0.3000	3	300	285	0	466	5046	1217	408	168	0.7097
19	7305	176	48	29	1	3.7	945	0	292	12635	51371	0.0057	0.9759	0.2727	1	263	292	0	473	5007	1253	416	156	0.7370
11	7305	178	56	18	1	3.2	888	0	296	15980	52660	0.0056	0.9756	0.3146	2	285	296	0	499	4946	1291	404	165	0.6960
20	7305	179	60	15	1	3.0	859	2	296	16268	52991	0.0056	0.9755	0.3352	3	271	296	0	495	5010	1234	398	168	0.6757
64	7305	171	55	11	1	3.1	930	2	310	16568	53060	0.0058	0.9766	0.3216	4	301	310	0	477	4960	1311	403	154	0.6900
23	7305	170	50	18	1	3.4	901	2	314	14821	53426	0.0059	0.9767	0.2941	2	296	314	0	475	4991	1257	425	157	0.7174
95	7305	188	53	17	1	3.5	873	1	286	16866	53678	0.0053	0.9743	0.2819	2	318	286	0	478	5013	1249	390	175	0.7276
8	7305	175	53	11	1	3.3	876	3	309	15732	54021	0.0057	0.9760	0.3029	4	297	309	0	477	4989	1242	432	165	0.7084
47	7305	203	54	17	1	3.8	872	3	266	14124	54061	0.0049	0.9722	0.2660	2	262	266	0	478	4940	1297	407	183	0.7422
65	7305	204	68	14	1	3.0	868	4	265	19091	54152	0.0049	0.9721	0.3333	3	281	265	0	484	5016	1161	454	190	0.6756
74	7305	183	55	13	1	3.3	900	2	297	16583	54335	0.0055	0.9749	0.3005	3	302	297	0	473	5018	1255	394	165	0.7099
90	7305	172	52	25	1	3.3	914	9	317	13524	54541	0.0058	0.9765	0.3023	2	260	317	0	471	4937	1268	472	157	0.7095
62	7305	200	57	23	1	3.5	866	1	273	14792	54581	0.0050	0.9726	0.2850	2	260	273	0	489	4986	1168	480	182	0.7238
39	7305	199	52	23	1	3.8	875	1	278	15890	55247	0.0050	0.9728	0.2613	2	306	278	0	469	5048	1215	391	182	0.7475
94	7305	192	57	33	1	3.4	868	1	288	15981	55390	0.0052	0.9737	0.2969	1	280	288	0	504	4928	1232	462	179	0.7130
33	7305	192	61	32	1	3.1	889	2	289	15981	55446	0.0052	0.9737	0.3177	1	262	289	0	475	5002	1210	441	177	0.6925
87	7305	174	45	31	1	3.9	889	1	319	10621	55523	0.0057	0.9762	0.2586	1	236	319	0	507	5059	1217	359	163	0.7527
29	7305	183	57	25	1	3.2	876	0	304	16239	55683	0.0055	0.9749	0.3115	2	285	304	0	472	5021	1183	458	171	0.6996
52	7305	194	59	26	1	3.3	879	0	290	15686	56194	0.0052	0.9734	0.3041	1	266	290	0	467	4958	1247	460	173	0.7060
61	7305	201	62	28	1	3.2	870	0	280	16562	56318	0.0050	0.9725	0.3085	1	267	280	0	466	5010	1208	437	184	0.7011
83	7305	188	51	31	1	3.7	873	2	301	15320	56552	0.0053	0.9743	0.2713	1	300	301	0	463	5007	1215	445	175	0.7390
97	7305	177	57	18	1	3.1	943	10	320	16002	56602	0.0056	0.9758	0.3220	2	281	320	0	462	5061	1213	404	165	0.6904
24	7305	183	53	19	1	3.5	874	1	311	14463	56824	0.0055	0.9749	0.2896	2	273	311	0	471	5005	1306	356	167	0.7216
86	7305	172	49	23	1	3.5	867	1	332	14161	57110	0.0058	0.9765	0.2849	2	289	332	0	477	4986	1217	460	165	0.7277
53	7305	186	55	20	1	3.4	876	4	308	15976	57288	0.0054	0.9745	0.2957	2	290	308	0	469	4944	1241	479	172	0.7154
43	7305	180	62	24	1	2.9	902	0	319	16282	57369	0.0056	0.9754	0.3444	2	263	319	0	462	5020	1176	484	163	0.6683
78	7305	177	46	43	1	3.8	874	0	326	11005	57654	0.0056	0.9758	0.2599	1	239	326	0	488	4967	1277	413	160	0.7519
48	7305	181	50	17	1	3.6	875	1	322	15269	58306	0.0055	0.9752	0.2762	2	305	322	0	493	4941	1271	434	166	0.7356
98	7305	194	57	17	1	3.4	877	1	301	18133	58482	0.0052	0.9734	0.2938	2	318	301	0	468	5018	1177	461	181	0.7169
42	7305	175	53	24	1	3.3	874	1	334	16416	58537	0.0057	0.9760	0.3029	2	310	334	0	481	4961	1264	437	162	0.7103
79	7305	197	62	15	1	3.2	923	2	297	15510	58548	0.0051	0.9730	0.3147	2	250	297	0	450	5038	1189	450	178	0.6960
14	7305	166	44	24	1	3.8	883	6	356	14007	59142	0.0060	0.9773	0.2651	2	318	356	0	457	5010	1257	427	154	0.7490
6	7305	183	54	17	1	3.4	876	0	325	17072	59503	0.0055	0.9749	0.2951	2	316	325	0	470	5006	1270	383	176	0.7173
69	7305	199	65	25	1	3.1	905	3	299	18429	59553	0.0050	0.9728	0.3266	1	284	299	0	487	4973	1246	415	184	0.6845

30	7305	199	62	19	1	3.2	915	2	301	20016	59806	0.0050	0.9728	0.3116	2	323	301	0	475	5014	1206	433	177	0.6994
73	7305	192	54	27	1	3.6	879	1	312	13403	59856	0.0052	0.9737	0.2813	1	248	312	0	469	5048	1196	419	173	0.7300
32	7305	181	45	27	1	4.0	880	4	332	13572	60152	0.0055	0.9752	0.2486	1	302	332	0	490	4981	1281	374	179	0.7635
92	7305	190	45	16	1	4.2	872	2	318	15098	60338	0.0053	0.9740	0.2368	2	336	318	0	454	5057	1236	375	183	0.7741
3	7305	207	63	23	1	3.3	878	0	292	19080	60456	0.0048	0.9717	0.3043	2	303	292	0	463	4955	1233	462	192	0.7060
35	7305	181	62	14	1	2.9	911	1	334	17996	60469	0.0055	0.9752	0.3425	3	290	334	0	493	4956	1232	457	167	0.6714
28	7305	197	63	18	1	3.1	877	0	311	18552	61200	0.0051	0.9730	0.3198	2	294	311	0	459	4937	1287	440	182	0.6920
9	7305	200	54	18	1	3.7	868	2	307	18233	61389	0.0050	0.9726	0.2700	2	338	307	0	479	4975	1229	438	184	0.7408
54	7305	216	60	28	1	3.6	876	1	287	15679	62061	0.0046	0.9704	0.2778	1	261	287	0	475	5050	1199	385	196	0.7319
51	7305	177	43	39	1	4.1	899	0	353	11758	62443	0.0056	0.9758	0.2429	1	273	353	0	483	5034	1227	394	167	0.7705
91	7305	181	44	17	1	4.1	877	2	345	14675	62535	0.0055	0.9752	0.2431	2	334	345	0	477	4979	1291	392	166	0.7698
66	7305	208	64	18	1	3.3	860	1	302	19575	62730	0.0048	0.9715	0.3077	2	306	302	0	476	4969	1238	424	198	0.7033
5	7305	214	50	22	1	4.3	868	0	306	16476	65445	0.0047	0.9707	0.2336	2	330	306	0	482	4993	1257	378	195	0.7766
44	7305	197	56	21	1	3.5	918	1	333	16820	65648	0.0051	0.9730	0.2843	2	300	333	0	494	5025	1160	443	183	0.7285
13	7305	187	42	23	1	4.5	894	5	352	14149	65788	0.0053	0.9744	0.2246	2	337	352	0	502	4963	1265	399	176	0.7885
50	7305	200	50	21	1	4.0	906	1	330	16311	65948	0.0050	0.9726	0.2500	2	326	330	0	482	4980	1219	436	188	0.7620
96	7305	196	49	18	1	4.0	931	0	339	16176	66534	0.0051	0.9732	0.2500	2	330	339	0	481	5011	1247	381	185	0.7627
67	7305	184	48	30	1	3.8	875	2	364	15944	66917	0.0054	0.9748	0.2609	1	332	364	0	479	4951	1252	445	178	0.7537
60	7305	202	51	30	1	4.0	875	5	333	14458	67196	0.0050	0.9723	0.2525	1	283	333	0	491	4973	1240	411	190	0.7598
57	7305	206	58	16	1	3.6	875	2	328	18848	67572	0.0049	0.9718	0.2816	2	325	328	0	484	4936	1269	418	198	0.7309
25	7305	218	63	21	1	3.5	903	1	310	17466	67604	0.0046	0.9702	0.2890	2	277	310	0	486	4985	1215	419	200	0.7224
59	7305	222	55	14	1	4.0	878	1	306	20140	67913	0.0045	0.9696	0.2477	2	366	306	0	460	4999	1241	404	201	0.7627
22	7305	200	46	31	1	4.3	945	2	342	13983	68465	0.0050	0.9726	0.2300	1	304	342	0	484	5031	1204	403	183	0.7826
77	7305	224	59	24	1	3.8	868	2	306	18354	68602	0.0045	0.9693	0.2634	1	311	306	0	504	4957	1175	464	205	0.7474
89	7305	207	55	34	1	3.8	951	3	333	15090	68994	0.0048	0.9717	0.2657	1	274	333	0	488	5047	1186	390	194	0.7468
70	7305	186	43	33	1	4.3	895	5	374	11850	69533	0.0054	0.9745	0.2312	1	276	374	0	459	5044	1198	429	175	0.7836
1	7305	191	48	30	1	4.0	878	0	364	14958	69553	0.0052	0.9739	0.2513	1	312	364	0	455	5031	1239	399	181	0.7632
21	7305	208	51	34	1	4.1	876	3	337	17642	70086	0.0048	0.9715	0.2452	1	346	337	0	486	4914	1244	463	198	0.7673
68	7305	215	57	18	1	3.8	883	2	326	17466	70121	0.0047	0.9706	0.2651	2	306	326	0	481	4918	1248	458	200	0.7470
10	7305	202	47	38	1	4.3	913	7	348	14282	70322	0.0050	0.9723	0.2327	1	304	348	0	456	5053	1212	397	187	0.7803
15	7305	202	58	21	1	3.5	879	2	349	17138	70404	0.0050	0.9723	0.2871	2	295	349	0	483	4953	1280	405	184	0.7269
31	7305	214	58	23	1	3.7	933	0	330	18572	70597	0.0047	0.9707	0.2710	1	320	330	0	448	4987	1287	384	199	0.7414
49	7305	234	53	27	1	4.4	878	4	302	16148	70671	0.0043	0.9680	0.2265	1	305	302	0	479	4965	1243	401	217	0.7835
63	7305	188	36	32	1	5.2	869	9	379	11663	71307	0.0053	0.9743	0.1915	1	324	379	0	482	5018	1240	381	184	0.8230
12	7305	203	47	35	1	4.3	918	2	353	13593	71591	0.0049	0.9722	0.2315	1	289	353	0	472	4989	1208	439	197	0.7818
34	7305	204	58	36	1	3.5	880	3	354	16247	72193	0.0049	0.9721	0.2843	1	280	354	0	482	4991	1242	400	190	0.7301
82	7305	222	54	33	1	4.1	886	1	333	16713	74016	0.0045	0.9696	0.2432	1	309	333	0	494	4958	1220	424	209	0.7690
37	7305	220	59	53	1	3.7	881	5	343	14884	75406	0.0045	0.9699	0.2682	1	252	343	0	506	4893	1244	453	209	0.7452
75	7305	226	60	21	1	3.8	895	3	336	19613	76022	0.0044	0.9691	0.2655	2	327	336	0	484	4929	1249	429	214	0.7474
46	7305	222	54	33	1	4.1	907	1	352	17701	78124	0.0045	0.9696	0.2432	1	328	352	0	489	5010	1232	370	204	0.7703
80	7305	234	57	36	1	4.1	948	0	335	15216	78344	0.0043	0.9680	0.2436	1	267	335	0	460	5054	1165	412	214	0.7688
45	7305	228	50	29	1	4.6	877	4	345	16013	78736	0.0044	0.9688	0.2193	1	320	345	0	482	4984	1241	377	221	0.7934
85	7305	244	63	19	1	3.9	896	1	324	19658	79057	0.0041	0.9666	0.2582	2	312	324	0	449	5023	1149	462	222	0.7538
99	7305	215	52	40	1	4.1	921	1	380	15021	81593	0.0047	0.9706	0.2419	1	289	380	0	478	4995	1248	382	202	0.7737
Minimum		135	36	11	1	2.7	613	0	220	10621	33725	0.0041	0.9666	0.1915	1	230	220	0	448	4893	1149	356	124	0.6438
Average		190	54	23	1	3.6	884	2	310	15583	59186	0.0053	0.9740	0.2852	2	290	310	0	477	4994	1235	423	176	0.7260
Maximum		244	68	53	1	5.2	951	10	380	20140	81593	0.0074	0.9815	0.3654	4	366	380	0	507	5061	1319	484	222	0.8230
Std.dev		20.3	5.9	8.0	0	0.5	36.9	2.0	31.5	2077.4	9959.0	0.0006	0.0028	0.0354	0.7	27.9	31.5	0.0	13.1	37.5	35.6	30.8	19.9	0.0363

Scenerio N Scenario 12a CSIROMk2b B11 with Base Case Setting with change of precipitation frequency
Date: 29/10/2007
Simulation 6:42:26 PM
Simulation 9:05:51 PM
Elapsed Ti 143.42 Minutes

