EVALUATION OF PERFORMANCE AND OPTIMUM VALVE SETTINGS FOR PRESSURE MANAGEMENT USING FORECASTED DAILY DEMAND CURVES BY ARTIFICIAL NEURAL NETWORKS

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EVALUATION OF PERFORMANCE AND OPTIMUM VALVE SETTINGS FOR PRESSURE MANAGEMENT USING FORECASTED DAILY DEMAND CURVES BY ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

EVALUATION OF PERFORMANCE AND OPTIMUM VALVE SETTINGS FOR PRESSURE MANAGEMENT USING FORECASTED DAILY DEMAND CURVES BY ARTIFICIAL NEURAL NETWORKS

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For the appropriate operation and correct short term planning, daily demand curve (DDC) of municipal water distribution networks should be forecasted beforehand. For that purpose, artificial neural networks (ANN) is used as a new method. The proposed approach employs already recorded DDCs extracted from the database of ASKI (Ankara Water Authority) SCADA center and related independent parameters such as temperature and relative humidity obtained from DMI (State Meteorological Institute). In this study, a computer model was developed in order to forecast hourly DDCs using Matlab and related modules.

Parameters that affect the consumption of the water were determined as temperature, relative humidity, human behavior (weekend or workday) and season. Randomly selected days were taken into account for performance of the ANN model. Forecasted DDC values were compared with recorded data and consequently the model gives relatively satisfactory results, an average of 75% match according to R^2 values for Ankara N8-3 network. Same architecture was applied for Antalya network give better results, average of 85%. For planning purposes; total volume and peak water consumption values for the selected recorded days, the day before recorded days, ANN forecasted days and seasonal average was compared and seasonal average gave relatively better results. Using the forecasted DDC, (i) performance analysis of the pressure zone and (ii) optimum valve setting evaluation for pressure management were realized.

The results of the study may help water utilities for short term planning of a water distribution network, rehabilitation of elements, taking counter measures and setting the valve openings for minimizing leakage and optimizing customer conformity of the distribution network.

Keywords: Artificial Neural Networks, Forecasting of DDC, Optimum Valve Settings, Pressure Management, Performance Evaluation

ÖZ

İÇMESUYU ŞEBEKELERİNDE YAPAY SİNİR AĞLARI KULLANILARAK HARCAMA EĞRİSİ TAHMİNİ İLE PERFORMANS TAYİNİ VE KAÇAKLARI EN DÜŞÜK SEVİYEDE TUTMAK İÇİN OPTİMUM VANA OPTİMİZASYONU

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Su dağıtım şebekelerini doğru bir şekilde işletmek ve kısa vadeli planlama yapabilmek için, günlük su harcama eğrisi (GSHE) önceden tahmin edilebilmelidir. Bu çalışmada Yapay Sinir Ağları (YSA) kullanılarak önceden kaydedilmiş GSHE'lerin ASKİ (Ankara Su ve Kanalizasyon İşletmesi) SCADA merkezi'nden temin edilmesi ve DMİ (Devlet Meteoroloji İşleri Genel Müdürlüğü)'den hava sıcaklığı ve bağıl nem gibi ilgili bağımsız parametreler kullanılarak oluşturulan bir tahmin mimarisi önerilmektedir. Çalışmada yapılacak hesaplamalar için Matlab ve ilgili modüller kullanılarak saatlik GSHE tahmin etmek için bir bilgisayar modeli geliştirilmiştir.

Literatürde yapılan araştırmalar sonucunda sıcaklık, bağıl nem, su kullanımı (hafta sonu veya iş günü) ve mevsim su tüketimini etkileyen parametreler olarak bu çalışma için belirlenmiştir. YSA modelinin performansını ölçmek için ASKİ ve DMİ verilerinin içerisinden rasgele günler seçilmiş ve tahmin edilen GSHE değerleri ile kaydedilmiş olan GSHE değerleri hesaplanarak belirlilik katsayısı (R^2) gözönüne alınarak karşılaştırılmışlardır. Ankara N8-3 basınç bölgesinde elde edilen sonuçlara gore ortalama %75 tahmin performansı ile tatmin edici sonuç vermiş, aynı modelin Antalya basınç bölgesindeki sonucu ise % 85 olarak hesaplanmıştır. Planlama hizmetlerinde kullanılmak üzere seçilen günler için toplam hacim ve pik su tüketimi değerleri, kaydedilen gün, kaydedilenden daha önceki gün, YSA tahmini, ve mevsimlik ortalama hesaplanarak kaydedilen gün ile karşılaştırılmıştır. Tahmin edilen GSHE ile (i) performans analizi ve (ii) basınç yönetimi için optimum vana ayarı çalışmaları da yapılmıştır.

Çalışmanın sonuçlarına göre kısa dönem planlama ihtiyaçlarının tahmini, şebeke elemanlarının performans artırımı için rehabilitasyonu, optimum vana açıklıkları ile kaçağı en aza indirmek ve abonelerden gelecek şikayetleri azaltmak için hazırlanacak bir rehberin işletmelere faydalı olacağı önerilmektedir.

Anahtar Kelimeler: Yapay Sinir Ağları, Günlük Harcama Eğrisi Tahmini, Optimum Vana Açıklığı, Basınç Yönetimi, Performans Değerlendirmesi

To my family,

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X_i	input variable
W_i	synaptic weights, connection weight
θ	Threshold
A	actual recorded values
F	forecasted values
$\overline{R}$	average of recorded values
$\overline{F}$	average of forecasted values
n	number of records in a day
H_j^{avl}	available nodal head at node j
H_j^{min}	minimum required nodal head at node j
q_j^{avl}	available discharge at node j
q_j^{req}	required discharge at node j
R_{nj}	Node Reliability Factor
R_v	Volume Reliability Factor
R_{nw}	Network Reliability Factor

F_t	Time Factor
F_n	Node Factor
V_{js}^{avl}	available outflow volume for a state at node j
V_{js}^{req}	required outflow volume for a state at node j
t_s	time duration of state
s	State
J	Total number of demand nodes
T	period of analysis (= $\Sigma\ t_s$)
a_{js}	discharge ratio
$\overline{I}$	average flowrate incoming to the system for a period of time dt, m^3 /hr
$\overline{Q}$	average flowrate outgoing from the system for a period of time dt, m^3 /hr
dS	storage in the tank T53 for a period of dt, m^3
net	neural network
newff	feed forward MLP architecture
HL_i	number of hidden layers
O	number of output layers
AF_i	Activation function
TA	Training Algorithm
a	output of MLP network

CHAPTER 1

INTRODUCTION

1.1 General

A water distribution network is an interconnected collection of sources, pipes, and hydraulic control elements (e.g. pumps, valves, reservoirs, tanks) delivering water to consumers in prescribed quantities and at desired pressures. During its economic life, a water distribution network should provide the required quality and quantity of water at required pressures. The system must be able to supply water at adequate pressure even during unusual conditions, such as pipe breaks, mechanical failure of pumps and valves, power outages, malfunction of storage facilities, inaccurate demand projections. The possibility of occurrence of these events should be examined to determine the overall performance of the distribution system.

Any hydraulic calculation of a water distribution network depends on the availability of the characteristics of the network (pipe diameter, length, nodes, storage information, pump information) pressure zone information (altitude of storage facility, altitude of service nodes) and recorded data (flow passed through pump, elevation status change of storage) during its operation.

Water utilities monitor and operate the distribution networks using Supervisory Control and Data Acquisition (SCADA) systems. Information received from the devices on the network were transmitted through radio waves and stored in a relational database management system.

In general, water utilities and researches use recorded statistical data for the hydraulic analysis of distribution networks. Daily Demand Curves (DDCs), which reflect the water consumption of the subscribers, are the main input for the hydraulic analysis which can be obtained from the SCADA data for a selected day. On the other hand, any water utility use statistical analysis for the forecast of the short or long term DDC forecasting in order to schedule the new operational procedures, planning needs and take necessary precautions such as setting the flow control valve openings, storage facility operation, pump schedule management.

Water demand forecast models may have various time-steps: long (annual or decadal), medium (monthly to annual) or short term (hourly, daily, or weekly) (AWWA, 1996). Long-term models usually focus on forecasts for 10 or more years into the future. These models help utilities to determine long-term infrastructure or supply changes while considering variables such as changes in population, price structure, or climate change. While these forecasts are critical to future management, such forecasts are often highly uncertain. Unlike the long-term vision of the decadal model, the short-term model typically investigates periods of less than one year. These models may be used to examine the impacts of climate variability and planned seasonal operations or financial changes. Short-term models are often quite accurate, but may be plagued by unexpected changes in weather or sociologic factors (Kame’enui, 2003). Knowing the short term water consumption, total volume and peak values of a network will help utility for operational and maintenance schedule management while long term consumption will help for planning and design stages of the network. In other words, knowing the shape of the DDCs will give a utility operational advance and guidance while content of DDCs give planning needs and estimation of future hydraulic model.

In this study, a new approach of forecasting the short term hourly DDC for any pressure zone using Artificial Neural Networks (ANN) is presented. Forecasting the short term hourly DDC using ANN needs big amount of recorded data and a working, satisfactory model. SCADA records from the distribution network with the corresponding temperature and relative humidity information are used as an input for the ANN model. A computer program is implemented for the short-term hourly DDC forecast using Matlab-Neural Network Toolbox. Parameters that affect the consumption of the water were determined as temperature, relative humidity, human behavior and season (Stark, 2002).

Beyond the availability, the accuracy and sustainability of the SCADA and meteorological records has great importance for the building of data domain series of the DDCs. After the collection of the series, randomly selected days were taken into account for the assessment of the ANN performance. As the model gives relatively satisfactory results; total volume and peak water consumption values for the selected recorded days, the day before recorded days, ANN forecasted days and seasonal average was compared for N8-3 pressure zone, Ankara Water Distribution Network. The neural network architecture was applied to one of the pressure zone of the Antalya Water Distribution Network to check whether the model is forecasting satisfactorily or not.

Furthermore, leakage from a water distribution network is a significant problem for a water utility to handle for operational and performance point of view. The best practice for the utilities is seeking for the leakage points for maintenance and repair. However, utilities sometimes change the operational procedures like decreasing the pressure of the distribution network, changing valve settings and pump schedules in order to minimize the amount of leakage from the system using pressure management. This operation is applied to the network momentarily till the leakage from the system is decreased to acceptable levels. Using the forecasted DDCs for randomly selected days, optimum valve analysis for minimizing the leakage calculation procedure was applied (Özkan, 2008). A computer program provides solution by using optimization techniques with defined pressure-leakage and pressure-demand relations in order to find optimal flow control valve configuration for minimizing the leakage. The related computer program was used in this study in order to calculate the valve settings of the related days for recorded, the day before recorded day, ANN forecasted and seasonal average. Estimation of short term hourly valve settings for different days were compared and discussed in detail.

The other procedure applied in this study is to evaluate the performance of the pressure zone by determining relatively weak pipes intersecting at nodes with relatively low performance; which will help to point out the pipes in order to improve both for an existing network and a network in the design and planning stage. Performance evaluation of the distribution network depends on the incident scenarios; pipe breaks, fire situation and power outages (Yıldız, 2002). Forecasted and recorded performance indicators were calculated and compared. Estimation of the short term performance evaluation of a water distribution network with a short term forecasted DDC rather than a past recorded one is presented and discussed.

Forecasted DDCs with the related valve settings will lead the utility to calculate the short term future water consumption and hence forecast of valve settings may guide for the operational stage while volume and peak value forecast may help for the planning and design stage of the pressure zone. Especially, hourly short term forecast (e.g. 6 hours period) may lead a water utility to take necessary precautions (setting the valve openings, re-scheduling pump operation, storage operation) about the system depends on the type of incident. Also the water demand trend of a particular pressure zone can be calculated for the operational point of view with the planning and design stage.