		ΣZ_t	ΣW_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Σ si	Ssj	$e_j = 1/\Sigma Z_t$				v=Ssjej	v= Ssiei								
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Total. Severity of Failure	Total Maximum Severity of Sojourn	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	Vulnerability 1	Average Vulnerability	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance	Total Severity/no. of days with failure
56	7305	129	44	16	1	2.9	876	3	40159	11618	0.0078	0.9823	0.3411	3.5	264	311	0	445	5086	1284	369	121	0.67	0
27	7305	131	43	23	1	3.0	873	8	46039	12664	0.0076	0.9821	0.3282	2.4	295	351	0	468	5156	1197	357	127	0.69	0
41	7305	133	46	17	1	2.9	909	0	41665	10845	0.0075	0.9818	0.3459	3.2	236	313	0	468	5075	1240	403	119	0.67	0
87	7305	134	36	19	1	3.7	887	2	47245	9947	0.0075	0.9817	0.2687	2.9	276	353	0	486	5039	1262	396	122	0.75	0
38	7305	136	44	11	1	3.1	898	3	40341	12764	0.0074	0.9814	0.3235	4.9	290	297	0	489	4967	1282	442	125	0.69	0
4	7305	141	44	28	1	3.2	876	1	34004	11374	0.0071	0.9807	0.3121	1.9	258	241	0	478	5100	1201	400	126	0.69	0
66	7305	142	53	19	1	2.7	858	0	42830	13479	0.0070	0.9806	0.3732	2.7	254	302	0	472	5042	1212	444	135	0.64	0
62	7305	142	40	13	1	3.6	876	4	46234	13096	0.0070	0.9806	0.2817	4.0	327	326	0	484	4920	1303	472	126	0.73	0
11	7305	146	46	16	1	3.2	875	1	43336	13682	0.0068	0.9800	0.3151	3.1	297	297	0	499	5031	1276	366	133	0.70	0
42	7305	146	49	14	1	3.0	878	0	48130	14044	0.0068	0.9800	0.3356	3.6	287	330	0	482	4955	1273	461	134	0.68	0
36	7305	148	40	24	1	3.7	870	0	40508	10973	0.0068	0.9797	0.2703	2.1	274	274	0	456	4999	1316	397	137	0.74	0
2	7305	149	49	26	1	3.0	868	3	41552	11625	0.0067	0.9796	0.3289	1.9	237	279	0	488	5026	1281	380	130	0.68	0
40	7305	150	45	18	1	3.3	508	3	35387	9978	0.0067	0.9795	0.3000	2.7	222	236	0	462	5127	1205	371	140	0.71	0
84	7305	150	59	11	1	2.5	881	0	39844	14605	0.0067	0.9795	0.3933	4.4	248	266	0	462	5087	1206	411	139	0.62	0
1	7305	150	37	27	1	4.1	1113	3	60948	10639	0.0067	0.9795	0.2467	1.8	288	406	0	451	5097	1240	378	139	0.77	0
74	7305	151	49	14	1	3.1	872	2	44290	13712	0.0066	0.9793	0.3245	3.5	280	293	0	465	5104	1218	374	144	0.69	0
55	7305	151	53	14	1	2.8	919	1	48142	14311	0.0066	0.9793	0.3510	3.5	270	319	0	488	4983	1238	462	134	0.66	0
72	7305	151	48	21	1	3.1	868	0	52132	12620	0.0066	0.9793	0.3179	2.3	263	345	0	493	5014	1261	396	141	0.70	0
81	7305	154	56	10	1	2.8	871	3	39165	15322	0.0065	0.9789	0.3636	4.7	274	254	0	472	5042	1194	460	137	0.64	0
69	7305	155	48	22	1	3.2	868	3	46598	14630	0.0065	0.9788	0.3097	2.1	305	301	0	476	5111	1190	384	144	0.70	0
14	7305	155	45	20	1	3.4	874	1	51262	11928	0.0065	0.9788	0.2903	2.4	265	331	0	451	5021	1241	447	145	0.72	0
92	7305	157	35	19	1	4.5	873	2	51632	9355	0.0064	0.9785	0.2229	2.4	267	329	0	448	5093	1288	329	147	0.79	0
78	7305	158	40	21	1	4.0	874	0	48071	12607	0.0063	0.9784	0.2532	2.2	315	304	0	497	5013	1277	378	140	0.76	0
73	7305	159	48	13	1	3.3	870	6	51599	13748	0.0063	0.9782	0.3019	3.5	286	325	0	463	5060	1279	356	147	0.71	0
86	7305	159	42	22	1	3.8	873	7	54352	13470	0.0063	0.9782	0.2642	2.1	321	342	0	481	5091	1174	409	150	0.75	0
17	7305	160	48	14	1	3.3	869	0	42496	11625	0.0063	0.9781	0.3000	3.3	242	266	0	489	5028	1266	379	143	0.71	0
76	7305	160	51	27	1	3.1	853	3	42697	14127	0.0063	0.9781	0.3188	1.7	277	267	0	471	5110	1190	386	148	0.69	0
58	7305	162	50	40	1	3.2	876	2	46947	12847	0.0062	0.9778	0.3086	1.1	257	290	0	470	5091	1236	355	153	0.70	0
50	7305	163	47	38	1	3.5	906	1	57888	11904	0.0061	0.9777	0.2883	1.2	253	355	0	491	4989	1232	444	149	0.73	0
71	7305	164	55	13	1	3.0	870	0	46478	14507	0.0061	0.9775	0.3354	3.4	264	283	0	477	4989	1269	422	148	0.67	0
93	7305	164	47	34	1	3.5	891	6	53192	14882	0.0061	0.9775	0.2866	1.3	317	324	0	504	4996	1250	401	154	0.73	0
26	7305	165	53	14	1	3.1	864	1	44838	14815	0.0061	0.9774	0.3212	3.2	280	272	0	469	4968	1283	435	150	0.69	0
88	7305	165	45	20	1	3.7	872	0	45992	11493	0.0061	0.9774	0.2727	2.2	255	279	0	470	5128	1191	361	155	0.74	0
90	7305	166	51	24	1	3.3	873	2	50625	12896	0.0060	0.9773	0.3072	1.8	253	305	0	470	5051	1251	386	147	0.70	0
18	7305	167	46	17	1	3.6	900	3	45863	12823	0.0060	0.9771	0.2754	2.6	279	275	0	493	4984	1233	444	151	0.73	0
91	7305	167	52	18	1	3.2	875	0	52155	16381	0.0060	0.9771	0.3114	2.4	315	312	0	484	5036	1258	374	153	0.70	0
51	7305	167	46	39	1	3.6	875	0	56476	12521	0.0060	0.9771	0.2754	1.1	272	338	0	475	5119	1152	408	151	0.74	0
48	7305	169	51	19	1	3.3	874	0	50880	12439	0.0059	0.9769	0.3018	2.3	244	301	0	486	5022	1220	420	157	0.71	0
7	7305	170	53	30	1	3.2	866	1	46285	15095	0.0059	0.9767	0.3118	1.4	285	272	0	474	5015	1256	407	153	0.70	0
64	7305	170	55	17	1	3.1	926	1	51209	13733	0.0059	0.9767	0.3235	2.5	250	301	0	460	5032	1219	448	146	0.69	0
82	7305	170	46	23	1	3.7	872	3	57495	13851	0.0059	0.9767	0.2706	1.9	301	338	0	480	5021	1289	355	160	0.74	0
33	7305	171	55	30	1	3.1	883	2	49984	13822	0.0058	0.9766	0.3216	1.4	251	292	0	466	5060	1209	413	157	0.69	0
43	7305	171	54	25	1	3.2	877	0	54790	15231	0.0058	0.9766	0.3158	1.7	282	320	0	474	5021	1225	431	154	0.70	0
52	7305	172	57	27	1	3.0	881	5	55559	15539	0.0058	0.9765	0.3314	1.6	273	323	0	485	5026	1203	434	157	0.68	0
22	7305	173	39	39	1	4.4	917	2	63254	11442	0.0058	0.9763	0.2254	1.1	293	366	0	476	4956	1314	394	165	0.79	0
83	7305	174	50	20	1	3.5	892	1	55729	16285	0.0057	0.9762	0.2874	2.1	326	320	0	458	5018	1284	381	164	0.72	0
24	7305	174	49	28	1	3.6	876	5	57382	12435	0.0057	0.9762	0.2816	1.5	254	330	0	453	5100	1215	377	160	0.73	0
34	7305	175	45	27	1	3.9	875	7	61420	14122	0.0057	0.9760	0.2571	1.5	314	351	0	469	5015	1259	393	169	0.76	0
67	7305	175	50	21	1	3.5	874	5	64121	15453	0.0057	0.9760	0.2857	2.0	309	366	0	489	5034	1182	432	168	0.73	0
47	7305	176	38	17	1	4.6	890	1	50454	13057	0.0057	0.9759	0.2159	2.4	344	287	0	479	5008	1230	422	166	0.79	0
59	7305	176	55	18	1	3.2	875	2	52063	16236	0.0057	0.9759	0.3125	2.3	295	296	0	454	5089	1204	392	166	0.70	0
23	7305	177	44	29	1	4.0	902	1	54654	12873	0.0056	0.9758	0.2486	1.4	293	309	0	455	5048	1260	377	165	0.76	0
79	7305	178	52	12	1	3.4	871	1	53984	15190	0.0056	0.9756	0.2921	3.4	292	303	0	464	5085	1190	402	164	0.72	0
6	7305	178	55	16	1	3.2	876	4	54989	15701	0.0056	0.9756	0.3090	2.6	285	309	0	468	5144	1153	374	166	0.70	0
9	7305	179	62	12	1	2.9	871	7	54106	18490	0.0056	0.9755	0.3464	3.4	298	302	0	485	5067	1203	380	170	0.67	0
13	7305	180	48	17	1	3.8	959	1	55871	15666	0.0056	0.9754	0.2667	2.4	326	310	0	487	5057	1158	436	167	0.74	0
60	7305	180	51	38	1	3.5	873	3	61564	12195	0.0056	0.9754	0.2833	1.1	239	342	0	493	5012	1236	396	168	0.73	0
15	7305	181	50	22	1	3.6	879	1	60495	13955	0.0055	0.9752	0.2762	1.8	279	334	0	470	5006	1245	420	164	0.74	0
54	7305	182	47	30	1	3.9	869	4	56596	14412	0.0055	0.9751	0.2582	1.3	307	311	0	481	5110	1171	371	172	0.75	0
32	7305	183	49	30	1	3.7	873	2	55965	13526	0.0055	0.9749	0.2678	1.3	276	306	0	471	5053	1221	387	173	0.74	0

53	7305	184	54	15	1	3.4	915	0	55641	16371	0.0054	0.9748	0.2935	2.6	303	302	0	473	5072	1192	400	168	0.72	0
98	7305	185	54	18	1	3.4	905	3	53914	17297	0.0054	0.9747	0.2919	2.2	320	291	0	465	5079	1153	441	167	0.72	0
70	7305	185	48	27	1	3.9	907	2	57952	12592	0.0054	0.9747	0.2595	1.5	262	313	0	460	5085	1212	380	168	0.75	0
5	7305	185	41	21	1	4.5	868	3	59467	13857	0.0054	0.9747	0.2216	1.9	338	321	0	478	5034	1247	370	176	0.79	0
8	7305	185	46	19	1	4.0	888	8	62346	15655	0.0054	0.9747	0.2486	2.1	340	337	0	465	5114	1201	349	176	0.76	0
96	7305	185	44	18	1	4.2	911	3	64495	14325	0.0054	0.9747	0.2378	2.2	326	349	0	483	5105	1142	402	173	0.78	0
29	7305	186	49	26	1	3.8	869	6	55480	15466	0.0054	0.9745	0.2634	1.5	316	298	0	454	5040	1274	364	173	0.75	0
20	7305	187	58	16	1	3.2	859	2	54571	16016	0.0053	0.9744	0.3102	2.4	276	292	0	479	5054	1192	413	167	0.70	0
49	7305	187	48	20	1	3.9	878	8	60736	15570	0.0053	0.9744	0.2567	2.0	324	325	0	479	5050	1268	330	178	0.76	0
12	7305	188	48	21	1	3.9	877	3	64025	13579	0.0053	0.9743	0.2553	1.9	283	341	0	475	5040	1223	391	176	0.76	0
10	7305	189	47	22	1	4.0	888	1	66534	14603	0.0053	0.9741	0.2487	1.8	311	352	0	456	5070	1208	395	176	0.76	0
19	7305	190	51	28	1	3.7	871	1	52011	14710	0.0053	0.9740	0.2684	1.4	288	274	0	477	5177	1114	362	175	0.74	0
68	7305	190	53	18	1	3.6	878	0	63567	15799	0.0053	0.9740	0.2789	2.1	298	335	0	468	5090	1158	418	171	0.73	0
30	7305	191	62	16	1	3.1	905	1	56136	18760	0.0052	0.9739	0.3246	2.4	303	294	0	466	5029	1197	437	176	0.69	0
21	7305	191	60	22	1	3.2	876	1	61535	16410	0.0052	0.9739	0.3141	1.7	273	322	0	491	4944	1272	417	181	0.70	0
63	7305	191	43	23	1	4.4	873	3	67276	11672	0.0052	0.9739	0.2251	1.7	271	352	0	483	5069	1231	347	175	0.79	0
100	7305	193	55	13	1	3.5	862	4	49493	15756	0.0052	0.9736	0.2850	2.9	286	256	0	477	5003	1231	422	172	0.72	0
31	7305	193	52	22	1	3.7	907	3	64751	15429	0.0052	0.9736	0.2694	1.7	297	335	0	447	5071	1271	333	183	0.74	0
94	7305	194	65	28	1	3.0	868	7	52894	15210	0.0052	0.9734	0.3351	1.3	234	273	0	496	4980	1226	421	182	0.67	0
97	7305	196	59	18	1	3.3	884	2	58007	15696	0.0051	0.9732	0.3010	2.1	266	296	0	479	5000	1245	402	179	0.71	0
44	7305	196	61	25	1	3.2	898	0	60206	15590	0.0051	0.9732	0.3112	1.5	256	307	0	488	5014	1262	361	180	0.70	0
61	7305	197	51	29	1	3.9	967	1	55758	15471	0.0051	0.9730	0.2589	1.3	303	283	0	491	4955	1262	415	182	0.75	0
35	7305	197	60	27	1	3.3	911	5	61712	16626	0.0051	0.9730	0.3046	1.4	277	313	0	494	5034	1137	461	179	0.71	0
28	7305	197	62	25	1	3.2	879	1	64024	16961	0.0051	0.9730	0.3147	1.5	274	325	0	444	5115	1165	400	181	0.70	0
25	7305	198	58	16	1	3.4	879	1	61139	17861	0.0051	0.9729	0.2929	2.3	308	309	0	477	5025	1222	394	187	0.72	0
37	7305	200	48	60	1	4.2	879	0	73049	12280	0.0050	0.9726	0.2400	0.6	256	365	0	493	4898	1337	394	183	0.77	0
95	7305	201	46	34	1	4.4	863	4	54311	13974	0.0050	0.9725	0.2289	1.1	304	270	0	469	4999	1219	427	191	0.78	0
57	7305	203	60	34	1	3.4	878	2	62972	17316	0.0049	0.9722	0.2956	1.1	289	310	0	474	5027	1214	401	189	0.72	0
3	7305	206	59	23	1	3.5	906	1	56527	16041	0.0049	0.9718	0.2864	1.5	272	274	0	455	5030	1174	460	186	0.72	0
80	7305	207	55	26	1	3.8	924	1	63979	14411	0.0048	0.9717	0.2657	1.4	262	309	0	455	5055	1175	430	190	0.75	0
85	7305	207	51	29	1	4.1	910	0	73973	15996	0.0048	0.9717	0.2464	1.2	314	357	0	454	4995	1213	453	190	0.77	0
65	7305	208	45	43	1	4.6	889	1	63386	14637	0.0048	0.9715	0.2163	0.8	325	305	0	500	5055	1133	425	192	0.79	0
16	7305	210	48	23	1	4.4	891	1	51749	12788	0.0048	0.9713	0.2286	1.5	266	246	0	461	5145	1116	393	190	0.78	0
77	7305	210	61	24	1	3.4	877	5	61050	19322	0.0048	0.9713	0.2905	1.4	317	291	0	499	4962	1207	444	193	0.72	0
39	7305	213	49	35	1	4.3	874	1	60571	16543	0.0047	0.9708	0.2300	1.0	338	284	0	456	5089	1162	408	190	0.78	0
46	7305	214	45	31	1	4.8	920	0	66945	12813	0.0047	0.9707	0.2103	1.1	285	313	0	481	5061	1186	382	195	0.80	0
99	7305	227	53	25	1	4.3	875	0	78417	16483	0.0044	0.9689	0.2335	1.3	311	345	0	479	5075	1151	387	213	0.78	0
75	7305	229	63	27	1	3.6	876	1	76849	18235	0.0044	0.9687	0.2751	1.2	289	336	0	492	4971	1128	503	211	0.74	0
45	7305	233	48	38	1	4.9	896	2	77890	12644	0.0043	0.9681	0.2060	0.8	263	334	0	456	5085	1224	321	219	0.81	0
89	7305	242	64	29	1	3.8	880	3	70436	19289	0.0041	0.9669	0.2645	1.0	301	291	0	483	5091	1125	381	225	0.75	0
Minimum		129	35	10	1	2.5	508	0	34004	9355	0.0041	0.9669	0.2060	1	222	236	0	444	4898	1114	321	119	0.62	
Average		177	50	23	1	3.6	882	2	54757	14247	0.0058	0.9758	0.2864	2	285	310	0	474	5045	1222	401	163	0.72	
Maximum		242	65	60	1	4.9	1113	8	78417	19322	0.0078	0.9823	0.3933	5	344	406	0	504	5177	1337	503	225	0.81	
Std.dev		23.5	6.5	8.3	0	0.5	48.3	2.1	9187.4	2087.6	0.0008	0.0032	0.0384	0.9	27.0	30.7	0.0	14.2	53.1	48.0	34.6	22.2	0.04	

Scenerio N Scenario 13 CSIROMk2b B11 with 5% additional WEMPs savings
Date: 13/10/2007
Simulation 1:44:15 PM
Simulation 2:21:39 PM
Elapsed Ti 37.4 Minutes

		ΣZ_t	ΣW_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Avg S_i	Ssj	Ssi	$e_j = 1/\Sigma Z_t$				v=Ssjej	v= Ssiei	no. of days with Demand						
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Avg. Severity of a Failure	Total Maximum Severity of Sojourn	Total Severity of Failure	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS *NF)	Vulnerability 1	Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance
40	7305	148	50	16	1	3.0	606	1	220	11217	32582	0.0068	0.9797	0.3378	3	224	220	0	517	5012	1254	392	130	0.6683
4	7305	134	46	23	1	2.9	868	1	252	11997	33824	0.0075	0.9817	0.3433	2	261	252	0	540	5026	1204	413	122	0.6647
7	7305	160	51	33	1	3.1	764	1	250	12427	40010	0.0063	0.9781	0.3188	1	244	250	0	516	4978	1234	433	144	0.6889
2	7305	152	56	18	1	2.7	857	1	266	13071	40373	0.0066	0.9792	0.3684	3	233	266	0	542	4986	1197	443	137	0.6408
38	7305	149	47	12	1	3.2	866	1	280	13207	41743	0.0067	0.9796	0.3154	4	281	280	0	541	4952	1229	449	134	0.6940
76	7305	175	58	13	1	3.0	861	2	245	15982	42913	0.0057	0.9760	0.3314	3	276	245	0	527	5025	1187	412	154	0.6762
81	7305	172	57	17	1	3.0	859	1	255	16456	43818	0.0058	0.9765	0.3314	2	289	255	0	521	5011	1177	440	156	0.6767
84	7305	168	55	20	1	3.1	864	1	263	14815	44109	0.0060	0.9770	0.3274	2	269	263	0	514	4996	1180	461	154	0.6812
26	7305	185	51	21	1	3.6	856	1	248	12979	45818	0.0054	0.9747	0.2757	2	254	248	0	522	4993	1186	441	163	0.7315
41	7305	141	47	17	1	3.0	893	1	328	13448	46220	0.0071	0.9807	0.3333	3	286	328	0	525	4994	1280	378	128	0.6797
16	7305	172	48	16	1	3.6	902	0	269	12720	46263	0.0058	0.9765	0.2791	3	265	269	0	516	4990	1228	411	160	0.7293
58	7305	176	57	31	1	3.1	855	5	267	14415	46994	0.0057	0.9759	0.3239	1	253	267	0	527	4987	1234	390	167	0.6849
17	7305	172	57	14	1	3.0	866	0	273	16228	47030	0.0058	0.9765	0.3314	3	285	273	0	539	4973	1206	436	151	0.6779
72	7305	169	64	18	1	2.6	863	2	279	15110	47152	0.0059	0.9769	0.3787	2	236	279	0	547	4951	1194	462	151	0.6317
18	7305	175	58	13	1	3.0	874	4	270	15463	47268	0.0057	0.9760	0.3314	3	267	270	0	531	5015	1164	434	161	0.6777
27	7305	159	49	28	1	3.2	865	6	298	13441	47369	0.0063	0.9782	0.3082	2	274	298	0	520	5050	1184	409	142	0.7023
71	7305	177	53	16	1	3.3	857	1	279	13690	49361	0.0056	0.9758	0.2994	3	258	279	0	521	4960	1211	449	164	0.7098
93	7305	169	55	30	1	3.1	883	3	293	15819	49469	0.0059	0.9769	0.3254	1	288	293	0	542	4960	1283	363	157	0.6850
36	7305	171	49	24	1	3.5	861	1	291	13604	49786	0.0058	0.9766	0.2865	2	278	291	0	501	5009	1190	449	156	0.7233
88	7305	173	47	18	1	3.7	865	7	288	13772	49792	0.0058	0.9763	0.2717	2	293	288	0	526	5053	1143	420	163	0.7377
55	7305	156	48	17	1	3.3	887	3	319	13673	49834	0.0064	0.9786	0.3077	3	285	319	0	551	4950	1218	444	142	0.7043
56	7305	171	54	24	1	3.2	899	1	292	13535	49859	0.0058	0.9766	0.3158	2	251	292	0	505	5026	1189	433	152	0.6945
100	7305	174	52	12	1	3.3	889	1	287	15810	49972	0.0057	0.9762	0.2989	3	304	287	0	518	5025	1190	407	165	0.7109
19	7305	168	43	29	1	3.9	937	1	298	12289	50064	0.0060	0.9770	0.2560	1	286	298	0	514	4998	1233	407	153	0.7539
11	7305	173	54	18	1	3.2	880	6	297	15559	51324	0.0058	0.9763	0.3121	2	288	297	0	553	4935	1257	401	159	0.6984
20	7305	176	59	14	1	3.0	852	4	293	15816	51639	0.0057	0.9759	0.3352	3	268	293	0	538	5010	1198	394	165	0.6755
64	7305	168	54	11	1	3.1	922	0	308	16153	51768	0.0060	0.9770	0.3214	4	299	308	0	530	4959	1264	401	151	0.6901
23	7305	165	47	18	1	3.5	893	2	316	14452	52147	0.0061	0.9774	0.2848	2	307	316	0	524	4988	1223	415	155	0.7266
95	7305	185	51	17	1	3.6	865	1	283	16475	52265	0.0054	0.9747	0.2757	2	323	283	0	520	5022	1209	383	171	0.7335
47	7305	199	53	17	1	3.8	864	0	264	13719	52524	0.0050	0.9728	0.2663	2	259	264	0	528	4933	1264	402	178	0.7417
65	7305	202	67	14	1	3.0	860	1	260	18577	52603	0.0050	0.9723	0.3317	3	277	260	0	527	5005	1142	453	178	0.6770
8	7305	173	52	11	1	3.3	868	1	305	15333	52692	0.0058	0.9763	0.3006	4	295	305	0	531	4970	1216	429	159	0.7103
74	7305	179	55	13	1	3.3	892	0	296	16711	52964	0.0056	0.9755	0.3073	3	304	296	0	518	5014	1232	381	160	0.7032
62	7305	197	55	23	1	3.6	859	4	269	14368	53075	0.0051	0.9730	0.2792	2	261	269	0	548	4967	1140	472	178	0.7293
90	7305	172	52	25	1	3.3	906	1	309	13129	53231	0.0058	0.9765	0.3023	2	252	309	0	517	4924	1242	467	155	0.7090
39	7305	192	51	21	1	3.8	867	2	280	15728	53760	0.0052	0.9737	0.2656	2	308	280	0	515	5054	1174	388	174	0.7433
94	7305	187	55	27	1	3.4	860	2	288	15957	53949	0.0053	0.9744	0.2941	1	290	288	0	546	4930	1199	453	177	0.7157
33	7305	188	60	30	1	3.1	882	0	287	15662	54001	0.0053	0.9743	0.3191	1	261	287	0	523	4987	1187	433	175	0.6910
87	7305	170	44	31	1	3.9	881	2	319	10285	54218	0.0059	0.9767	0.2588	1	234	319	0	557	5057	1174	357	160	0.7524
29	7305	181	56	25	1	3.2	868	1	300	15812	54296	0.0055	0.9752	0.3094	2	282	300	0	523	5005	1156	452	169	0.7014
52	7305	190	58	26	1	3.3	871	2	288	15469	54730	0.0053	0.9740	0.3053	1	267	288	0	528	4931	1222	454	170	0.7047
61	7305	197	60	28	1	3.3	862	2	278	16102	54810	0.0051	0.9730	0.3046	1	268	278	0	523	4992	1174	440	176	0.7048
83	7305	187	50	31	1	3.7	866	0	295	14939	55126	0.0053	0.9744	0.2674	1	299	295	0	510	5004	1176	444	171	0.7425
97	7305	177	57	18	1	3.1	935	3	312	15569	55255	0.0056	0.9758	0.3220	2	273	312	0	519	5038	1188	402	158	0.6898
24	7305	176	50	19	1	3.5	866	2	315	14071	55454	0.0057	0.9759	0.2841	2	281	315	0	523	4991	1275	352	164	0.7273
86	7305	169	49	23	1	3.4	859	3	330	13848	55812	0.0059	0.9769	0.2899	2	283	330	0	539	4959	1184	462	161	0.7226
53	7305	183	55	16	1	3.3	868	1	305	16384	55876	0.0055	0.9749	0.3005	2	298	305	0	522	4938	1203	472	170	0.7105
43	7305	176	61	24	1	2.9	894	2	318	15816	56011	0.0057	0.9759	0.3466	2	259	318	0	512	5013	1143	479	158	0.6661
78	7305	174	45	43	1	3.9	866	0	324	10659	56320	0.0057	0.9762	0.2586	1	237	324	0	550	4950	1243	406	156	0.7530
48	7305	179	49	17	1	3.7	867	3	318	14895	56940	0.0056	0.9755	0.2737	2	304	318	0	551	4928	1235	427	164	0.7377
98	7305	192	57	17	1	3.4	869	2	297	17699	57012	0.0052	0.9737	0.2969	2	311	297	0	511	5030	1135	450	179	0.7136
79	7305	192	62	15	1	3.1	915	1	297	15056	57067	0.0052	0.9737	0.3229	3	243	297	0	497	5035	1151	450	172	0.6879
42	7305	172	52	24	1	3.3	866	1	333	16019	57218	0.0058	0.9765	0.3023	2	308	333	0	531	4959	1225	432	158	0.7106
14	7305	165	44	24	1	3.8	876	4	351	13673	57879	0.0061	0.9774	0.2667	2	311	351	0	505	5008	1219	420	153	0.7470
69	7305	196	63	25	1	3.1	897	0	296	17941	58046	0.0051	0.9732	0.3214	1	285	296	0	531	4978	1206	412	178	0.6894
6	7305	180	54	17	1	3.3	868	6	323	16661	58121	0.0056	0.9754	0.3000	2	309	323	0	528	4993	1230	382	172	0.7122

30	7305	198	62	19	1	3.2	907	0	294	19544	58294	0.0051	0.9729	0.3131	2	315	294	0	520	5012	1171	430	172	0.6974
73	7305	190	54	14	1	3.5	871	1	307	13854	58404	0.0053	0.9740	0.2842	3	257	307	0	512	5054	1156	414	169	0.7267
32	7305	180	45	27	1	4.0	873	7	327	13231	58779	0.0056	0.9754	0.2500	2	294	327	0	536	4969	1253	372	175	0.7617
3	7305	203	62	23	1	3.3	870	5	290	18605	58898	0.0049	0.9722	0.3054	2	300	290	0	506	4950	1205	457	187	0.7048
92	7305	188	43	16	1	4.4	864	2	313	14764	58900	0.0053	0.9743	0.2287	2	343	313	0	497	5060	1198	368	182	0.7818
35	7305	178	62	14	1	2.9	904	3	332	17525	59104	0.0056	0.9756	0.3483	3	283	332	0	554	4929	1204	460	158	0.6655
28	7305	195	62	18	1	3.1	869	1	306	18080	59715	0.0051	0.9733	0.3179	2	292	306	0	514	4931	1246	437	177	0.6935
9	7305	192	53	18	1	3.6	860	7	312	18058	59896	0.0052	0.9737	0.2760	2	341	312	0	522	4989	1183	433	178	0.7351
54	7305	212	59	28	1	3.6	869	1	285	15236	60432	0.0047	0.9710	0.2783	1	258	285	0	533	5036	1160	383	193	0.7312
51	7305	176	42	39	1	4.2	891	2	347	11438	61101	0.0057	0.9759	0.2386	1	272	347	0	521	5037	1197	384	166	0.7743
66	7305	206	63	18	1	3.3	853	2	297	19094	61154	0.0049	0.9718	0.3058	2	303	297	0	522	4980	1190	421	192	0.7048
91	7305	177	44	17	1	4.0	869	3	346	14377	61173	0.0056	0.9758	0.2486	2	327	346	0	529	4965	1259	390	162	0.7644
5	7305	210	49	22	1	4.3	860	1	304	16123	63837	0.0048	0.9713	0.2333	2	329	304	0	530	4992	1220	372	191	0.7768
44	7305	193	56	19	1	3.4	911	1	332	16841	64160	0.0052	0.9736	0.2902	2	301	332	0	540	5013	1138	437	177	0.7227
13	7305	186	41	23	1	4.5	886	4	346	13832	64365	0.0054	0.9745	0.2204	2	337	346	0	546	4966	1226	398	169	0.7922
50	7305	195	51	21	1	3.8	898	1	330	16028	64441	0.0051	0.9733	0.2615	2	314	330	0	540	4962	1193	426	184	0.7507
96	7305	193	47	18	1	4.1	923	1	337	15814	65061	0.0052	0.9736	0.2435	2	336	337	0	541	4999	1209	375	181	0.7689
67	7305	182	46	30	1	4.0	867	5	360	15587	65520	0.0055	0.9751	0.2527	1	339	360	0	532	4948	1217	431	177	0.7614
60	7305	198	51	30	1	3.9	867	0	332	14076	65662	0.0051	0.9729	0.2576	1	276	332	0	536	4963	1212	408	186	0.7547
25	7305	213	64	21	1	3.3	895	5	310	17176	65965	0.0047	0.9708	0.3005	2	268	310	0	523	4994	1173	418	197	0.7110
57	7305	202	56	16	1	3.6	867	3	327	18415	66014	0.0050	0.9723	0.2772	2	329	327	0	531	4932	1232	417	193	0.7350
59	7305	216	54	14	1	4.0	870	1	307	19728	66245	0.0046	0.9704	0.2500	2	365	307	0	514	4998	1198	399	196	0.7605
77	7305	217	61	24	1	3.6	860	3	308	18330	66925	0.0046	0.9703	0.2811	1	300	308	0	559	4946	1138	461	201	0.7300
22	7305	195	44	31	1	4.4	937	0	343	13735	66957	0.0051	0.9733	0.2256	1	312	343	0	532	5022	1170	400	181	0.7869
89	7305	204	53	34	1	3.8	943	2	331	14679	67428	0.0049	0.9721	0.2598	1	277	331	0	533	5048	1146	388	190	0.7524
1	7305	187	48	30	1	3.9	871	4	364	14638	68117	0.0053	0.9744	0.2567	1	305	364	0	515	5015	1199	400	176	0.7579
70	7305	185	42	33	1	4.4	888	1	368	11527	68120	0.0054	0.9747	0.2270	1	274	368	0	516	5036	1157	422	174	0.7873
68	7305	209	56	18	1	3.7	875	3	328	18188	68506	0.0048	0.9714	0.2679	2	325	328	0	517	4917	1225	450	196	0.7443
21	7305	207	50	34	1	4.1	869	1	331	17258	68507	0.0048	0.9717	0.2415	1	345	331	0	531	4905	1218	454	197	0.7704
10	7305	201	47	38	1	4.3	905	1	342	13925	68783	0.0050	0.9725	0.2338	1	296	342	0	512	5038	1177	394	184	0.7788
15	7305	199	57	21	1	3.5	871	1	346	16697	68873	0.0050	0.9728	0.2864	2	293	346	0	528	4953	1241	402	181	0.7274
49	7305	231	53	27	1	4.4	870	1	298	15744	68897	0.0043	0.9684	0.2294	1	297	298	0	522	4972	1200	399	212	0.7804
31	7305	209	59	16	1	3.5	925	2	330	19024	68987	0.0048	0.9714	0.2823	2	322	330	0	498	4978	1261	373	195	0.7303
63	7305	188	36	32	1	5.2	862	1	372	11389	69874	0.0053	0.9743	0.1915	1	316	372	0	526	5018	1202	376	183	0.8225
12	7305	202	47	35	1	4.3	910	5	347	13237	70055	0.0050	0.9723	0.2327	1	282	347	0	535	4969	1172	434	195	0.7803
34	7305	198	55	33	1	3.6	872	2	357	15943	70659	0.0051	0.9729	0.2778	1	290	357	0	532	4979	1211	394	189	0.7367
82	7305	217	55	25	1	3.9	878	2	333	16809	72346	0.0046	0.9703	0.2535	1	306	333	0	544	4948	1192	418	203	0.7589
37	7305	219	59	53	1	3.7	873	0	337	14436	73731	0.0046	0.9700	0.2694	1	245	337	0	550	4891	1210	448	206	0.7435
75	7305	224	58	21	1	3.9	888	2	332	19162	74305	0.0045	0.9693	0.2589	2	330	332	0	534	4919	1217	426	209	0.7535
46	7305	218	52	33	1	4.2	899	3	351	17300	76453	0.0046	0.9702	0.2385	1	333	351	0	534	4994	1211	366	200	0.7749
80	7305	229	57	36	1	4.0	940	1	334	14867	76587	0.0044	0.9687	0.2489	1	261	334	0	503	5055	1132	407	208	0.7636
45	7305	227	51	29	1	4.5	869	1	339	15747	77003	0.0044	0.9689	0.2247	1	309	339	0	536	4977	1199	373	220	0.7877
85	7305	240	64	19	1	3.8	889	2	322	19200	77220	0.0042	0.9671	0.2667	2	300	322	0	498	5022	1111	459	215	0.7453
99	7305	212	52	40	1	4.1	913	0	377	14626	79965	0.0047	0.9710	0.2453	1	281	377	0	530	4987	1209	380	199	0.7702
Minimum		134	36	11	1	2.6	606	0	220	10285	32582	0.0042	0.9671	0.1915	1	224	220	0	497	4891	1111	352	122	0.6317
Average		187	53	23	1	3.6	876	2	308	15276	57752	0.0054	0.9744	0.2861	2	289	308	0	527	4987	1201	418	172	0.7250
Maximum		240	67	53	1	5.2	943	7	377	19728	79965	0.0075	0.9817	0.3787	4	365	377	0	559	5060	1283	479	220	0.8225
Std.dev		20.1	6.1	7.9	0	0.5	36.9	1.7	31.2	2078.5	9829.4	0.0006	0.0028	0.0364	0.7	28.8	31.2	0.0	14.0	38.8	35.8	30.4	19.8	0.0373

Scenerio N Scenario 13a CSIROMk2b B11 with 5% additional WEMPs savings with change of precipitation frequency
Date: 30/10/2007
Simulation 9:35:13 AM
Simulation 12:16:00 PM
Elapsed Ti 160.78 Minutes