The results of the study may help utilities for the plans of expanding the water distribution network, rehabilitation of network considering the new hydraulic model, taking counter measures for incidents and setting the valve openings for pressure management in order to minimize leakage and optimizing total performance of the distribution network.

The objective of this study is to evaluate the performance of a water distribution network through developing a new methodology for forecasting hourly Daily Demand Curves by artificial neural network (ANN). For this purpose performance analysis under prescribed conditions and optimum valve setting for pressure management is applied.

1.2 Outline

This study has the following structure; Chapter 1 gives general and brief information about the subject of this thesis study. Chapter 2 demonstrates literature review of the study; fundamentals of Artificial Neural Networks (ANN), ANN usages in engineering and other research areas, methodologies, algorithms, functions and mathematical functions, information about performance analysis review and pressure dependent demand theory and optimum valve setting analysis for pressure management from the recent studies. Besides, fundamental elements of a water distribution network and brief information about the hydraulic analysis are given.

Chapter 3 presents the ANN forecast methodology, problem formulation and related assumptions in detail. Additionally, DDC extraction from SCADA records, obtaining data domain and building ANN architecture with performance and optimum valve setting analysis for pressure management methodology are presented.

Chapter 4 demonstrates the case study; brief information about the selected pressure zone of N8-3; population, storeys of building, generating recorded DDCs, Matlab calculations, optimum valve setting analysis for pressure management and performance of the system calculations. Besides, DDC forecast method is applied for a sub-pressure zone of Antalya Water Distribution Network.

Chapter 5 summarizes the results of previous chapters, discusses the results of calculations and the modeling procedures. Finally, Chapter 6 presents conclusions, consequences and recommendations for the future studies.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the fundamentals of the water distribution networks with literature review and information about the forecasting of daily demand curves (DDCs), basics and uses of ANN with related mathematical functions and formulations will be presented. Additionally, information about pressure dependent demand theory, performance analysis and optimum valve setting analysis for pressure management will be introduced from the related studies.

2.1 Water Distribution Networks

2.1.1 General

In a city, one of the most important infrastructural systems is water supply and distribution system. The main aim to construct a water supply and distribution system is to supply adequate water in quantity and quality for the people living in the city. Extensive amount of clean and fresh water for different uses such as domestic, commercial, industrial and public is supplied by water distribution system.

Available pressure head at each node is the most important criterion while designing a distribution system. Pressure heads should be sufficient to meet the consumers’ demands at the peak hours and for fire fighting needs.

Generally the allowable range for the pressure head in gravity pipelines is between 5 m and 80 m. Meanwhile, pressure heads should be great enough to meet the demand but should not exceed the upper limits because of the excessive leakage risk.

A water distribution system includes pipe network, pumps, storage facilities, valves, fire hydrants, house service connections, and other appurtenances. The main elements of a typical water supply and distribution system are shown in Figure 2.1. Water is transferred from source via main transmission line to the treatment plant and from there it is conveyed to distribution reservoir and given to the city network via main feeder pipe.

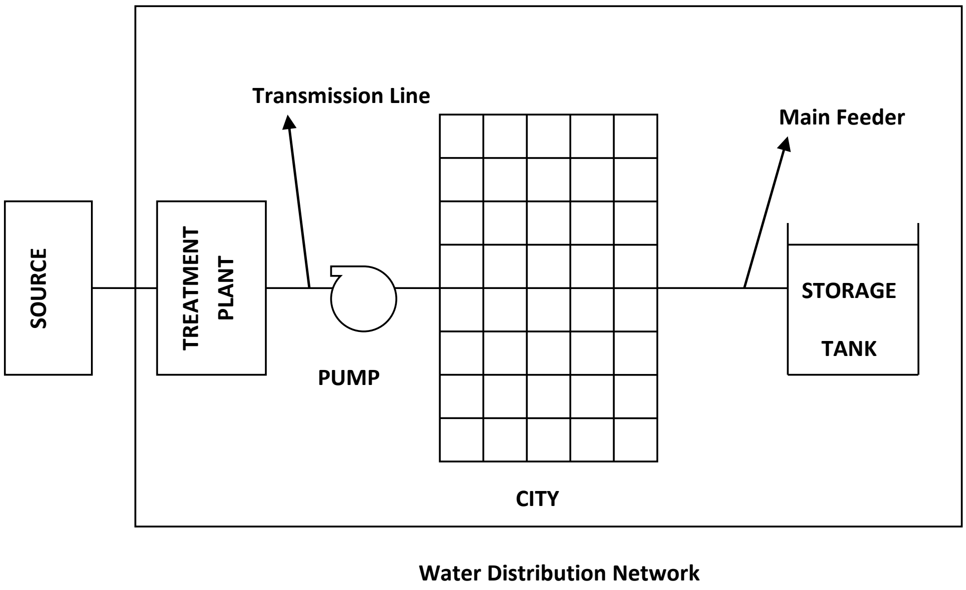

Figure 2.1 Elements of a typical water distribution network

2.1.2 Components of Water Distribution Network

Water distribution networks consist of pipes, pumps, tanks, valves (isolating, control, check etc.) and fire hydrants.

- **Pipes:**

Pipes are the main components of a water distribution system with various lengths and diameters and material types. The pipes are mainly grouped into three categories:

- Transmission Line
- Distribution Pipes
- Service Pipes

The transmission line is the line between the water treatment plant and the storage tank. The distribution pipes are inside the pressure zones and used to distribute water to the service nodes. Service pipes are used to send water to the consumers from service nodes.

- **Pumps:**

Pump is the heart of the system. Booster pumps are mainly used in several water distribution networks. These pumps add energy to the flow against the head losses in the pipes and hydraulic grade differentials within the system.

Most pump stations include multiple pumps in order to provide reliability and flexibility as well as to ensure efficient operation. Pumps are consuming a great deal of energy in distribution systems. The study area has one pump station with two main and a back-up identical pump called as P23.

- **Tanks:**

Tanks are used generally to prevent the effect of oscillations in the customer demands, to store the excess water during low demand periods especially at nights. In daytime hours if the supply from the pump is inadequate then tanks will feed the network. Water stored in tanks may be used to equalize emergency, fire and pressure regulation during a day.