		ΣZ_t	ΣW_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Σ si	Ssj	$e_j = 1/\Sigma Z_t$				v=Ssjej	v= Ssiei	no. of days with demand						
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Total. Severity of Failure	Total Maximum Severity of Sojourn	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	Vulnerability 1	Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance
4	7305	137	45	28	1	3.0	868	0	32945	11103	0.0073	0.9812	0.3285	1.9	247	240	0	533	5082	1169	398	123	0.679
40	7305	148	44	18	1	3.4	500	1	34259	9641	0.0068	0.9797	0.2973	2.7	219	231	0	521	5115	1169	361	139	0.709
81	7305	148	55	10	1	2.7	864	1	38013	14900	0.0068	0.9797	0.3716	4.9	271	257	0	523	5045	1148	457	132	0.637
84	7305	145	57	11	1	2.5	873	1	38725	14167	0.0069	0.9802	0.3931	4.6	249	267	0	506	5089	1166	410	134	0.617
56	7305	127	42	16	1	3.0	868	0	39188	11293	0.0079	0.9826	0.3307	3.6	269	309	0	496	5084	1242	366	117	0.681
38	7305	133	43	11	1	3.1	890	1	39317	12432	0.0075	0.9818	0.3233	5.0	289	296	0	537	4953	1256	439	120	0.687
36	7305	144	40	23	1	3.6	862	5	39400	10669	0.0069	0.9803	0.2778	2.2	267	274	0	507	4992	1281	393	132	0.731
2	7305	147	48	26	1	3.1	860	0	40421	11256	0.0068	0.9799	0.3265	1.9	235	275	0	543	5016	1251	367	128	0.683
41	7305	129	46	17	1	2.8	902	3	40670	10685	0.0078	0.9823	0.3566	3.3	232	315	0	525	5061	1208	395	116	0.656
17	7305	158	48	14	1	3.3	861	1	41288	11286	0.0063	0.9784	0.3038	3.3	235	261	0	530	5036	1221	379	139	0.704
76	7305	159	51	27	1	3.1	846	0	41482	13738	0.0063	0.9782	0.3208	1.7	269	261	0	524	5097	1161	377	146	0.688
66	7305	141	52	19	1	2.7	851	3	41761	13084	0.0071	0.9807	0.3688	2.7	252	296	0	522	5038	1172	441	132	0.643
11	7305	143	45	16	1	3.2	868	2	42240	13337	0.0070	0.9804	0.3147	3.2	296	295	0	550	5035	1228	361	131	0.696
74	7305	150	49	14	1	3.1	864	2	43148	13340	0.0067	0.9795	0.3267	3.5	272	288	0	517	5093	1181	377	137	0.683
26	7305	163	52	14	1	3.1	856	2	43593	14418	0.0061	0.9777	0.3190	3.2	277	267	0	510	4979	1237	430	149	0.690
18	7305	163	46	17	1	3.5	893	3	44608	12474	0.0061	0.9777	0.2822	2.6	271	274	0	543	4983	1193	439	147	0.726
88	7305	162	43	20	1	3.8	865	2	44758	11163	0.0062	0.9778	0.2654	2.3	260	276	0	523	5106	1168	354	154	0.743
7	7305	162	49	30	1	3.3	858	2	45029	14865	0.0062	0.9778	0.3025	1.5	303	278	0	521	5001	1231	401	151	0.707
27	7305	131	43	23	1	3.0	865	0	45040	12338	0.0076	0.9821	0.3282	2.4	287	344	0	516	5157	1155	352	125	0.686
62	7305	139	39	13	1	3.6	868	0	45162	12796	0.0072	0.9810	0.2806	4.0	328	325	0	521	4937	1255	466	126	0.731
71	7305	156	49	13	1	3.2	862	8	45261	14110	0.0064	0.9786	0.3141	3.6	288	290	0	521	4986	1237	415	146	0.696
69	7305	152	48	22	1	3.2	860	2	45426	14280	0.0066	0.9792	0.3158	2.2	298	299	0	533	5093	1157	379	143	0.695
58	7305	159	49	40	1	3.2	869	4	45734	12473	0.0063	0.9782	0.3082	1.1	255	288	0	529	5085	1185	360	146	0.702
87	7305	130	34	18	1	3.8	879	1	46239	9679	0.0077	0.9822	0.2615	3.1	285	356	0	532	5028	1234	392	119	0.752
78	7305	154	40	21	1	3.9	866	0	46889	12303	0.0065	0.9789	0.2597	2.3	308	304	0	542	5018	1237	372	136	0.751
55	7305	147	53	14	1	2.8	911	2	47015	13932	0.0068	0.9799	0.3605	3.5	263	320	0	545	4970	1200	459	131	0.652
42	7305	141	47	14	1	3.0	870	5	47042	13678	0.0071	0.9807	0.3333	3.7	291	334	0	537	4951	1228	458	131	0.680
100	7305	189	56	13	1	3.4	855	3	48027	15367	0.0053	0.9741	0.2963	3.0	274	254	0	530	4988	1201	422	164	0.711
33	7305	168	53	30	1	3.2	875	1	48694	13412	0.0060	0.9770	0.3155	1.4	253	290	0	521	5048	1173	409	154	0.695
47	7305	174	38	17	1	4.6	883	2	49119	12767	0.0057	0.9762	0.2184	2.5	336	282	0	528	5000	1204	412	161	0.790
90	7305	164	51	24	1	3.2	865	0	49367	12917	0.0061	0.9775	0.3110	1.9	253	301	0	521	5042	1224	378	140	0.700
48	7305	166	49	19	1	3.4	866	4	49613	12061	0.0060	0.9773	0.2952	2.3	246	299	0	538	5016	1180	417	154	0.715
64	7305	169	55	17	1	3.1	918	0	49920	13314	0.0059	0.9769	0.3254	2.5	242	295	0	519	5017	1185	442	142	0.685
14	7305	148	43	19	1	3.4	867	7	50116	11598	0.0068	0.9797	0.2905	2.6	270	339	0	493	5027	1200	440	145	0.723
16	7305	204	47	23	1	4.3	884	0	50174	12429	0.0049	0.9721	0.2304	1.6	264	246	0	512	5136	1086	389	182	0.776
73	7305	158	47	13	1	3.4	862	2	50391	13386	0.0063	0.9784	0.2975	3.6	285	319	0	504	5071	1239	348	143	0.714
92	7305	154	33	19	1	4.7	865	3	50443	9097	0.0065	0.9789	0.2143	2.5	276	328	0	499	5077	1259	326	144	0.797
19	7305	184	49	28	1	3.8	864	2	50592	14444	0.0054	0.9748	0.2663	1.4	295	275	0	516	5181	1073	366	169	0.742
59	7305	173	54	18	1	3.2	868	5	50735	15823	0.0058	0.9763	0.3121	2.3	293	293	0	506	5088	1162	387	162	0.698
91	7305	164	51	17	1	3.2	867	1	50897	15989	0.0061	0.9775	0.3110	2.6	314	310	0	528	5033	1226	369	149	0.700
72	7305	146	46	21	1	3.2	860	11	50997	12327	0.0068	0.9800	0.3151	2.4	268	349	0	550	4998	1229	392	136	0.699
94	7305	193	65	28	1	3.0	860	0	51422	14716	0.0052	0.9736	0.3368	1.4	226	266	0	539	4976	1191	423	176	0.672
93	7305	162	46	34	1	3.5	883	1	51942	14526	0.0062	0.9778	0.2840	1.3	316	321	0	551	4997	1209	398	150	0.728
98	7305	183	54	18	1	3.4	897	1	52512	16887	0.0055	0.9749	0.2951	2.2	313	287	0	508	5072	1125	441	159	0.715
79	7305	175	52	12	1	3.4	863	2	52638	14795	0.0057	0.9760	0.2971	3.5	285	301	0	510	5079	1154	400	162	0.713
9	7305	177	61	12	1	2.9	863	13	52744	18019	0.0056	0.9758	0.3446	3.4	295	298	0	540	5059	1159	387	160	0.667
95	7305	199	46	34	1	4.3	855	1	52782	13623	0.0050	0.9728	0.2312	1.1	296	265	0	524	4989	1182	425	185	0.777
86	7305	158	41	22	1	3.9	865	7	53143	13152	0.0063	0.9784	0.2595	2.1	321	336	0	534	5078	1142	403	148	0.753
20	7305	182	59	16	1	3.1	851	1	53160	15583	0.0055	0.9751	0.3242	2.5	264	292	0	532	5045	1156	408	164	0.686
23	7305	174	44	29	1	4.0	894	0	53315	12538	0.0057	0.9762	0.2529	1.4	285	306	0	511	5042	1215	376	161	0.757
43	7305	168	53	25	1	3.2	869	0	53498	14822	0.0060	0.9770	0.3155	1.7	280	318	0	532	5009	1184	427	153	0.697
6	7305	177	54	16	1	3.3	868	3	53635	15287	0.0056	0.9758	0.3051	2.6	283	303	0	515	5134	1126	369	161	0.706
29	7305	183	50	26	1	3.7	862	0	54064	15761	0.0055	0.9749	0.2732	1.5	315	295	0	517	5017	1243	357	171	0.737
52	7305	169	55	27	1	3.1	873	4	54253	15110	0.0059	0.9769	0.3254	1.6	275	321	0	531	5022	1167	429	156	0.687
53	7305	180	53	15	1	3.4	907	1	54257	15965	0.0056	0.9754	0.2944	2.7	301	301	0	523	5066	1155	399	162	0.716
61	7305	192	48	29	1	4.0	959	3	54276	15090	0.0052	0.9737	0.2500	1.3	314	283	0	533	4957	1229	407	179	0.759
83	7305	171	49	20	1	3.5	885	0	54420	15910	0.0058	0.9766	0.2865	2.1	325	318	0	514	5006	1247	379	159	0.725

13	7305	175	48	17	1	3.6	952	3	54530	15301	0.0057	0.9760	0.2743	2.5	319	312	0	541	5047	1121	437	159	0.737
32	7305	182	48	30	1	3.8	866	1	54575	13159	0.0055	0.9751	0.2637	1.3	274	300	0	526	5056	1176	376	171	0.746
30	7305	185	61	16	1	3.0	897	0	54717	18505	0.0054	0.9747	0.3297	2.5	303	296	0	513	5033	1157	427	175	0.681
3	7305	204	59	23	1	3.5	898	1	54965	15593	0.0049	0.9721	0.2892	1.6	264	269	0	509	5011	1148	454	183	0.719
54	7305	180	47	30	1	3.8	861	2	55215	14148	0.0056	0.9754	0.2611	1.4	301	307	0	534	5105	1130	367	169	0.749
51	7305	161	44	39	1	3.7	868	2	55230	12175	0.0062	0.9780	0.2733	1.2	277	343	0	526	5113	1111	408	147	0.740
24	7305	172	48	28	1	3.6	869	1	56062	12065	0.0058	0.9765	0.2791	1.5	251	326	0	509	5086	1182	374	154	0.733
82	7305	168	47	20	1	3.6	865	5	56203	13562	0.0060	0.9770	0.2798	2.2	289	335	0	530	5012	1254	353	156	0.733
97	7305	192	58	18	1	3.3	876	2	56527	15254	0.0052	0.9737	0.3021	2.1	263	294	0	529	4996	1209	398	173	0.708
70	7305	179	46	27	1	3.9	899	1	56563	12266	0.0056	0.9755	0.2570	1.5	267	316	0	522	5057	1187	376	163	0.754
50	7305	156	46	38	1	3.4	898	2	56675	11554	0.0064	0.9786	0.2949	1.2	251	363	0	533	4993	1197	435	147	0.720
5	7305	183	40	20	1	4.6	860	0	58064	13549	0.0055	0.9749	0.2186	2.0	339	317	0	525	5040	1198	368	174	0.792
44	7305	192	59	25	1	3.3	891	1	58728	15143	0.0052	0.9737	0.3073	1.5	257	306	0	530	5023	1219	361	172	0.704
39	7305	207	49	17	1	4.2	866	0	58967	16782	0.0048	0.9717	0.2367	2.1	342	285	0	505	5082	1130	399	189	0.772
15	7305	175	49	22	1	3.6	871	3	59138	13580	0.0057	0.9760	0.2800	1.9	277	338	0	524	5001	1203	420	157	0.733
49	7305	187	48	20	1	3.9	871	0	59314	15205	0.0053	0.9744	0.2567	2.0	317	317	0	529	5031	1243	328	174	0.755
77	7305	207	61	24	1	3.4	869	0	59461	18859	0.0048	0.9717	0.2947	1.5	309	287	0	556	4952	1169	441	187	0.715
25	7305	193	59	16	1	3.3	871	2	59651	17653	0.0052	0.9736	0.3057	2.4	299	309	0	515	5024	1193	390	183	0.706
1	7305	146	34	27	1	4.3	1105	6	59819	10369	0.0068	0.9800	0.2329	1.9	305	410	0	514	5071	1210	373	137	0.785
34	7305	174	45	27	1	3.9	867	4	60087	13779	0.0057	0.9762	0.2586	1.6	306	345	0	524	5010	1217	388	166	0.755
21	7305	187	57	22	1	3.3	869	1	60096	15959	0.0053	0.9744	0.3048	1.8	280	321	0	540	4933	1243	409	180	0.707
60	7305	177	48	38	1	3.7	866	2	60203	11819	0.0056	0.9758	0.2712	1.1	246	340	0	547	5005	1199	390	164	0.742
35	7305	194	58	27	1	3.3	904	2	60212	16174	0.0052	0.9734	0.2990	1.4	279	310	0	558	5003	1107	465	172	0.712
8	7305	185	46	19	1	4.0	880	0	60931	15304	0.0054	0.9747	0.2486	2.1	333	329	0	511	5115	1165	343	171	0.763
57	7305	199	59	34	1	3.4	871	1	61443	16864	0.0050	0.9728	0.2965	1.1	286	309	0	527	5008	1188	396	186	0.715
65	7305	204	43	43	1	4.7	881	1	61807	14301	0.0049	0.9721	0.2108	0.8	333	303	0	549	5046	1097	431	182	0.799
22	7305	169	37	39	1	4.6	910	0	61950	11150	0.0059	0.9769	0.2189	1.1	301	367	0	540	4935	1283	386	161	0.795
68	7305	184	50	18	1	3.7	871	1	62145	15503	0.0054	0.9748	0.2717	2.2	310	338	0	531	5074	1125	404	171	0.741
80	7305	202	54	26	1	3.7	916	2	62426	14073	0.0050	0.9723	0.2673	1.4	261	309	0	497	5055	1145	421	187	0.744
28	7305	192	60	25	1	3.2	872	3	62545	16498	0.0052	0.9737	0.3125	1.5	275	326	0	489	5119	1128	391	178	0.700
12	7305	187	49	21	1	3.8	869	1	62601	13236	0.0053	0.9744	0.2620	1.9	270	335	0	528	5026	1193	383	175	0.750
67	7305	174	49	21	1	3.6	866	3	62787	15076	0.0057	0.9762	0.2816	2.0	308	361	0	533	5044	1136	426	166	0.733
96	7305	184	44	18	1	4.2	903	2	63090	13990	0.0054	0.9748	0.2391	2.2	318	343	0	544	5091	1102	399	169	0.774
31	7305	192	52	22	1	3.7	900	1	63286	15034	0.0052	0.9737	0.2708	1.7	289	330	0	498	5067	1229	332	179	0.741
10	7305	186	47	22	1	4.0	881	3	65107	14246	0.0054	0.9745	0.2527	1.8	303	350	0	517	5042	1186	388	172	0.761
46	7305	210	46	31	1	4.6	912	1	65330	12541	0.0048	0.9713	0.2190	1.1	273	311	0	523	5067	1143	382	190	0.791
63	7305	188	41	23	1	4.6	866	0	65827	11350	0.0053	0.9743	0.2181	1.7	277	350	0	530	5078	1182	340	175	0.795
89	7305	240	64	29	1	3.8	872	1	68600	18882	0.0042	0.9671	0.2667	1.0	295	286	0	532	5097	1077	378	221	0.743
37	7305	196	47	60	1	4.2	871	1	71545	11923	0.0051	0.9732	0.2398	0.6	254	365	0	542	4890	1303	389	181	0.775
85	7305	199	48	29	1	4.1	903	2	72428	15621	0.0050	0.9728	0.2412	1.3	325	364	0	505	4983	1184	445	188	0.773
75	7305	223	62	27	1	3.6	869	1	75133	17762	0.0045	0.9695	0.2780	1.2	286	337	0	545	4970	1088	495	207	0.735
45	7305	232	49	38	1	4.7	888	2	76121	12285	0.0043	0.9682	0.2112	0.8	251	328	0	513	5068	1194	318	212	0.800
99	7305	225	52	25	1	4.3	868	2	76696	16087	0.0044	0.9692	0.2311	1.3	309	341	0	528	5060	1125	384	208	0.781
Minimum		127	33	10	1	2.5	500	0	32945	9097	0.0042	0.9671	0.2108	0.6	219	231	0	489	4890	1073	318	116	0.617
Average		173	49	23	1	3.6	875	2	53426	13903	0.0059	0.9763	0.2865	2.1	283	308	0	525	5038	1186	397	159	0.725
Maximum		240	65	60	1	4.7	1105	13	76696	18882	0.0079	0.9826	0.3931	5.0	342	410	0	558	5181	1303	495	221	0.800
Std.dev		23.4	6.6	8.2	0	0.5	48.3	2.2	9041.4	2066.2	0.0008	0.0032	0.0388	0.9	27.2	31.3	0.0	14.5	52.4	48.1	34.5	21.7930	0.039

Scenerio N Scenario 13c CSIROMk2b B11 with 5% additional WEMPs savings□Higher population projection and Climate Change effect
Date: 19/10/2007
Simulation 8:01:23 PM
Simulation 8:49:14 PM
Elapsed Ti 47.85 Minutes

Trial No.	Total no. of Days	ΣZ_t No. of Days Failed	ΣW_t No. of Consecutive Failures	Max T_f Max. Failure Duration	Min T_f Min. Failure Duration	$E[T_f]$ Avg. Failure Duration	Max S_i Max Severity of Failure	Min S_i Min Severity of Failure	Ssi Total Severity of Failure	Ssj Total Maximum Severity of Sojourn	$e_j = 1/\Sigma Z_t$ Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	v=Ssjej Vulnerability 1	v= Ssiei Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance
1	7305	567	116	53	1	4.9	1878	1	311068	54127	0.0018	0.9224	0.2046	0.243	467	549	0	-181	2732	5735	3744	543	0.829
2	7305	551	141	64	1	3.9	1862	2	261745	60085	0.0018	0.9246	0.2559	0.207	426	475	0	-81	2808	5688	3667	527	0.772
3	7305	629	147	51	1	4.3	1880	0	327750	70611	0.0016	0.9139	0.2337	0.228	480	521	0	-108	2765	5630	3647	592	0.799
4	7305	509	119	54	1	4.3	1875	2	239181	57838	0.0020	0.9303	0.2338	0.266	486	470	0	-297	2612	5736	3907	490	0.792
5	7305	527	113	55	1	4.7	1865	8	303287	56273	0.0019	0.9279	0.2144	0.252	498	575	0	-216	2664	5760	3838	507	0.822
6	7305	518	128	31	1	4.0	1876	2	284603	61269	0.0019	0.9291	0.2471	0.455	479	549	0	-158	2731	5749	3799	493	0.788
7	7305	537	127	48	1	4.2	1762	0	258236	55198	0.0019	0.9265	0.2365	0.283	435	481	0	-188	2681	5710	3824	506	0.791
8	7305	560	123	58	1	4.6	1875	1	292509	58779	0.0018	0.9233	0.2196	0.225	478	522	0	-169	2765	5726	3728	532	0.811
9	7305	568	127	39	1	4.5	1865	1	301688	57703	0.0018	0.9222	0.2236	0.330	454	531	0	-168	2725	5671	3741	544	0.809
10	7305	552	102	59	1	5.4	1924	4	323109	50324	0.0018	0.9244	0.1848	0.224	493	585	0	-300	2675	5767	3830	534	0.852
11	7305	522	128	46	1	4.1	1890	1	269109	57028	0.0019	0.9285	0.2452	0.304	446	516	0	-84	2759	5658	3738	499	0.786
12	7305	565	116	56	1	4.9	1929	0	309768	54840	0.0018	0.9227	0.2053	0.231	473	548	0	-214	2690	5714	3802	535	0.828
13	7305	543	114	52	1	4.8	1898	2	296930	49363	0.0018	0.9257	0.2099	0.259	433	547	0	-187	2707	5674	3780	524	0.823
14	7305	521	120	43	1	4.3	1883	0	272501	53977	0.0019	0.9287	0.2303	0.326	450	523	0	-135	2755	5727	3780	494	0.801
15	7305	539	117	39	1	4.6	1879	1	325183	59905	0.0019	0.9262	0.2171	0.348	512	603	0	-184	2695	5724	3810	523	0.823
16	7305	542	125	74	1	4.3	1920	2	263799	54115	0.0018	0.9258	0.2306	0.182	433	487	0	-205	2741	5714	3782	508	0.797
17	7305	539	113	45	1	4.8	1872	1	277746	54347	0.0019	0.9262	0.2096	0.301	481	515	0	-198	2698	5705	3817	509	0.820
18	7305	552	128	31	1	4.3	1882	1	282939	61107	0.0018	0.9244	0.2319	0.427	477	513	0	-124	2784	5715	3693	527	0.799
19	7305	563	111	77	1	5.1	1963	5	289652	49875	0.0018	0.9229	0.1972	0.169	449	514	0	-287	2680	5756	3819	542	0.832
20	7305	545	120	60	1	4.5	1856	3	286567	55048	0.0018	0.9254	0.2202	0.223	459	526	0	-96	2794	5724	3678	513	0.811
21	7305	603	123	39	1	4.9	1877	1	336822	58806	0.0017	0.9175	0.2040	0.311	478	559	0	-156	2740	5645	3688	585	0.831
22	7305	577	111	61	1	5.2	1964	3	314807	56523	0.0017	0.9210	0.1924	0.208	509	546	0	-239	2694	5772	3764	556	0.840
23	7305	542	113	65	1	4.8	1909	1	278682	47346	0.0018	0.9258	0.2085	0.207	419	514	0	-212	2725	5708	3780	512	0.821
24	7305	515	111	50	1	4.6	1874	2	274898	56233	0.0019	0.9295	0.2155	0.284	507	534	0	-142	2760	5741	3770	490	0.816
25	7305	552	112	38	1	4.9	1909	1	318719	57063	0.0018	0.9244	0.2029	0.348	509	577	0	-204	2680	5705	3793	534	0.833
26	7305	588	118	60	1	5.0	1861	2	300582	56951	0.0017	0.9195	0.2007	0.207	483	511	0	-201	2762	5694	3696	564	0.829
27	7305	528	116	51	1	4.6	1872	2	274120	57179	0.0019	0.9277	0.2197	0.271	493	519	0	-199	2707	5736	3801	505	0.811
28	7305	569	121	55	1	4.7	1876	0	312723	56944	0.0018	0.9221	0.2127	0.233	471	550	0	-193	2654	5686	3829	542	0.821
29	7305	588	130	50	1	4.5	1875	1	307830	63270	0.0017	0.9195	0.2211	0.248	487	524	0	-165	2775	5733	3698	559	0.811
30	7305	577	114	46	1	5.1	1925	0	318785	61430	0.0017	0.9210	0.1976	0.275	539	552	0	-273	2629	5739	3838	556	0.836
31	7305	521	117	67	1	4.5	1949	2	319539	63363	0.0019	0.9287	0.2246	0.209	542	613	0	-248	2603	5731	3922	503	0.816
32	7305	505	110	38	1	4.6	1881	5	274408	55613	0.0020	0.9309	0.2178	0.381	506	543	0	-280	2627	5735	3897	485	0.815
33	7305	577	104	46	1	5.5	1895	1	311858	53431	0.0017	0.9210	0.1802	0.275	514	540	0	-242	2633	5718	3819	560	0.851
34	7305	538	115	47	1	4.7	1879	1	317801	58881	0.0019	0.9264	0.2138	0.289	512	591	0	-175	2735	5677	3769	511	0.824
35	7305	584	120	32	1	4.9	1920	0	312760	63544	0.0017	0.9201	0.2055	0.391	530	536	0	-181	2659	5668	3774	562	0.827
36	7305	563	116	56	1	4.9	1867	0	282127	56618	0.0018	0.9229	0.2060	0.232	488	501	0	-261	2631	5689	3846	541	0.822
37	7305	611	127	60	1	4.8	1881	1	349557	59257	0.0016	0.9164	0.2079	0.199	467	572	0	-154	2760	5630	3670	583	0.829
38	7305	572	120	37	1	4.8	1873	2	264658	55261	0.0017	0.9217	0.2098	0.345	461	463	0	-196	2710	5662	3746	551	0.815
39	7305	544	114	71	1	4.8	1876	1	288971	53454	0.0018	0.9255	0.2096	0.189	469	531	0	-201	2727	5745	3774	520	0.822
40	7305	489	115	41	1	4.3	1538	0	231726	51195	0.0020	0.9331	0.2352	0.364	445	474	0	-178	2700	5739	3853	465	0.791
41	7305	477	113	28	1	4.2	1907	1	246787	56495	0.0021	0.9347	0.2369	0.547	500	517	0	-146	2764	5730	3783	451	0.793
42	7305	539	111	44	1	4.9	1871	2	285506	54125	0.0019	0.9262	0.2059	0.308	488	530	0	-212	2640	5698	3851	517	0.825
43	7305	618	129	60	1	4.8	1910	1	332266	61721	0.0016	0.9154	0.2087	0.197	478	538	0	-139	2788	5709	3641	595	0.824
44	7305	556	108	33	1	5.1	1929	1	320176	57657	0.0018	0.9239	0.1942	0.398	534	576	0	-270	2658	5702	3809	537	0.841
45	7305	550	109	66	1	5.0	1877	1	333863	49174	0.0018	0.9247	0.1982	0.201	451	607	0	-237	2635	5696	3854	524	0.841
46	7305	536	104	50	1	5.2	1916	0	341383	56158	0.0019	0.9266	0.1940	0.273	540	637	0	-180	2725	5753	3768	519	0.848
47	7305	523	116	62	1	4.5	1870	0	288319	55182	0.0019	0.9284	0.2218	0.225	476	551	0	-212	2679	5726	3849	505	0.812
48	7305	573	117	43	1	4.9	1873	1	308704	61089	0.0017	0.9216	0.2042	0.296	522	539	0	-157	2675	5682	3773	542	0.828
49	7305	587	113	87	1	5.2	1878	1	330701	50945	0.0017	0.9196	0.1925	0.143	451	563	0	-259	2649	5687	3812	562	0.842
50	7305	585	132	43	1	4.4	1913	1	315385	61000	0.0017	0.9199	0.2256	0.290	462	539	0	-95	2838	5691	3609	567	0.808
51	7305	528	116	52	1	4.6	1905	1	293230	48634	0.0019	0.9277	0.2197	0.266	419	555	0	-235	2657	5752	3863	494	0.815
52	7305	584	115	67	1	5.1	1878	0	309233	55901	0.0017	0.9201	0.1969	0.187	486	530	0	-134	2723	5712	3736	557	0.834
53	7305	573	117	41	1	4.9	1876	1	306632	57044	0.0017	0.9216	0.2042	0.311	488	535	0	-168	2707	5648	3739	549	0.828
54	7305	528	105	56	1	5.0	1876	2	311533	50598	0.0019	0.9277	0.1989	0.247	482	590	0	-259	2663	5730	3851	507	0.838
55	7305	562	140	45	1	4.0	1900	0	276380	60652	0.0018	0.9231	0.2491	0.289	433	492	0	-58	2822	5690	3650	530	0.780
56	7305	544	125	45	1	4.4	1916	2	280880	55589	0.0018	0.9255	0.2298	0.298	445	516	0	-198	2709	5707	3784	525	0.801
57	7305	560	120	35	1	4.7	1874	1	319792	63830	0.0018	0.9233	0.2143	0.373	532	571	0	-170	2720	5680	3751	541	0.822
58	7305	541	123	59	1	4.4	1860	6	267901	58053	0.0018	0.9259	0.2274	0.229	472	495	0	-226	2692	5702	3805	515	0.801

59	7305	569	98	38	1	5.8	1877	2	334978	57673	0.0018	0.9221	0.1722	0.338	589	589	0	-314	2659	5695	3819	549	0.864
60	7305	572	124	59	1	4.6	1874	0	312782	57330	0.0017	0.9217	0.2168	0.216	462	547	0	-168	2740	5670	3729	539	0.817
61	7305	570	108	44	1	5.3	1868	2	298405	54194	0.0018	0.9220	0.1895	0.291	502	524	0	-233	2630	5695	3838	539	0.841
62	7305	591	132	38	1	4.5	1864	0	298559	56608	0.0017	0.9191	0.2234	0.325	429	505	0	-119	2826	5636	3617	570	0.807
63	7305	549	132	35	1	4.2	1868	0	307825	55791	0.0018	0.9248	0.2404	0.380	423	561	0	-151	2761	5731	3744	522	0.796
64	7305	495	112	32	1	4.4	1943	1	267395	54768	0.0020	0.9322	0.2263	0.461	489	540	0	-206	2637	5686	3900	476	0.806
65	7305	600	114	39	1	5.3	1865	1	314663	57587	0.0017	0.9179	0.1900	0.312	505	524	0	-177	2753	5690	3667	582	0.841
66	7305	584	97	52	1	6.0	1857	2	316362	52699	0.0017	0.9201	0.1661	0.241	543	542	0	-312	2606	5717	3856	561	0.865
67	7305	582	115	52	1	5.1	1875	1	323998	60567	0.0017	0.9203	0.1976	0.241	527	557	0	-165	2723	5658	3729	560	0.837
68	7305	614	112	58	1	5.5	1880	0	338287	53927	0.0016	0.9159	0.1824	0.205	481	551	0	-257	2602	5680	3840	579	0.851
69	7305	577	111	39	1	5.2	1913	1	322786	58927	0.0017	0.9210	0.1924	0.325	531	559	0	-186	2727	5700	3727	551	0.842
70	7305	578	125	66	1	4.6	1901	2	310110	51579	0.0017	0.9209	0.2163	0.191	413	537	0	-192	2786	5702	3690	550	0.816
71	7305	571	111	57	1	5.1	1862	7	285803	49250	0.0018	0.9218	0.1944	0.224	444	501	0	-192	2700	5763	3783	549	0.834
72	7305	573	128	43	1	4.5	1870	0	280672	60814	0.0017	0.9216	0.2234	0.296	475	490	0	-83	2820	5677	3645	538	0.805
73	7305	534	116	54	1	4.6	1878	0	295976	52694	0.0019	0.9269	0.2172	0.253	454	554	0	-248	2688	5748	3827	514	0.817
74	7305	506	109	35	1	4.6	1907	1	277808	55262	0.0020	0.9307	0.2154	0.412	507	549	0	-195	2687	5733	3839	491	0.818
75	7305	599	123	45	1	4.9	1900	0	350484	65672	0.0017	0.9180	0.2053	0.271	534	585	0	-148	2741	5660	3688	575	0.832
76	7305	544	102	45	1	5.3	1868	1	279075	52432	0.0018	0.9255	0.1875	0.298	514	513	0	-345	2530	5738	3947	529	0.841
77	7305	633	104	70	1	6.1	1865	0	358478	54986	0.0016	0.9133	0.1643	0.165	529	566	0	-196	2731	5675	3653	613	0.870
78	7305	542	124	58	1	4.4	1874	0	276655	48030	0.0018	0.9258	0.2288	0.232	387	510	0	-158	2739	5702	3768	513	0.801
79	7305	585	110	42	1	5.3	1937	0	311962	55337	0.0017	0.9199	0.1880	0.297	503	533	0	-145	2749	5708	3700	564	0.843
80	7305	586	112	68	1	5.2	1966	5	350748	53668	0.0017	0.9198	0.1911	0.183	479	599	0	-197	2729	5728	3711	568	0.847
81	7305	577	131	42	1	4.4	1864	0	276793	64896	0.0017	0.9210	0.2270	0.301	495	480	0	-124	2790	5690	3676	553	0.800
82	7305	593	115	52	1	5.2	1890	1	342355	57370	0.0017	0.9188	0.1939	0.237	499	577	0	-274	2622	5679	3822	571	0.842
83	7305	545	99	36	1	5.5	1872	0	289672	49867	0.0018	0.9254	0.1817	0.372	504	532	0	-288	2604	5694	3890	520	0.849
84	7305	589	138	55	1	4.3	1869	1	284837	60649	0.0017	0.9194	0.2343	0.225	439	484	0	-90	2869	5729	3595	570	0.794
85	7305	648	117	56	1	5.5	1905	2	368860	59595	0.0015	0.9113	0.1806	0.201	509	569	0	-228	2705	5685	3687	623	0.855
86	7305	580	118	56	1	4.9	1864	0	297668	52661	0.0017	0.9206	0.2034	0.225	446	513	0	-220	2688	5683	3777	555	0.826
87	7305	492	110	60	1	4.5	1894	1	262729	46487	0.0020	0.9326	0.2236	0.247	423	534	0	-155	2720	5774	3791	470	0.808
88	7305	554	115	40	1	4.8	1872	1	284032	56575	0.0018	0.9242	0.2076	0.330	492	513	0	-130	2826	5789	3674	531	0.822
89	7305	558	110	54	1	5.1	1971	0	314247	57751	0.0018	0.9236	0.1971	0.242	525	563	0	-230	2745	5762	3739	537	0.837
90	7305	571	141	38	1	4.0	1923	0	286613	59537	0.0018	0.9218	0.2469	0.337	422	502	0	-105	2729	5637	3726	545	0.783
91	7305	518	118	53	1	4.4	1875	3	285719	47865	0.0019	0.9291	0.2278	0.266	406	552	0	-200	2661	5710	3848	491	0.806
92	7305	526	106	52	1	5.0	1871	4	297623	53403	0.0019	0.9280	0.2015	0.267	504	566	0	-193	2744	5797	3793	509	0.833
93	7305	509	110	47	1	4.6	1895	2	258095	50626	0.0020	0.9303	0.2161	0.305	460	507	0	-181	2696	5713	3815	490	0.813
94	7305	605	131	49	1	4.6	1865	1	305789	61594	0.0017	0.9172	0.2165	0.246	470	505	0	-82	2791	5647	3636	574	0.813
95	7305	527	102	42	1	5.2	1872	2	289240	52451	0.0019	0.9279	0.1935	0.330	514	549	0	-304	2602	5727	3893	510	0.839
96	7305	541	114	85	1	4.7	1946	2	299095	53135	0.0018	0.9259	0.2107	0.159	466	553	0	-158	2746	5724	3737	520	0.823
97	7305	532	119	65	1	4.5	1961	0	284358	53777	0.0019	0.9272	0.2237	0.211	452	535	0	-156	2743	5740	3764	507	0.809
98	7305	566	126	28	1	4.5	1876	2	311739	61759	0.0018	0.9225	0.2226	0.461	490	551	0	-138	2790	5703	3676	550	0.812
99	7305	565	121	66	1	4.7	1932	0	343208	54692	0.0018	0.9227	0.2142	0.196	452	607	0	-231	2696	5734	3782	548	0.826
100	7305	528	99	58	1	5.3	1904	2	283837	51366	0.0019	0.9277	0.1875	0.239	519	538	0	-262	2650	5742	3858	507	0.844
Minimum		477	97	28	1	3.9	1538	0	231726	46487	0.0015	0.9113	0.1643	0.143	387	463	0	-345	2530	5630	3595	451	0.772
Average		557	117	51	1	4.8	1886	1	300177	56139	0.0018	0.9237	0.2110	0.276	480	538	0	-192	2711	5709	3770	534	0.822
Maximum		648	147	87	1	6.1	1971	8	368860	70611	0.0021	0.9347	0.2559	0.547	589	637	0	-58	2869	5797	3947	623	0.870
Std.dev		32.6	9.9	12.1	0	0.4	46.7	1.5	26604.0	4420.1	0.0001	0.0045	0.0185	0.074	36.6	34.1	0	59	62	35	76	32	0.020

Scenerio N Scenario 14 CSIROMk2b B11 with 15% additional WEMPs savings
Date: ########
Simulation ########
Simulation ########
Elapsed Ti 37.82 Minutes