Tanks are also important to maintain sufficient amount of water during flushing activities in order to preserve and improve the quality of water conveyed. The study area has a capacity of 5000 m^3 prismatic, storage facility called as T53.

- **Valves:**

There are several types of valves in pressurized systems. Valves have different behaviors and responsibilities in a system. Some of them maintain flow in one direction (check valves), some regulate the pressure, control the flow by opening, closing or throttling (butterfly valves). In this study, and in most of the water distribution systems, isolating valves are widely used to isolate water within the system.

- *Isolating Valves*

Gate valves are used for isolation of water from one area to another. Under a pipe failure, isolation of a section with a minimum reduction in service and fire protection is done by selecting these valves efficiently. Isolating valves should be operated only in fully open or closed position.

- *Flow Control Valves*

These valves are designed to control the flow of water in pipelines by reducing the pipe area. Butterfly valves are widely used for this purpose. By slightly closing these valves, the flow area is reduced and hence the flow rate decreases. These valves are generally used for regulation purpose.

- *Check Valves*

Check valves are used to stop the flow in reverse direction. They are designed to permit the flow in one direction only. When the flow is in desired direction check valve status is open, when flow is interrupted then check valve status is closed and do not permit water to flow in reverse direction. Check valves are automatically incorporated in pumps to prevent flow reversal through the pump.

- **Fire Hydrants:**

Fire hydrants are used for mainly fire fighting, watering the streets and for immediate water needs.

2.1.3 Daily Demand Curves

Daily Demand Curve (DDC) of a prescribed pressure zone of the water distribution network reflects the water consumption of the subscribers. Daily demand curve for a selected day can be extracted by the help of SCADA using water budget equation.

SCADA Center receives information from the distribution network for every second from all of the stations 7 days in a week and 24 hours in a day. During a day, water levels in the tanks, the inlet and outlet pressures, flow rate at the pump and many more information with the equipment supplied in the distribution network store all data in its relational database.

It is vital that any hydraulic calculation can be applied to the distribution network by obtaining the DDC which will be theoretically presented in Chapter 3.

2.2 Artificial Neural Networks (ANN)

2.2.1 General

Although there is no universally accepted definition, one can define Artificial Neural Networks (ANN) as a functional demonstration of the biologic neural structures of the central nervous system. They are powerful pattern recognizers and classifiers; and they operate like a black-box, flexible, and adaptive tools in order to capture and learn a significant structure in the data. Their computing abilities have been proven in the fields of forecast and estimation, pattern recognition, and optimization (Adeli, 2001).

ANN are developed by considering the human nervous system. Researchers develop this system from the experience of the human being behaviors. Human being behaves differently under distinct environmental conditions. ANN take the same process and implement it on a computer system. ANN are suitable particularly for problems too complex to be modeled and solved by classical mathematical models (McCulloch and Pitts, 1943; Adeli, 2001; Lawrence, 1994; Lingireddy and Brion, 2005).

Furthermore, ANN are commonly used in civil engineering area; structural optimization, earthquake induced liquefaction, tide forecasting, irrigation modeling etc (Adeli, 2001). Additionally, handling of microbial data for polluted water, salinity forecasting in rivers (Lingireddy and Brion, 2005), industrial wood demand forecast (Güngör et. al., 2007), Temperature forecast for a lake (Terzi, 2006), forecasting of evaporation of a dam reservoir (Okkan et. al., 2010), dissolved oxygen change in a river (Özkan et. al. 2006). A very comprehensive study was conducted in 2005 as nodal outflow forecast as a function of pressure in water distribution networks (Mansoor and Viravamoorthy, 2005).In this study, however, it is used for short term forecast of DDCs.

On the other hand, DDC forecast, in other words water demand forecast, can be obtained using different techniques; (i) single coefficient methods which have only one explanatory variable; (ii) multiple coefficient methods with more than one explanatory variable and (iii) probabilistic methods. Explanatory variables are variables that are used to explain the demand for water such as population, price, income and annual precipitation. Regression methodologies were the fundamental approach for the estimation of water demand. On the other hand cascade models, time series detrending, deseasonalization, autoregressive filtering and climatic regression were introduced for long term water demand forecast. (Mays and Tung, 2005)

Regression analysis and time series forecasting for the forecast of water demand generally does not reflect the non-linearity of variables and related correlation. Besides, regression analysis was superior for larger data sets while ANN was a better tool for smaller data sets. (Rossini 1998).

2.2.2 Fundamentals of ANN

Artificial Neural Network's (ANN) born after McCulloch and Pitts introduced a set of simplified neurons in 1943. These neurons were represented as models of biological networks into conceptual components for circuits that could perform computational tasks. The basic model of the artificial neuron is founded upon the functionality of the biological neuron. By definition, "Neurons are basic signaling units of the nervous system of a living being in which each neuron is a discrete cell whose several processes are from its cell body" (McCulloch and Pitts, 1943).

The working principle of neural network is based on functioning of the human brain. The human brain, an unparalleled pattern recognition system, consists of 10^{10} computing elements called neurons. They communicate through a network of axons and synapses thus the human brain can be considered as a densely connected electrical switching network conditioned largely by biochemical process (Loh, 2003). The structure of an ANN is same as the human nervous system (Figure 2.2).