		ΣZ_t	ΣW_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Avg S_i	Ssj	Ssi	$e_j = 1/\Sigma Z_t$				v=Ssjej	v= Ssiei	no. of days with Demand							
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Avg. Severity of a Failure	Total Maximum Severity of Sojourn	Total Severity of Failure	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	Vulnerability 1	Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance	Total Severity/no. of days with failure
40	7305	139	50	16	1	2.8	590	1	219	10761	30408	0.0072	0.9810	0.3597	3	215	219	0	630	4986	1191	373	125	0.6465	219
4	7305	129	47	20	1	2.7	852	0	247	11612	31826	0.0078	0.9823	0.3643	3	247	247	0	648	4987	1146	409	115	0.6435	247
7	7305	153	50	33	1	3.1	749	2	246	11665	37633	0.0065	0.9791	0.3268	1	233	246	0	637	4925	1185	422	136	0.6807	246
2	7305	145	52	17	1	2.8	841	0	263	12243	38099	0.0069	0.9802	0.3586	3	235	263	0	666	4926	1148	437	128	0.6502	263
38	7305	140	43	12	1	3.3	851	1	282	12527	39537	0.0071	0.9808	0.3071	4	291	282	0	662	4895	1185	435	128	0.7023	282
76	7305	167	56	13	1	3.0	846	4	241	15162	40314	0.0060	0.9771	0.3353	3	271	241	0	625	5001	1133	397	149	0.6720	241
81	7305	167	57	17	1	2.9	843	0	247	15702	41256	0.0060	0.9771	0.3413	3	275	247	0	644	4952	1129	431	149	0.6664	247
84	7305	157	53	20	1	3.0	848	2	265	14336	41626	0.0064	0.9785	0.3376	2	270	265	0	633	4950	1130	447	145	0.6712	265
26	7305	174	49	20	1	3.6	841	0	248	12264	43078	0.0057	0.9762	0.2816	2	250	248	0	638	4963	1120	425	159	0.7256	248
16	7305	169	46	16	1	3.7	887	0	259	12011	43687	0.0059	0.9769	0.2722	3	261	259	0	619	4952	1176	409	149	0.7355	259
41	7305	135	45	17	1	3.0	877	1	327	12780	44129	0.0074	0.9815	0.3333	3	284	327	0	623	4984	1204	376	118	0.6796	327
58	7305	173	58	31	1	3.0	840	1	256	13917	44343	0.0058	0.9763	0.3353	1	240	256	0	643	4956	1162	385	159	0.6730	256
17	7305	159	56	14	1	2.8	851	0	280	15394	44508	0.0063	0.9782	0.3522	3	275	280	0	647	4943	1145	429	141	0.6578	280
72	7305	159	61	17	1	2.6	848	2	281	14555	44645	0.0063	0.9782	0.3836	3	239	281	0	667	4911	1142	438	147	0.6269	281
18	7305	168	56	13	1	3.0	858	1	266	14710	44652	0.0060	0.9770	0.3333	3	263	266	0	641	4994	1092	424	154	0.6755	266
27	7305	155	47	28	1	3.3	850	0	290	12713	44968	0.0065	0.9788	0.3032	2	270	290	0	613	5018	1140	395	139	0.7067	290
71	7305	169	51	16	1	3.3	841	1	277	12904	46745	0.0059	0.9769	0.3018	3	253	277	0	642	4939	1126	445	153	0.7073	277
93	7305	163	52	30	1	3.1	868	2	288	14992	46924	0.0061	0.9777	0.3190	1	288	288	0	669	4920	1206	358	152	0.6910	288
88	7305	167	45	18	1	3.7	849	6	283	13457	47188	0.0060	0.9771	0.2695	2	299	283	0	625	5036	1081	408	155	0.7396	283
36	7305	163	47	23	1	3.5	846	2	290	12878	47263	0.0061	0.9777	0.2883	2	274	290	0	598	4994	1123	441	149	0.7214	290
56	7305	159	47	24	1	3.4	884	6	298	12813	47369	0.0063	0.9782	0.2956	2	273	298	0	619	4989	1132	419	146	0.7147	298
100	7305	169	47	12	1	3.6	874	3	280	15074	47381	0.0059	0.9769	0.2781	4	321	280	0	642	4969	1139	398	157	0.7309	280
55	7305	151	46	17	1	3.3	871	0	315	12963	47501	0.0066	0.9793	0.3046	3	282	315	0	661	4920	1157	430	137	0.7070	315
19	7305	161	44	26	1	3.7	922	0	295	12212	47570	0.0062	0.9780	0.2733	2	278	295	0	618	4971	1171	395	150	0.7366	295
11	7305	167	52	18	1	3.2	864	1	292	14791	48732	0.0060	0.9771	0.3114	2	284	292	0	667	4903	1192	395	148	0.6988	292
20	7305	171	58	14	1	2.9	836	1	287	14988	48995	0.0058	0.9766	0.3392	3	258	287	0	650	4975	1139	383	158	0.6711	287
64	7305	159	53	11	1	3.0	906	0	310	15540	49265	0.0063	0.9782	0.3333	4	293	310	0	649	4923	1202	386	145	0.6784	310
95	7305	180	49	17	1	3.7	849	0	275	15714	49501	0.0056	0.9754	0.2722	2	321	275	0	620	4993	1156	367	169	0.7365	275
47	7305	190	51	17	1	3.7	849	1	261	13196	49545	0.0053	0.9740	0.2684	2	259	261	0	621	4919	1196	407	162	0.7394	261
65	7305	193	66	14	1	2.9	845	2	257	18084	49602	0.0052	0.9736	0.3420	3	274	257	0	637	4978	1077	440	173	0.6665	257
23	7305	161	45	18	1	3.6	878	3	309	13762	49670	0.0062	0.9780	0.2795	3	306	309	0	633	4954	1162	405	151	0.7313	309
8	7305	166	47	11	1	3.5	853	4	302	14586	50126	0.0060	0.9773	0.2831	4	310	302	0	630	4946	1152	423	154	0.7273	302
62	7305	190	54	16	1	3.5	843	0	264	13915	50127	0.0053	0.9740	0.2842	2	258	264	0	646	4938	1087	470	164	0.7240	264
74	7305	169	50	13	1	3.4	877	0	298	15932	50340	0.0059	0.9769	0.2959	3	319	298	0	628	4972	1180	377	148	0.7145	298
90	7305	164	52	25	1	3.2	890	3	309	12475	50677	0.0061	0.9775	0.3171	2	240	309	0	630	4887	1192	447	149	0.6944	309
39	7305	185	51	16	1	3.6	852	0	275	15721	50901	0.0054	0.9747	0.2757	2	308	275	0	615	5036	1107	381	166	0.7331	275
94	7305	181	53	27	1	3.4	845	4	283	15141	51160	0.0055	0.9752	0.2928	1	286	283	0	637	4913	1150	434	171	0.7166	283
33	7305	182	56	30	1	3.3	866	1	281	14782	51186	0.0055	0.9751	0.3077	1	264	281	0	614	4979	1122	420	170	0.7018	281
29	7305	172	54	24	1	3.2	852	7	300	14980	51601	0.0058	0.9765	0.3140	2	277	300	0	639	4955	1110	437	164	0.6969	300
87	7305	165	43	21	1	3.8	866	0	313	10471	51669	0.0061	0.9774	0.2606	2	244	313	0	664	5040	1092	356	153	0.7503	313
61	7305	187	55	28	1	3.4	847	2	277	15247	51887	0.0053	0.9744	0.2941	1	277	277	0	633	4956	1122	423	171	0.7150	277
52	7305	181	56	26	1	3.2	855	0	287	14629	51916	0.0055	0.9752	0.3094	2	261	287	0	636	4905	1164	434	166	0.7005	287
83	7305	176	48	24	1	3.7	850	5	298	15074	52367	0.0057	0.9759	0.2727	2	314	298	0	630	4957	1117	438	163	0.7373	298
97	7305	168	51	17	1	3.3	919	3	313	14737	52629	0.0060	0.9770	0.3036	3	289	313	0	630	4994	1138	391	152	0.7080	313
24	7305	170	50	19	1	3.4	851	3	311	13472	52816	0.0059	0.9767	0.2941	2	269	311	0	636	4964	1201	348	156	0.7171	311
53	7305	175	54	16	1	3.2	853	1	304	15595	53161	0.0057	0.9760	0.3086	3	289	304	0	628	4912	1144	460	161	0.7024	304
86	7305	167	49	23	1	3.4	843	6	319	13103	53254	0.0060	0.9771	0.2934	2	267	319	0	652	4920	1125	452	156	0.7184	319
43	7305	171	56	24	1	3.1	879	0	312	14931	53371	0.0058	0.9766	0.3275	2	267	312	0	627	4966	1105	458	149	0.6844	312
78	7305	164	40	43	1	4.1	851	1	328	10022	53753	0.0061	0.9775	0.2439	1	251	328	0	651	4937	1167	402	148	0.7677	328
98	7305	186	55	17	1	3.4	854	1	291	16840	54130	0.0054	0.9745	0.2957	2	306	291	0	632	4976	1085	443	169	0.7143	291
79	7305	181	60	12	1	3.0	900	1	300	14333	54214	0.0055	0.9752	0.3315	3	239	300	0	622	4997	1079	440	167	0.6796	300
48	7305	168	45	17	1	3.7	852	0	323	14180	54275	0.0060	0.9770	0.2679	3	315	323	0	668	4889	1168	419	161	0.7438	323
42	7305	164	50	21	1	3.3	850	0	333	15425	54673	0.0061	0.9775	0.3049	2	309	333	0	622	4957	1160	414	152	0.7082	333
69	7305	186	62	25	1	3.0	882	2	296	17066	55119	0.0054	0.9745	0.3333	2	275	296	0	635	4941	1157	399	173	0.6776	296
30	7305	184	61	19	1	3.0	892	0	301	18629	55368	0.0054	0.9748	0.3315	2	305	301	0	646	4961	1117	412	169	0.6797	301
6	7305	178	52	17	1	3.4	853	5	311	15850	55384	0.0056	0.9756	0.2921	2	305	311	0	633	4969	1170	367	166	0.7191	311
14	7305	158	44	19	1	3.6	860	1	351	13707	55395	0.0063	0.9784	0.2785	2	312	351	0	613	4974	1165	408	145	0.7353	351

73	7305	177	53	14	1	3.3	856	0	314	13427	55631	0.0056	0.9758	0.2994	3	253	314	0	621	5009	1115	394	166	0.7122	314
3	7305	198	63	17	1	3.1	855	0	282	18050	55837	0.0051	0.9729	0.3182	2	287	282	0	602	4930	1150	443	180	0.6916	282
32	7305	179	45	27	1	4.0	857	8	313	12549	56049	0.0056	0.9755	0.2514	2	279	313	0	629	4957	1194	355	170	0.7594	313
92	7305	184	43	16	1	4.3	849	5	305	14108	56069	0.0054	0.9748	0.2337	2	328	305	0	614	5026	1130	361	174	0.7763	305
35	7305	170	58	14	1	2.9	888	0	332	16605	56441	0.0059	0.9767	0.3412	3	286	332	0	660	4887	1163	440	155	0.6725	332
28	7305	185	60	18	1	3.1	853	0	307	17164	56812	0.0054	0.9747	0.3243	2	286	307	0	611	4914	1184	426	170	0.6872	307
9	7305	188	55	12	1	3.4	845	2	303	18121	56996	0.0053	0.9743	0.2926	3	329	303	0	645	4947	1119	425	169	0.7182	303
54	7305	201	57	28	1	3.5	853	1	285	14410	57299	0.0050	0.9725	0.2836	1	253	285	0	630	5010	1099	380	186	0.7260	285
66	7305	201	63	18	1	3.2	837	0	289	18136	58064	0.0050	0.9725	0.3134	2	288	289	0	637	4943	1120	420	185	0.6968	289
51	7305	168	40	39	1	4.2	876	4	348	11113	58490	0.0060	0.9770	0.2381	1	278	348	0	621	5010	1141	374	159	0.7749	348
91	7305	174	43	17	1	4.0	853	1	336	13711	58502	0.0057	0.9762	0.2471	2	319	336	0	639	4930	1199	380	157	0.7652	336
5	7305	203	50	18	1	4.1	845	2	299	16187	60686	0.0049	0.9722	0.2463	2	324	299	0	636	4967	1152	363	187	0.7636	299
44	7305	184	53	19	1	3.5	895	2	333	16289	61272	0.0054	0.9748	0.2880	2	307	333	0	644	5007	1059	431	164	0.7247	333
50	7305	190	49	21	1	3.9	883	2	324	15265	61498	0.0053	0.9740	0.2579	2	312	324	0	652	4935	1127	416	175	0.7538	324
13	7305	179	41	23	1	4.4	870	2	344	13310	61571	0.0056	0.9755	0.2291	2	325	344	0	662	4927	1169	381	166	0.7835	344
96	7305	188	44	18	1	4.3	907	1	331	15118	62157	0.0053	0.9743	0.2340	2	344	331	0	644	4969	1155	363	174	0.7777	331
60	7305	193	50	30	1	3.9	851	1	325	13312	62689	0.0052	0.9736	0.2591	1	266	325	0	656	4928	1142	402	177	0.7527	325
67	7305	181	45	30	1	4.0	852	1	347	14897	62749	0.0055	0.9752	0.2486	1	331	347	0	630	4914	1172	419	170	0.7645	347
25	7305	206	60	21	1	3.4	879	1	305	16222	62755	0.0049	0.9718	0.2913	2	270	305	0	632	4960	1116	412	185	0.7197	305
57	7305	200	57	16	1	3.5	851	1	315	17646	62947	0.0050	0.9726	0.2850	2	310	315	0	633	4911	1171	406	184	0.7265	315
59	7305	208	54	14	1	3.9	854	1	303	18907	63013	0.0048	0.9715	0.2596	3	350	303	0	620	4956	1147	391	191	0.7508	303
77	7305	214	60	24	1	3.6	845	1	297	17410	63644	0.0047	0.9707	0.2804	1	290	297	0	671	4897	1095	448	194	0.7300	297
22	7305	187	42	31	1	4.5	922	0	343	13166	64067	0.0053	0.9744	0.2246	1	313	343	0	647	4992	1100	390	176	0.7878	343
89	7305	197	49	34	1	4.0	927	2	327	13918	64404	0.0051	0.9730	0.2487	1	284	327	0	639	5021	1078	383	184	0.7630	327
1	7305	182	45	30	1	4.0	856	2	359	13933	65311	0.0055	0.9751	0.2473	1	310	359	0	628	4982	1140	383	172	0.7667	359
70	7305	178	43	33	1	4.1	872	1	367	12062	65350	0.0056	0.9756	0.2416	1	281	367	0	631	4996	1094	414	170	0.7729	367
21	7305	200	46	33	1	4.3	853	2	327	16523	65396	0.0050	0.9726	0.2300	1	359	327	0	627	4883	1162	443	190	0.7815	327
68	7305	201	54	18	1	3.7	859	3	325	17350	65402	0.0050	0.9725	0.2687	2	321	325	0	622	4891	1166	435	191	0.7433	325
49	7305	222	53	26	1	4.2	855	2	295	15154	65439	0.0045	0.9696	0.2387	1	286	295	0	629	4933	1143	396	204	0.7709	295
10	7305	190	46	30	1	4.1	890	1	346	14695	65797	0.0053	0.9740	0.2421	1	319	346	0	620	5000	1123	382	180	0.7709	346
31	7305	202	60	16	1	3.4	910	2	326	18632	65852	0.0050	0.9723	0.2970	2	311	326	0	611	4948	1192	364	190	0.7155	326
15	7305	189	53	21	1	3.6	855	2	349	16099	65920	0.0053	0.9741	0.2804	2	304	349	0	643	4919	1175	394	174	0.7334	349
12	7305	200	46	35	1	4.3	895	4	335	12535	67006	0.0050	0.9726	0.2300	1	272	335	0	648	4928	1111	425	193	0.7821	335
63	7305	184	34	32	1	5.4	846	8	364	10853	67045	0.0054	0.9748	0.1848	1	319	364	0	618	5007	1136	364	180	0.8285	364
34	7305	195	53	33	1	3.7	857	0	347	15120	67668	0.0051	0.9733	0.2718	1	285	347	0	636	4952	1149	382	186	0.7418	347
82	7305	213	55	25	1	3.9	863	1	324	15994	69079	0.0047	0.9708	0.2582	1	291	324	0	645	4924	1126	412	198	0.7536	324
37	7305	212	56	52	1	3.8	857	1	332	13561	70459	0.0047	0.9710	0.2642	1	242	332	0	667	4850	1149	440	199	0.7483	332
75	7305	215	57	20	1	3.8	872	3	330	18287	70949	0.0047	0.9706	0.2651	2	321	330	0	647	4874	1163	422	199	0.7472	330
80	7305	219	53	24	1	4.1	924	2	334	14885	73181	0.0046	0.9700	0.2420	1	281	334	0	619	5014	1065	406	201	0.7703	334
46	7305	211	53	33	1	4.0	883	1	347	16982	73187	0.0047	0.9711	0.2512	1	320	347	0	645	4978	1125	364	193	0.7621	347
45	7305	223	49	29	1	4.6	854	1	330	15401	73585	0.0045	0.9695	0.2197	1	314	330	0	645	4959	1121	372	208	0.7919	330
85	7305	231	60	19	1	3.9	873	0	319	18253	73634	0.0043	0.9684	0.2597	2	304	319	0	607	4977	1059	450	212	0.7518	319
99	7305	207	51	40	1	4.1	898	2	371	13840	76773	0.0048	0.9717	0.2464	1	271	371	0	640	4952	1149	368	196	0.7686	371
Minimum		129	34	11	1	2.6	590	0	219	10022	30408	0.0043	0.9684	0.1848	1	215	219	0	598	4850	1059	348	115	0.6269	219
Average		180	51	22	1	3.5	861	2	304	14658	54961	0.0056	0.9754	0.2875	2	287	304	0	636	4955	1141	408	165	0.7233	304
Maximum		231	66	52	1	5.4	927	8	371	18907	76773	0.0078	0.9823	0.3836	4	359	371	0	671	5040	1206	470	212	0.8285	371
Std.dev		20.1	6.1	7.7	0	0.5	36.8	1.8	30.9	1987.9	9569.6	0.0006	0.0028	0.0379	0.8	28.6	30.9	0.0	16.0	39.7	35.0	28.9	19.9	0.0388	31

Scenerio N Scenario 14b CSIROMk2b B11 with 15% additioanl WEMPs savings
Date: 13/10/2007
Simulation 9:11:37 PM
Simulation 10:04:50 PM
Elapsed Tii 53.22 Minutes