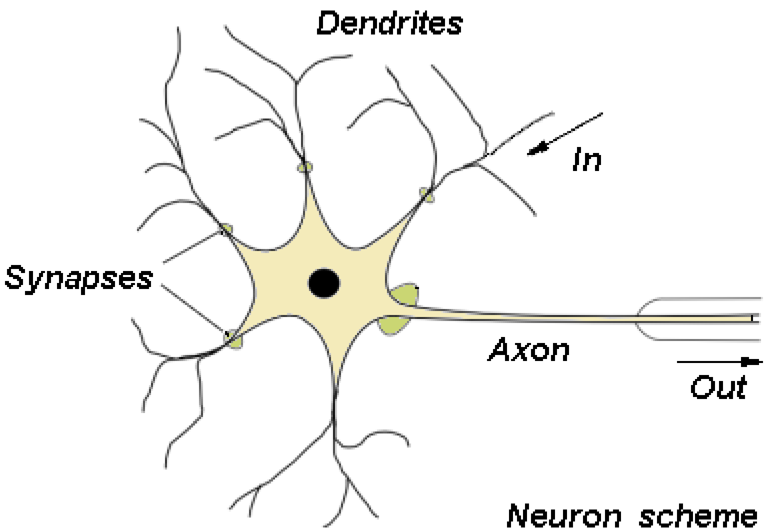

Figure 2.2 Schematic view of a neuron (Web 3)

As seen from the Figure 2.2, the biological neuron has four main regions on its structure. The cell body, or soma, has two offshoots from it. The dendrites and the axon end in pre-synaptic terminals. The cell body, center of the neuron denoted by big black point, is the heart of the cell. It contains the nucleus and maintains protein synthesis. A neuron has many dendrites, which look like a tree structure, receives signals from other neurons. A single neuron usually has one axon, which expands off from a part of the cell body. This is called the axon hillock. The axon main purpose is to conduct electrical signals generated at the axon hillock down its length. These signals are called action potentials.

The other end of the axon may split into several branches, which end in a pre-synaptic terminal. The electrical signals (action potential) that the neurons use to convey the information of the brain are all identical. The brain can determine which type of information is being received based on the path of the signal. The brain analyzes all patterns of signals sent, and from that information it interprets the type of information received. The myelin, (shielded cover of the axon, Figure 2.2) is a fatty issue that insulates the axon. The non-insulated parts of the axon area are called Nodes of Ranvier. At these nodes, the signal traveling down the axon is regenerated. This ensures that the signal travel down the axon to be fast and constant. Neuron’s are connected to each other and transfer the signals from one to another. From neuron A, the data is processed and obtained result is transferred to neuron B through the synapses as input value. (Figure 2.3)

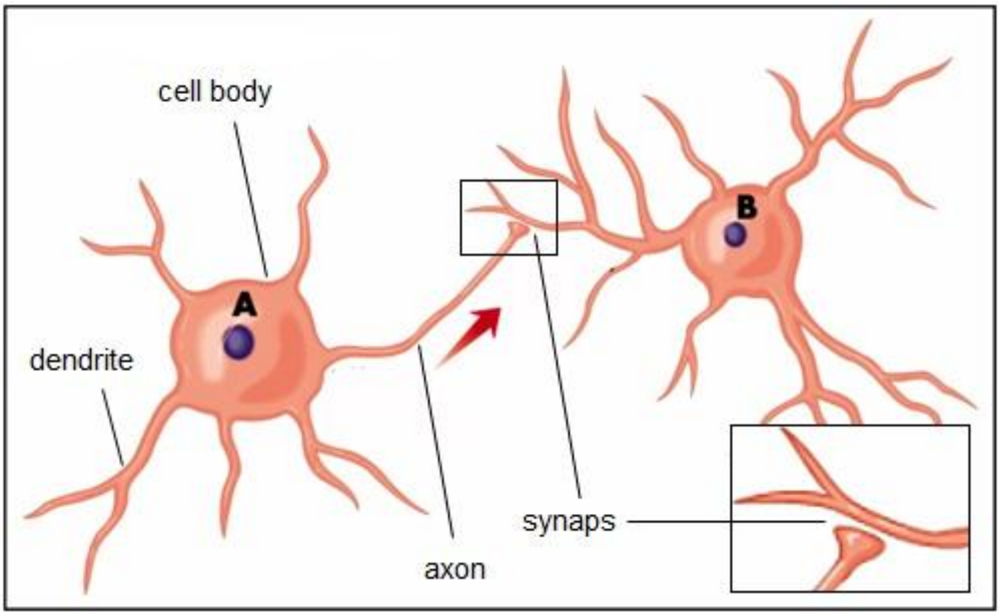

Figure 2.3 Schematic views of two neurons and interconnection (Web 6)

The synapse is the area of contact between two neurons. They do not physically touch because they are separated by a cleft. The electric signals are sent through chemical interaction. The neuron sending the signal is called pre-synaptic cell and the neuron receiving the electrical signal is called postsynaptic cell. The electrical signals are generated by the membrane potential which is based on differences in concentration of sodium and potassium ions and outside the cell membrane.

Biological neurons can be classified by their function or by the quantity of processes they carry out. When they are classified by processes, they fall into three categories: Unipolar neurons, bipolar neurons and multipolar neurons.

Unipolar neurons have a single process. Their dendrites and axon are located on the same stem. These neurons are found in invertebrates.

Bipolar neurons have two processes. Their dendrites and axon have two separated processes too.

Multipolar neurons: These are commonly found in mammals. Some examples of these neurons are spinal motor neurons, pyramidal cells and purkinje cells.

When biological neurons are classified by function they fall into three categories. The first group is sensory neurons. These neurons provide all information for perception and motor coordination. The second group provides information to muscles, and glands. These are called motor neurons. The last group, the interneuron, contains all other neurons and has two subclasses. One group called relay or protection interneurons. They are usually found in the brain and connect different parts of it. The other group called local interneurons are only used in local circuits.

In a mathematical point of view, a researcher may conduct these neural networks by first trying to deduce the essential features of neurons and their interconnections and typically program a computer to simulate these features. However because our knowledge of neurons is incomplete and our computing power is limited, our models are necessarily gross idealizations of real networks of neurons (Saraç, 2004; Web 2). Considering Figure 2.2; a more realistic imagination is given in Figure 2.4

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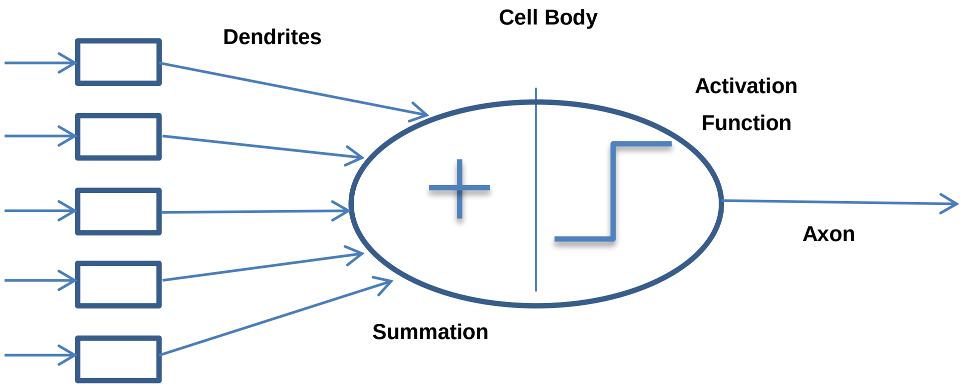


Figure 2.4 The flowchart presentation of bio-neuron model (Artificial Neuron)

2.2.3 ANN Model

A neural network is a powerful data modeling tool that is able to capture and represent complex input/output relationships. The motivation for the development of neural network technology is a key to develop an artificial system that could perform "intelligent" tasks similar to those performed by the human brain. Neural networks resemble the human brain in the following two ways:

1. A neural network acquires knowledge through learning.
2. A neural network's knowledge is stored within inter-neuron connection strengths known as synaptic weights.

The true power and advantage of neural networks lies in their ability to represent both linear and non-linear relationships and in their ability to learn these relationships directly from the data being modeled. Traditional linear models are simply inadequate when it comes to modeling data that contains non-linear characteristics. ANN is used due to their ability to handle nonlinearity and large amounts of data, as well as their fault and noise tolerance and their learning and generalization capabilities (Lawrence, 1994).

As stated before, an artificial neural network include a pool of simple processing units which communicate by sending signals to each other over a large number of weighted connections. The neuron receives information through a number of input nodes, called as synapses. In a mathematical point of view the inputs are multiplied by a weight and summed up and moved to the transfer function (activation function, Chapter 2.2.5). The threshold is the magnitude offset that affects the activation of the node output y (Figure 2.5).

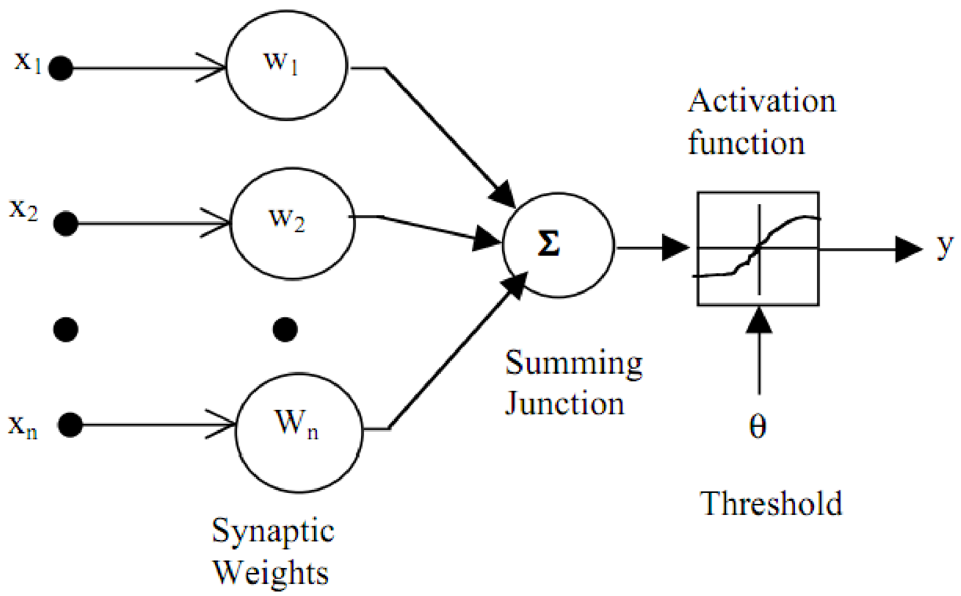


Figure 2.5 Basic elements of an artificial neuron

2.2.3.1 ANN Topologies

In the previous section the properties of the basic processing unit in an artificial neural network were given. This section focuses on the pattern of connections between the units and the propagation of data.

- **Feed-forward neural networks**, where the data from input to output units is strictly feed forward. The data processing can extend over multiple (layers of) units, but no feedback connections are present, that is, connections extending from outputs of units to inputs of units in the same layer or previous layers.

- **Recurrent neural networks** contain feedback connections. Contrary to feed-forward networks, the dynamical properties of the network are important. In some cases, the activation values of the units undergo a relaxation process such that the neural network will evolve to a stable state in which these activations do not change anymore. In other applications, the changes of the activation values of the output neurons are significant, such that the dynamical behavior constitutes the output of the neural network.

Classical examples of feed-forward neural networks are the Perceptron and Adaline. Examples of recurrent networks have been presented by Anderson (Anderson, 1977), Kohonen (Kohonen, 1977), and Hopfield (Hopfield, 1982) (Web 2). In this study, Feed forward perceptron neural network model was used.

2.2.3.2 ANN Training Methods

A neural network has to be configured such that the application of a set of inputs produces the desired set of outputs. There exist methods to set the strengths of the connections exist. One way is to set the weights explicitly, using a priori knowledge. Another way is to train the neural network by feeding it, teaching patterns and letting it change its weights according to some learning rule.

- **Supervised Learning** or Associative Learning in which the network is trained by providing it with input and matching output patterns. These input-output pairs can be provided by an external teacher, or by the system which contains the neural network (self-supervised).