		Σ Z_t	Σ W_t	Max T_f	Min T_f	$E[T_f]$	Max S_i	Min S_i	Avg S_i	Ssj	Ssi	$e_j = 1/\Sigma Z_t$				v=Ssjej	v= Ssiei	no. of days with Demand							
Trial No.	Total no. of Days	No. of Days Failed	No. of Consecutive Failures	Max. Failure Duration	Min. Failure Duration	Avg. Failure Duration	Max Severity of Failure	Min Severity of Failure	Avg. Severity of a Failure	Total Maximum Severity of Sojourn	Total Severity of Failure	Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	Vulnerability 1	Vulnerability 2	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500	Eculidean Distance	Total Severity/no. of days with failure
4	7305	127	43	26	1	3.0	852	6	243	10432	30908	0.0079	0.9826	0.3386	2	243	243	0	641	5058	1098	389	119	0.6688	243
40	7305	142	44	18	1	3.2	485	2	226	9271	32085	0.0070	0.9806	0.3099	3	211	226	0	621	5091	1113	348	132	0.6963	226
81	7305	142	53	10	1	2.7	848	1	252	14079	35804	0.0070	0.9806	0.3732	5	266	252	0	631	5010	1093	445	126	0.6351	252
84	7305	141	55	11	1	2.6	858	4	259	13349	36543	0.0071	0.9807	0.3901	5	243	259	0	629	5042	1113	394	127	0.6190	259
36	7305	137	38	22	1	3.6	847	8	272	10075	37246	0.0073	0.9812	0.2774	2	265	272	0	597	4978	1222	383	125	0.7310	272
56	7305	122	39	16	1	3.1	853	7	306	10679	37298	0.0082	0.9833	0.3197	4	274	306	0	611	5071	1155	356	112	0.6914	306
38	7305	128	40	11	1	3.2	875	5	292	11798	37331	0.0078	0.9825	0.3125	5	295	292	0	652	4915	1199	426	113	0.6975	292
2	7305	134	47	18	1	2.9	844	2	286	11418	38267	0.0075	0.9817	0.3507	3	243	286	0	654	4992	1184	354	121	0.6595	286
41	7305	121	44	17	1	2.8	886	4	320	10038	38763	0.0083	0.9834	0.3636	4	228	320	0	629	5038	1140	391	107	0.6493	320
17	7305	146	45	14	1	3.2	845	2	267	10592	38971	0.0068	0.9800	0.3082	4	235	267	0	622	5004	1180	370	129	0.7003	267
76	7305	152	46	27	1	3.3	830	1	257	12995	39112	0.0066	0.9792	0.3026	2	283	257	0	614	5080	1099	376	136	0.7052	257
66	7305	138	51	19	1	2.7	835	0	287	12301	39653	0.0072	0.9811	0.3696	3	241	287	0	634	4994	1119	432	126	0.6411	287
11	7305	137	42	16	1	3.3	852	2	293	12676	40105	0.0073	0.9812	0.3066	3	302	293	0	657	4999	1172	350	127	0.7035	293
74	7305	147	47	14	1	3.1	848	1	278	12605	40890	0.0068	0.9799	0.3197	4	268	278	0	604	5088	1109	381	123	0.6896	278
26	7305	154	49	14	1	3.1	841	0	267	13649	41165	0.0065	0.9789	0.3182	3	279	267	0	631	4941	1178	413	142	0.6905	267
18	7305	152	44	17	1	3.5	877	2	278	11871	42203	0.0066	0.9792	0.2895	3	270	278	0	648	4961	1128	422	146	0.7195	278
88	7305	156	42	20	1	3.7	849	5	272	10572	42357	0.0064	0.9786	0.2692	2	252	272	0	638	5065	1116	336	150	0.7391	272
7	7305	154	48	29	1	3.2	843	0	277	14451	42614	0.0065	0.9789	0.3117	2	301	277	0	624	4994	1146	399	142	0.6975	277
71	7305	152	46	13	1	3.3	847	1	282	13379	42908	0.0066	0.9792	0.3026	4	291	282	0	638	4941	1188	397	141	0.7068	282
27	7305	129	42	23	1	3.1	850	6	334	11699	43070	0.0078	0.9823	0.3256	2	279	334	0	612	5142	1090	337	124	0.6877	334
62	7305	133	39	13	1	3.4	852	1	324	12204	43086	0.0075	0.9818	0.2932	4	313	324	0	627	4905	1203	451	119	0.7188	324
69	7305	146	47	20	1	3.1	845	5	296	13667	43148	0.0068	0.9800	0.3219	3	291	296	0	628	5086	1085	368	138	0.6886	296
58	7305	156	47	40	1	3.3	853	6	278	11736	43341	0.0064	0.9786	0.3013	1	250	278	0	623	5062	1124	355	141	0.7078	278
87	7305	125	31	18	1	4.0	864	2	354	9197	44312	0.0080	0.9829	0.2480	3	297	354	0	646	4995	1171	376	117	0.7654	354
78	7305	146	40	18	1	3.7	851	1	306	12158	44616	0.0068	0.9800	0.2740	3	304	306	0	646	4986	1185	354	134	0.7365	306
55	7305	141	50	14	1	2.8	895	1	318	13161	44843	0.0071	0.9807	0.3546	4	263	318	0	657	4934	1143	445	126	0.6581	318
42	7305	135	44	14	1	3.1	854	4	333	12968	44918	0.0074	0.9815	0.3259	4	295	333	0	616	4951	1169	444	125	0.6873	333
100	7305	178	55	12	1	3.2	839	1	254	14684	45233	0.0056	0.9756	0.3090	3	267	254	0	648	4946	1135	426	150	0.6989	254
33	7305	161	51	16	1	3.2	860	4	287	13140	46214	0.0062	0.9780	0.3168	3	258	287	0	611	5039	1108	402	145	0.6932	287
47	7305	168	40	17	1	4.2	867	2	277	12338	46513	0.0060	0.9770	0.2381	3	308	277	0	626	4975	1153	400	151	0.7703	277
90	7305	155	48	24	1	3.2	850	0	303	12170	46918	0.0065	0.9788	0.3097	2	254	303	0	629	5016	1162	363	135	0.7012	303
16	7305	194	47	23	1	4.1	868	1	243	12196	47126	0.0052	0.9734	0.2423	2	259	243	0	611	5105	1030	385	174	0.7644	243
48	7305	159	46	18	1	3.5	850	1	296	11345	47135	0.0063	0.9782	0.2893	3	247	296	0	645	4991	1112	411	146	0.7208	296
64	7305	153	50	17	1	3.1	902	1	310	12646	47481	0.0065	0.9791	0.3268	3	253	310	0	621	4993	1121	436	134	0.6849	310
19	7305	176	49	28	1	3.6	848	6	272	14089	47841	0.0057	0.9759	0.2784	1	288	272	0	624	5146	1013	363	159	0.7301	272
14	7305	147	42	19	1	3.5	851	1	326	10953	47869	0.0068	0.9799	0.2857	3	261	326	0	598	5002	1136	430	139	0.7263	326
73	7305	151	45	13	1	3.4	847	2	318	12678	48049	0.0066	0.9793	0.2980	4	282	318	0	613	5031	1188	335	138	0.7137	318
59	7305	169	51	18	1	3.3	852	1	285	15023	48124	0.0059	0.9769	0.3018	2	295	285	0	622	5043	1108	375	157	0.7078	285
92	7305	147	29	19	1	5.1	850	8	327	8623	48140	0.0068	0.9799	0.1973	3	297	327	0	615	5054	1185	310	141	0.8136	327
91	7305	159	49	17	1	3.2	852	2	305	15230	48438	0.0063	0.9782	0.3082	3	311	305	0	644	4995	1163	362	141	0.7028	305
94	7305	186	62	28	1	3.0	845	1	261	13869	48566	0.0054	0.9745	0.3333	1	224	261	0	643	4959	1121	413	169	0.6753	261
72	7305	144	44	21	1	3.3	845	1	339	11636	48781	0.0069	0.9803	0.3056	2	264	339	0	651	4978	1165	380	131	0.7078	339
93	7305	155	45	34	1	3.4	868	3	319	14577	49513	0.0065	0.9788	0.2903	1	324	319	0	664	4965	1145	387	144	0.7214	319
98	7305	173	55	18	1	3.1	882	1	288	16616	49796	0.0058	0.9763	0.3179	2	302	288	0	624	5030	1064	441	146	0.6921	288
95	7305	192	46	34	1	4.2	840	7	259	13182	49807	0.0052	0.9737	0.2396	1	287	259	0	622	4971	1119	413	180	0.7679	259
79	7305	167	54	12	1	3.1	848	2	300	14107	50027	0.0060	0.9771	0.3234	4	261	300	0	616	5056	1085	393	155	0.6876	300
9	7305	174	59	12	1	2.9	847	1	288	17093	50051	0.0057	0.9762	0.3391	3	290	288	0	646	5039	1093	379	148	0.6713	288
20	7305	172	54	15	1	3.2	835	1	293	14743	50474	0.0058	0.9765	0.3140	3	273	293	0	646	5009	1096	395	159	0.6964	293
23	7305	172	44	29	1	3.9	879	1	295	11885	50676	0.0058	0.9765	0.2558	1	270	295	0	630	5013	1144	362	156	0.7538	295
86	7305	153	43	22	1	3.6	849	1	332	12666	50766	0.0065	0.9791	0.2810	2	295	332	0	632	5056	1082	389	146	0.7314	332
6	7305	173	53	16	1	3.3	853	1	295	14476	50969	0.0058	0.9763	0.3064	3	273	295	0	615	5103	1067	371	149	0.7040	295
43	7305	162	53	25	1	3.1	853	1	315	14016	50986	0.0062	0.9778	0.3272	2	264	315	0	640	4981	1124	418	142	0.6849	315
29	7305	173	47	25	1	3.7	846	12	297	15020	51337	0.0058	0.9763	0.2717	2	320	297	0	647	4997	1146	353	162	0.7383	297
61	7305	182	48	29	1	3.8	944	11	282	14634	51409	0.0055	0.9751	0.2637	1	305	282	0	656	4907	1174	401	167	0.7453	282
53	7305	172	52	15	1	3.3	892	3	300	15158	51575	0.0058	0.9765	0.3023	3	292	300	0	629	5046	1078	394	158	0.7083	300
52	7305	158	50	26	1	3.2	858	6	327	14302	51741	0.0063	0.9784	0.3165	2	286	327	0	644	4990	1104	419	148	0.6963	327
32	7305	178	45	30	1	4.0	850	2	291	12456	51833	0.0056	0.9756	0.2528	1	277	291	0	620	5057	1099	367	162	0.7566	291
83	7305	167	48	20	1	3.5	869	0	310	15180	51841	0.0060	0.9771	0.2874	2	316	310	0	619	5010	1161	362	153	0.7237	310
13	7305	169	46	17	1	3.7	936	2	307	14743	51923	0.0059	0.9769	0.2722	3	321	307	0	652	5006	1066	427	154	0.7385	307
3	7305	194	56	20	1	3.5	883	0	268	14963	51931	0.0052	0.9734	0.2887	2	267	268	0	614	4983	1084	447	177	0.7198	268
30	7305	178	60	16	1	3.0	882	5	292	17678	51953	0.0056	0.9756	0.3371	3	295	292	0	612	5013	1090	420	170	0.6736	292

54	7305	175	47	30	1	3.7	846	1	300	13479	52522	0.0057	0.9760	0.2686	1	287	300	0	622	5101	1059	359	164	0.7416	300
51	7305	157	41	39	1	3.8	852	1	336	11524	52808	0.0064	0.9785	0.2611	1	281	336	0	630	5084	1047	402	142	0.7513	336
24	7305	163	47	28	1	3.5	853	5	328	11741	53525	0.0061	0.9777	0.2883	2	250	328	0	630	5045	1115	367	148	0.7240	328
97	7305	183	54	18	1	3.4	860	0	293	14436	53665	0.0055	0.9749	0.2951	2	267	293	0	642	4971	1145	383	164	0.7151	293
82	7305	162	45	20	1	3.6	849	1	331	12864	53680	0.0062	0.9778	0.2778	2	286	331	0	622	4995	1197	337	154	0.7346	331
70	7305	170	44	27	1	3.9	884	3	317	11694	53917	0.0059	0.9767	0.2588	2	266	317	0	628	5045	1109	367	156	0.7523	317
50	7305	152	45	38	1	3.4	883	0	357	10863	54322	0.0066	0.9792	0.2961	1	241	357	0	634	4955	1152	421	143	0.7186	357
5	7305	178	37	20	1	4.8	845	3	311	12968	55314	0.0056	0.9756	0.2079	2	350	311	0	608	5039	1141	348	169	0.8022	311
44	7305	186	54	25	1	3.4	875	3	300	14304	55873	0.0054	0.9745	0.2903	2	265	300	0	630	4996	1160	357	162	0.7202	300
39	7305	194	50	17	1	3.9	850	0	288	16706	55935	0.0052	0.9734	0.2577	2	334	288	0	614	5056	1065	390	180	0.7516	288
77	7305	195	59	24	1	3.3	853	0	289	18955	56411	0.0051	0.9733	0.3026	2	321	289	0	663	4916	1117	428	181	0.7075	289
15	7305	169	49	22	1	3.4	855	1	334	13300	56495	0.0059	0.9769	0.2899	2	271	334	0	642	4959	1145	408	151	0.7229	334
49	7305	183	46	20	1	4.0	855	2	309	14490	56499	0.0055	0.9749	0.2514	2	315	309	0	627	5010	1178	322	168	0.7592	309
25	7305	189	57	16	1	3.3	856	5	300	17165	56739	0.0053	0.9741	0.3016	2	301	300	0	624	4993	1130	379	179	0.7091	300
21	7305	183	56	21	1	3.3	853	1	313	15104	57292	0.0055	0.9749	0.3060	2	270	313	0	623	4958	1156	395	173	0.7056	313
35	7305	185	54	27	1	3.4	888	1	310	15313	57317	0.0054	0.9747	0.2919	1	284	310	0	648	4993	1041	460	163	0.7193	310
34	7305	169	43	27	1	3.9	851	13	340	13114	57469	0.0059	0.9769	0.2544	2	305	340	0	626	5002	1148	368	161	0.7582	340
60	7305	171	46	38	1	3.7	850	2	337	11105	57550	0.0058	0.9766	0.2690	1	241	337	0	659	4975	1131	380	160	0.7437	337
1	7305	140	30	27	1	4.7	1090	3	412	9875	57624	0.0071	0.9808	0.2143	2	329	412	0	630	5021	1164	356	134	0.8030	412
8	7305	179	45	19	1	4.0	864	2	325	14608	58157	0.0056	0.9755	0.2514	2	325	325	0	621	5094	1094	331	165	0.7602	325
57	7305	192	56	34	1	3.4	855	1	304	15985	58458	0.0052	0.9737	0.2917	1	285	304	0	634	4989	1115	391	176	0.7192	304
65	7305	196	44	25	1	4.5	866	2	300	15376	58729	0.0051	0.9732	0.2245	1	349	300	0	651	5010	1045	422	177	0.7852	300
80	7305	194	51	26	1	3.8	900	1	306	13276	59412	0.0052	0.9734	0.2629	1	260	306	0	613	5003	1092	418	179	0.7477	306
68	7305	172	43	18	1	4.0	855	3	346	14804	59427	0.0058	0.9765	0.2500	2	344	346	0	634	5034	1077	394	166	0.7630	346
22	7305	165	36	39	1	4.6	894	7	360	10598	59429	0.0061	0.9774	0.2182	1	294	360	0	642	4928	1205	374	156	0.7953	360
28	7305	184	58	25	1	3.2	856	1	324	15711	59668	0.0054	0.9748	0.3152	2	271	324	0	588	5106	1059	379	173	0.6974	324
12	7305	180	49	21	1	3.7	854	4	332	12790	59818	0.0056	0.9754	0.2722	2	261	332	0	627	5005	1129	371	173	0.7402	332
67	7305	171	46	21	1	3.7	850	1	352	14364	60162	0.0058	0.9766	0.2690	2	312	352	0	645	5005	1090	408	157	0.7448	352
96	7305	175	42	18	1	4.2	887	1	345	13325	60339	0.0057	0.9760	0.2400	2	317	345	0	651	5050	1052	390	162	0.7728	345
31	7305	186	51	22	1	3.6	884	0	325	14248	60405	0.0054	0.9745	0.2742	2	279	325	0	602	5060	1150	320	173	0.7378	325
46	7305	199	45	31	1	4.4	897	4	313	11903	62211	0.0050	0.9728	0.2261	1	265	313	0	641	5030	1075	377	182	0.7844	313
10	7305	180	44	22	1	4.1	865	0	346	13545	62306	0.0056	0.9754	0.2444	2	308	346	0	613	5046	1103	376	167	0.7685	346
63	7305	178	38	23	1	4.7	850	2	354	11384	63032	0.0056	0.9756	0.2135	2	300	354	0	626	5060	1129	323	167	0.7995	354
89	7305	232	60	29	1	3.9	856	0	280	17932	64996	0.0043	0.9682	0.2586	1	299	280	0	635	5088	995	378	209	0.7505	280
37	7305	190	45	60	1	4.2	856	1	361	11225	68607	0.0053	0.9740	0.2368	1	249	361	0	660	4864	1224	381	176	0.7771	361
85	7305	191	45	29	1	4.2	887	4	364	15047	69455	0.0052	0.9739	0.2356	1	334	364	0	617	4959	1112	434	183	0.7786	364
75	7305	215	60	27	1	3.6	853	2	334	16827	71790	0.0047	0.9706	0.2791	1	280	334	0	646	4939	1038	482	200	0.7338	334
45	7305	225	47	38	1	4.8	873	0	323	12283	72639	0.0044	0.9692	0.2089	1	261	323	0	633	5018	1137	317	200	0.8022	323
99	7305	218	49	25	1	4.4	852	4	336	15314	73314	0.0046	0.9702	0.2248	1	313	336	0	633	5035	1062	371	204	0.7874	336
Minimum		121	29	10	1	2.6	485	0	226	8623	30908	0.0043	0.9682	0.1973	1	211	226	0	588	4864	995	310	107	0.6190	226
Average		166	47	22	1	3.6	859	3	306	13307	50839	0.0061	0.9772	0.2869	2	282	306	0	631	5013	1122	387	153	0.7240	306
Maximum		232	62	60	1	5.1	1090	13	412	18955	73314	0.0083	0.9834	0.3901	5	350	412	0	664	5146	1224	482	209	0.8136	412
Std.dev		22.6	6.4	8.0	0	0.5	48.3	2.5	31.2	2026.2	8755.7	0.0008	0.0031	0.0391	0.9	28.5	31.2	0.0	15.8	53.3	47.1	34.7	21.3	0.0395	31