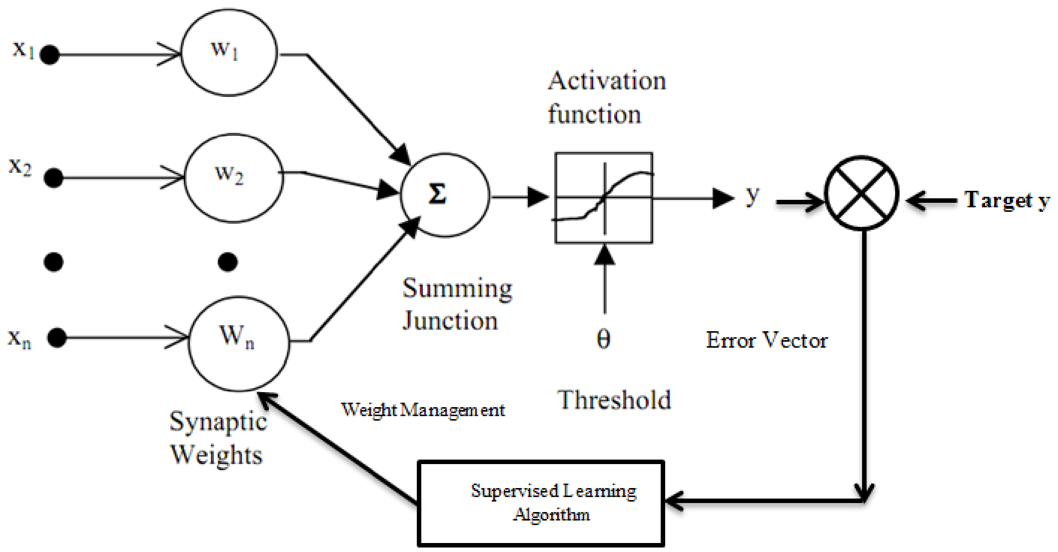


Figure 2.6 Supervised learning algorithm flowchart

- **Unsupervised Learning** or Self-Organization in which an (output) unit is trained to respond to clusters of pattern within the input. In this paradigm the system is supposed to discover statistically salient features of the input population. Unlike the supervised learning paradigm, there is no a priori set of categories into which the patterns are to be classified; rather the system must develop its own representation of the input stimuli.

- **Reinforced Learning** may be considered as an intermediate form of the above two types of learning. Here the learning machine does some action on the environment and gets a feedback response from the environment. The learning system grades its action good (rewarding) or bad (punishable) based on the environmental response and accordingly adjusts its parameters. Generally, parameter adjustment is continued until an equilibrium state occurs, following which there will be no more changes in its parameters. The self-organizing neural learning may be categorized under this type of learning (Web 2, Web 7). In this study, back propagation algorithm is selected as a supervised learning method for the neural model .

2.2.4 Feed Forward Neural Networks

A feedforward neural network is an artificial neural network where connections between the units do *not* form a directed cycle. This is different from recurrent neural networks.

Feedforward neural network was the first and arguably simplest type of artificial neural network devised. In this network, the information moves in only one direction, forward, from the input nodes, through the hidden nodes (if any) and to the output nodes. There are no cycles or loops in the network. In most cases, feed forward neural networks are used for the engineering optimization process and forecast (Figure 2.7).

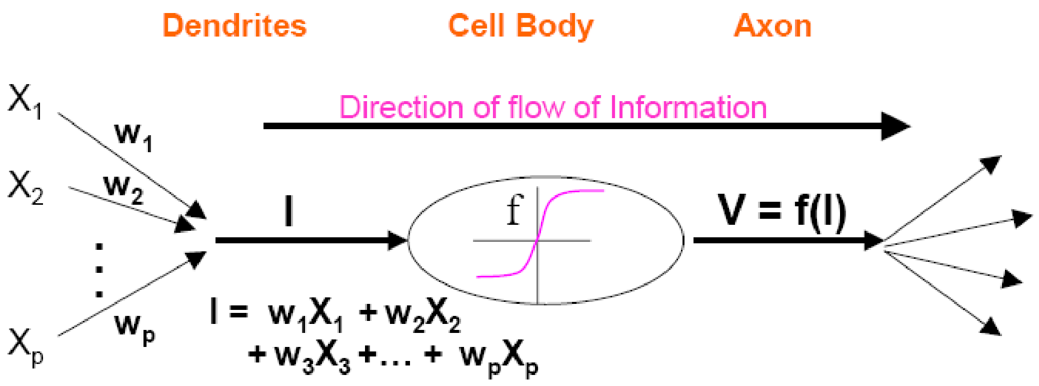


Figure 2.7 A simple feed forward single layer perceptron network

where;

X_p : input variables

w_p: weight of synapses

I: summation

f : activation function

V: output value

- **Single Layer Perceptron (SLP)** is the earliest kind of neural network consists of a single layer of output nodes. The inputs are fed directly to the outputs via a series of weights. In this way it can be considered the simplest kind of feed-forward network. The sum of the products of the weights and the inputs is calculated in each node, and if the value is above some threshold (typically 0) the neuron fires and takes the activated value (typically 1); otherwise it takes the deactivated value (typically -1). Neurons with this kind of activation function are also called *Artificial neurons* or *linear threshold units*. In the literature the term *perceptron* often refers to networks consisting of just one of these units. A similar neuron was described by Warren McCulloch and Walter Pitts in the 1940s (Figure 2.8).