Scenerio N Scenario 14c CSIROMk2b B11 with 15% additional WEMPs savings Higher population projection and change of precipitation frequency of occurrence
Date: 19/10/2007
Simulation 9:56:04 PM
Simulation 12:14:27 AM
Elapsed Tiı -1301.62 Minutes

Trial No.	Total no. of Days	ΣZ_t No. of Days Failed	ΣW_t No. of Consecutive Failures	Max T_f Max. Failure Duration	Min T_f Min. Failure Duration	$E[T_f]$ Avg. Failure Duration	Max S_i Max Severity of Failure	Min S_i Min Severity of Failure	Ssi Total Severity of Failure	Ssj Total Maximum Severity of Sojourn	$e_j = 1/\Sigma Z_t$ Prob. [Correspond to S_j]	Reliability, α	Resiliency, $F(E[T_f])$	Resiliency, 1/(MD/NS*NF)	v=Ssjej Vulnerability 1	v= Ssiei Vulnerability 2
1	7305	556	113	53	1	4.9	1862	1	302175	52319	0.0018	0.9239	0.2032	0.25	463	543
2	7305	541	138	34	1	3.9	1846	1	253067	59009	0.0018	0.9259	0.2551	0.40	428	468
3	7305	613	145	51	1	4.2	1863	2	317842	68653	0.0016	0.9161	0.2365	0.23	473	519
4	7305	496	113	54	1	4.4	1859	3	231198	56016	0.0020	0.9321	0.2278	0.27	496	466
5	7305	519	110	44	1	4.7	1849	0	294930	55516	0.0019	0.9290	0.2119	0.32	505	568
6	7305	506	124	31	1	4.1	1860	1	276458	59268	0.0020	0.9307	0.2451	0.47	478	546
7	7305	520	122	48	1	4.3	1746	1	249845	53230	0.0019	0.9288	0.2346	0.29	436	480
8	7305	543	121	48	1	4.5	1858	0	283751	57955	0.0018	0.9257	0.2228	0.28	479	523
9	7305	558	125	39	1	4.5	1849	1	292733	55702	0.0018	0.9236	0.2240	0.34	446	525
10	7305	543	103	59	1	5.3	1908	0	314374	49537	0.0018	0.9257	0.1897	0.23	481	579
11	7305	510	124	46	1	4.1	1874	1	260928	55044	0.0020	0.9302	0.2431	0.31	444	512
12	7305	551	116	47	1	4.8	1913	1	300939	54995	0.0018	0.9246	0.2105	0.28	474	546
13	7305	531	112	52	1	4.7	1882	2	288393	47803	0.0019	0.9273	0.2109	0.26	427	543
14	7305	506	120	43	1	4.2	1867	1	264345	52424	0.0020	0.9307	0.2372	0.34	437	522
15	7305	534	116	39	1	4.6	1863	2	316633	58055	0.0019	0.9269	0.2172	0.35	500	593
16	7305	525	121	74	1	4.3	1904	2	255335	52150	0.0019	0.9281	0.2305	0.19	431	486
17	7305	524	109	45	1	4.8	1855	0	269321	52936	0.0019	0.9283	0.2080	0.31	486	514
18	7305	532	122	31	1	4.4	1866	0	274296	59205	0.0019	0.9272	0.2293	0.44	485	516
19	7305	553	109	77	1	5.1	1947	2	280738	48151	0.0018	0.9243	0.1971	0.17	442	508
20	7305	524	111	60	1	4.7	1839	0	278064	53266	0.0019	0.9283	0.2118	0.23	480	531
21	7305	594	119	39	1	5.0	1860	1	327314	56886	0.0017	0.9187	0.2003	0.32	478	551
22	7305	564	112	60	1	5.0	1947	1	305733	55134	0.0018	0.9228	0.1986	0.22	492	542
23	7305	525	109	65	1	4.8	1893	1	270178	47818	0.0019	0.9281	0.2076	0.21	439	515
24	7305	504	109	50	1	4.6	1858	0	266804	54784	0.0020	0.9310	0.2163	0.29	503	529
25	7305	542	110	38	1	4.9	1892	1	310042	55880	0.0018	0.9258	0.2030	0.35	508	572
26	7305	572	114	60	1	5.0	1845	0	291325	56351	0.0017	0.9217	0.1993	0.21	494	509
27	7305	515	115	51	1	4.5	1856	1	265827	56218	0.0019	0.9295	0.2233	0.28	489	516
28	7305	550	112	55	1	4.9	1859	0	303850	55291	0.0018	0.9247	0.2036	0.24	494	552
29	7305	570	127	50	1	4.5	1859	1	298636	62184	0.0018	0.9220	0.2228	0.26	490	524
30	7305	569	115	46	1	4.9	1908	1	309682	61331	0.0018	0.9221	0.2021	0.28	533	544
31	7305	513	113	67	1	4.5	1933	1	311319	61554	0.0019	0.9298	0.2203	0.21	545	607
32	7305	500	110	38	1	4.5	1864	1	266421	53900	0.0020	0.9316	0.2200	0.38	490	533
33	7305	565	99	46	1	5.7	1878	3	302773	52191	0.0018	0.9227	0.1752	0.28	527	536
34	7305	524	115	47	1	4.6	1862	0	309341	58305	0.0019	0.9283	0.2195	0.30	507	590
35	7305	575	115	32	1	5.0	1904	3	303534	61675	0.0017	0.9213	0.2000	0.40	536	528
36	7305	552	116	56	1	4.8	1851	1	273286	56202	0.0018	0.9244	0.2101	0.24	485	495
37	7305	599	123	60	1	4.9	1864	0	339925	57305	0.0017	0.9180	0.2053	0.20	466	567
38	7305	556	117	37	1	4.8	1857	8	255666	53741	0.0018	0.9239	0.2104	0.36	459	460
39	7305	532	112	71	1	4.8	1860	0	280414	51732	0.0019	0.9272	0.2105	0.19	462	527
40	7305	477	115	41	1	4.1	1521	0	224083	49397	0.0021	0.9347	0.2411	0.37	430	470
41	7305	463	107	28	1	4.3	1891	0	239294	54939	0.0022	0.9366	0.2311	0.56	513	517
42	7305	528	107	44	1	4.9	1855	3	277053	52406	0.0019	0.9277	0.2027	0.31	490	525
43	7305	607	123	60	1	4.9	1894	0	322514	59727	0.0016	0.9169	0.2026	0.20	486	531
44	7305	547	108	33	1	5.1	1912	1	311391	57333	0.0018	0.9251	0.1974	0.40	531	569
45	7305	537	107	66	1	5.0	1860	0	325251	47606	0.0019	0.9265	0.1993	0.21	445	606
46	7305	525	100	50	1	5.3	1900	4	332953	54862	0.0019	0.9281	0.1905	0.28	549	634
47	7305	515	114	62	1	4.5	1853	1	280098	54114	0.0019	0.9295	0.2214	0.23	475	544

48	7305	551	113	43	1	4.9	1857	1	299727	60362	0.0018	0.9246	0.2051	0.31	534	544
49	7305	574	111	87	1	5.2	1862	1	321447	49843	0.0017	0.9214	0.1934	0.15	449	560
50	7305	575	132	43	1	4.4	1897	2	306166	59477	0.0017	0.9213	0.2296	0.30	451	532
51	7305	511	113	52	1	4.5	1889	0	284952	46910	0.0020	0.9300	0.2211	0.27	415	558
52	7305	568	112	67	1	5.1	1862	0	300060	54682	0.0018	0.9222	0.1972	0.19	488	528
53	7305	559	110	28	1	5.1	1859	1	297627	56285	0.0018	0.9235	0.1968	0.47	512	532
54	7305	517	104	56	1	5.0	1860	0	303216	49740	0.0019	0.9292	0.2012	0.25	478	586
55	7305	547	139	45	1	3.9	1884	3	267582	58766	0.0018	0.9251	0.2541	0.30	423	489
56	7305	532	126	45	1	4.2	1900	2	272321	54954	0.0019	0.9272	0.2368	0.31	436	512
57	7305	550	117	35	1	4.7	1858	0	310980	61955	0.0018	0.9247	0.2127	0.38	530	565
58	7305	530	124	59	1	4.3	1844	0	259380	57304	0.0019	0.9274	0.2340	0.23	462	489
59	7305	558	97	38	1	5.8	1861	3	326019	57310	0.0018	0.9236	0.1738	0.34	591	584
60	7305	553	120	59	1	4.6	1858	2	303859	55522	0.0018	0.9243	0.2170	0.22	463	549
61	7305	548	100	44	1	5.5	1851	1	289526	52903	0.0018	0.9250	0.1825	0.30	529	528
62	7305	579	126	38	1	4.6	1848	2	289313	55114	0.0017	0.9207	0.2176	0.33	437	500
63	7305	530	132	35	1	4.0	1851	1	299266	54520	0.0019	0.9274	0.2491	0.39	413	565
64	7305	481	111	32	1	4.3	1927	1	259657	54213	0.0021	0.9342	0.2308	0.47	488	540
65	7305	589	114	39	1	5.2	1849	4	305218	56059	0.0017	0.9194	0.1935	0.32	492	518
66	7305	578	95	52	1	6.1	1841	1	307138	51191	0.0017	0.9209	0.1644	0.24	539	531
67	7305	571	115	52	1	5.0	1858	0	314845	59606	0.0018	0.9218	0.2014	0.25	518	551
68	7305	594	111	58	1	5.4	1864	1	328655	53400	0.0017	0.9187	0.1869	0.21	481	553
69	7305	557	110	39	1	5.1	1896	0	313753	59236	0.0018	0.9238	0.1975	0.34	539	563
70	7305	562	118	66	1	4.8	1885	3	301042	49634	0.0018	0.9231	0.2100	0.20	421	536
71	7305	561	105	57	1	5.3	1846	4	276783	47557	0.0018	0.9232	0.1872	0.23	453	493
72	7305	557	124	43	1	4.5	1853	1	271686	60104	0.0018	0.9238	0.2226	0.30	485	488
73	7305	523	110	54	1	4.8	1861	0	287578	50909	0.0019	0.9284	0.2103	0.26	463	550
74	7305	494	109	35	1	4.5	1891	10	269861	54478	0.0020	0.9324	0.2206	0.42	500	546
75	7305	585	121	45	1	4.8	1883	0	341091	64331	0.0017	0.9199	0.2068	0.28	532	583
76	7305	540	102	45	1	5.3	1852	2	270455	52607	0.0019	0.9261	0.1889	0.30	516	501
77	7305	621	103	54	1	6.0	1849	0	348474	54431	0.0016	0.9150	0.1659	0.22	528	561
78	7305	524	116	58	1	4.5	1857	1	268231	47688	0.0019	0.9283	0.2214	0.24	411	512
79	7305	577	110	42	1	5.2	1920	2	302715	53961	0.0017	0.9210	0.1906	0.30	491	525
80	7305	579	108	68	1	5.4	1950	1	341458	51916	0.0017	0.9207	0.1865	0.19	481	590
81	7305	565	127	42	1	4.4	1847	2	267758	63430	0.0018	0.9227	0.2248	0.31	499	474
82	7305	581	113	52	1	5.1	1873	0	333007	55733	0.0017	0.9205	0.1945	0.24	493	573
83	7305	535	100	36	1	5.4	1856	1	281143	48660	0.0019	0.9268	0.1869	0.38	487	526
84	7305	579	136	55	1	4.3	1853	0	275537	59317	0.0017	0.9207	0.2349	0.23	436	476
85	7305	634	110	56	1	5.8	1889	1	358687	57817	0.0016	0.9132	0.1735	0.21	526	566
86	7305	562	112	56	1	5.0	1848	0	288640	52412	0.0018	0.9231	0.1993	0.23	468	514
87	7305	480	106	60	1	4.5	1878	1	255034	45277	0.0021	0.9343	0.2208	0.25	427	531
88	7305	543	113	40	1	4.8	1855	2	275329	55063	0.0018	0.9257	0.2081	0.34	487	507
89	7305	548	110	54	1	5.0	1955	1	305475	56135	0.0018	0.9250	0.2007	0.25	510	557
90	7305	556	141	38	1	3.9	1907	0	277717	58646	0.0018	0.9239	0.2536	0.35	416	499
91	7305	507	113	53	1	4.5	1858	0	277551	46175	0.0020	0.9306	0.2229	0.27	409	547
92	7305	517	101	52	1	5.1	1854	1	289328	51790	0.0019	0.9292	0.1954	0.27	513	560
93	7305	498	105	47	1	4.7	1879	3	250096	48949	0.0020	0.9318	0.2108	0.31	466	502
94	7305	590	128	49	1	4.6	1849	0	296303	59811	0.0017	0.9192	0.2169	0.25	467	502
95	7305	518	100	42	1	5.2	1856	1	280941	51026	0.0019	0.9291	0.1931	0.34	510	542
96	7305	529	116	85	1	4.6	1929	0	290569	51948	0.0019	0.9276	0.2193	0.16	448	549
97	7305	522	116	65	1	4.5	1944	1	275989	51927	0.0019	0.9285	0.2222	0.22	448	529
98	7305	558	121	28	1	4.6	1860	0	302815	59820	0.0018	0.9236	0.2168	0.47	494	543
99	7305	556	118	66	1	4.7	1915	0	334289	52801	0.0018	0.9239	0.2122	0.20	447	601
100	7305	520	100	58	1	5.2	1887	1	275497	49938	0.0019	0.9288	0.1923	0.24	499	530
Minimum		463	95	28	1	3.9	1521	0	224083	45277	0.0016	0.9132	0.1644	0.15	409	460
Average		545	115	50	1	4.8	1870	1	291419	54837	0.0018	0.9254	0.2109	0.29	480	535
Maximum		634	145	87	1	6.1	1955	10	358687	68653	0.0022	0.9366	0.2551	0.56	591	634
Std.dev		32.2	9.7	12.1	0	0.4	46.7	1.5	26233.0	4377.0	0.0001	0.0044	0.0190	0.08	37.0	33.9

Appendix D

Optimization Results

Improvement Cost, Z1	X1	X2	X3	X4	X5
Cost($ in K)	$187	$196.40	$215	$1,098.0	1695
System Performance, Z2					
Reliability	0.9970	0.9970	0.9972	0.9991	0.9998
Resiliency	0.5480	0.5502	0.5540	0.6832	0.8380
Vulnerability	0.0760	0.0754	0.0750	0.0596	0.0250
Euclidean distances	0.4584	0.4561	0.4523	0.3224	0.1639

Cost and Performance Weight the same

Best Solution		Worst Solution			
z1*=	-$187	z1**=	-$1,695	α1=	1.00
z2*=	-0.164	z2**=	-0.458	α2=	1.00

	Cost	Performance	z1*-z1(x)	z2*-z2(x)	s=	1	s=	2	s=	100
Alternative Implementation	Z1	Z2	z1*-z1**	z2*-z2**	Ls(x)	Rank	Ls(x)	Rank	Ls(x)	Rank
Alt. 1	-$187	-0.45835	0.00	1.00	1.000	3	1.000	4	1.000	4
Alt. 2	-$196	-0.45609	0.01	0.99	0.999	2	0.985	3	0.463	3
Alt. 3	-$215	-0.45231	0.02	0.98	0.998	1	0.960	2	0.126	2
Alt. 4	-$1,098	-0.32237	0.60	0.54	1.142	5	0.655	1	0.000	1
Alt. 5	-$1,695	-0.16393	1.00	0.00	1.000	3	1.000	4	1.000	4

Cost weights more

Best Solution		Worst Solution			
z1*=	-$187	z1**=	-$1,695	α1=	10.00
z2*=	-0.164	z2**=	-0.458	α2=	1.00

	Cost	Performance	z1*-z1(x)	z2*-z2(x)	s=	1	s=	2	s=	100
Alternative Implementation	Z1	Z2	z1*-z1**	z2*-z2**	Ls(x)	Rank	Ls(x)	Rank	Ls(x)	Rank
Alt. 1	-$187	-0.45835	0.00	1.00	1.000	1	1.000	3	1.000	4
Alt. 2	-$196	-0.45609	0.01	0.99	1.055	2	0.985	2	0.463	3
Alt. 3	-$215	-0.45231	0.02	0.98	1.166	3	0.963	1	0.126	2
Alt. 4	-$1,098	-0.32237	0.60	0.54	6.579	4	3.939	4	0.000	1
Alt. 5	-$1,695	-0.16393	1.00	0.00	10.000	5	10.000	5	10.000	5

Performance weights more

Best Solution		Worst Solution			
z1*=	-$187	z1**=	-$1,695	α1=	1.00
z2*=	-0.164	z2**=	-0.458	α2=	10.00

	Cost	Performance	z1*-z1(x)	z2*-z2(x)	s=	1	s=	2	s=	100
Alternative Implementation	Z1	Z2	z1*-z1**	z2*-z2**	Ls(x)	Rank	Ls(x)	Rank	Ls(x)	Rank
Alt. 1	-$187	-0.45835	0.00	1.00	10.000	5	10.000	5	10.000	5
Alt. 2	-$196	-0.45609	0.01	0.99	0.999	2	9.847	4	4.625	4
Alt. 3	-$215	-0.45231	0.02	0.98	0.998	1	9.594	3	1.258	3
Alt. 4	-$1,098	-0.32237	0.60	0.54	1.142	4	3.261	2	0.000	1
Alt. 5	-$1,695	-0.16393	1.00	0.00	1.000	3	1.000	1	1.000	2