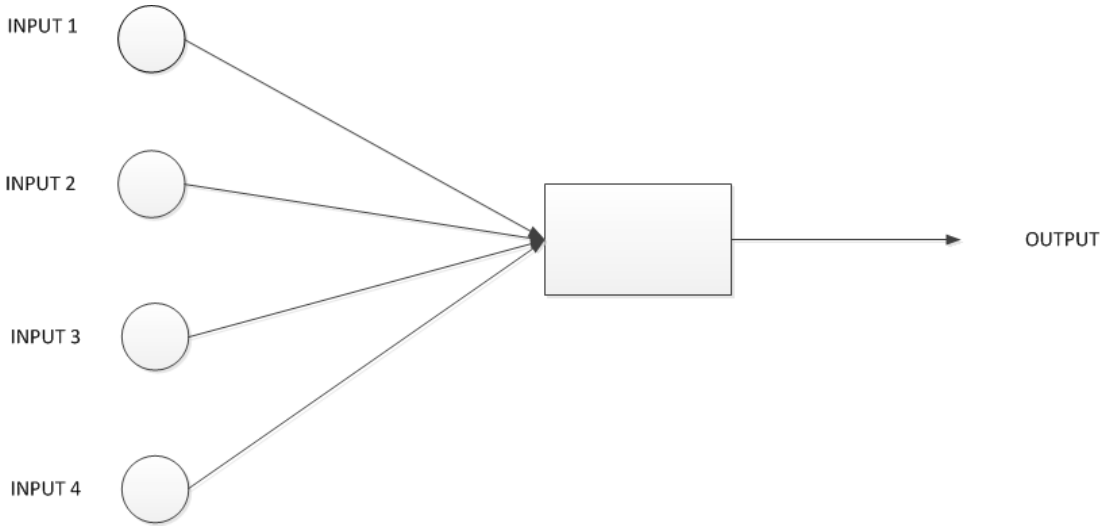


Figure 2.8 Typical Layout of a SLP ANN

- **Multi Layer Perceptron (MLP)** networks consist of multiple layers of computational units, usually interconnected in a feed-forward way. Each neuron in one layer has directed connections to the neurons of the subsequent layer. In many applications the units of these networks apply a sigmoid function as an activation function.

Multi-layer networks use a variety of learning techniques, the most popular being *back-propagation (BP)*. Here, the output values are compared with the correct answer to compute the value of some predefined error-function. By various techniques, the error is then fed back through the network. Using this information, the algorithm adjusts the weights of each connection in order to reduce the value of the error function by some small amount. After repeating this process for a sufficiently large number of training cycles, the network will usually converge to some state where the error of the calculations is small. In this case, one would say that the network has *learned* a certain target function. To adjust weights properly, one applies a general method for non-linear optimization that is called gradient descent.

For this, the derivative of the error function with respect to the network weights is calculated, and the weights are then changed such that the error decreases (thus going downhill on the surface of the error function). For this reason, BP can only be applied on networks with differentiable activation functions.

- ✓ In general, the problem of teaching a network to perform well, even on samples that were not used as training samples, is a quite subtle issue that requires additional techniques. This is especially important for cases where only very limited numbers of training samples are available. The danger is that the network overfits the training data and fails to capture the true statistical process generating the data.
- ✓ Other typical problems of the back-propagation algorithm are the speed of convergence and the possibility of ending up in a local minimum of the error function. Today there are practical solutions that make BP in multi-layer perceptrons the solution of choice for many machine learning tasks.

Consequently, typical Neural Network consists an input layer, hidden layer(s) and an output layer. Multi-Layer Perceptron (MLP) models using back propagating algorithm (BP) are most widely used in literature for forecasting and prediction. MLP’s generally consist of three layers: an input layer, a hidden layer and an output layer, as shown in Figure 2.9. However, MLP’s may contain more than one hidden layer in this kind of analysis upon the experience about building more neural networks for particular situations.

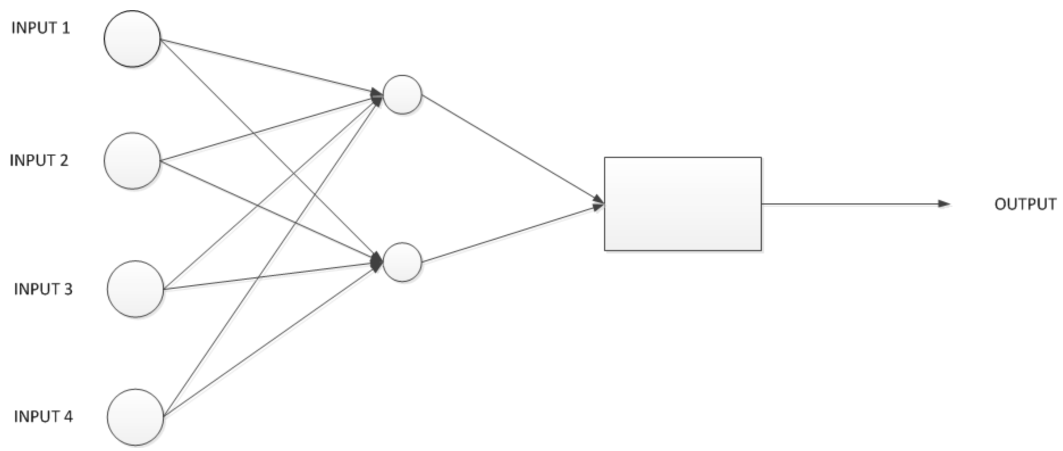


Figure 2.9 Typical layout of a MLP ANN

Considering Figure 2.6 architecture, apparently each layer consists of nodes or neurons, which are connected to nodes in the previous and following layers by connections. The strength of each connection, referred to as its connection weight, can be adjusted. The connection weight from the i^{th} node to the j^{th} node is denoted by w_{ij}.

Input data are presented to the network through the input layer, the values of which are denoted by x_i. Data are passed from the input layer to the hidden layer. The outputs are then summed and added to a threshold value θ_j to produce the node input, I_j, as given in (2.1).

$$I_j = \sum_i w_{ij} x_i + \theta_j \quad \text{......................................} \ (2.1)$$

The network is mainly trained using back propagation with three major phases;

- ✓ *First phase*: an input vector is presented to the network which leads via the forward pass to the activation of the network as a whole. This generates a difference (error) between the output of the network and the desired output.

- ✓ *Second phase:* computing the error factor (signal) for the output unit and propagates this factor successively back through the network (error backward pass).
- ✓ *Third phase:* computing the changes for the connection weights by feeding the summed squared errors from the output layer back through the hidden layers to the input layer.

Continuing this process until the connection weights in the network have been adjusted so that the network output has converged, to an acceptable level, with the desired output the model has been name as trained.

Several architectures and models exist in ANN modeling as stated previously. Considering the non-linearity of the input variables and the best practices Feed-Forward Back propagation (FFBP) ANN model shall selected as the suitable model for this study. A typical schematic view is given in Figure 2.10.

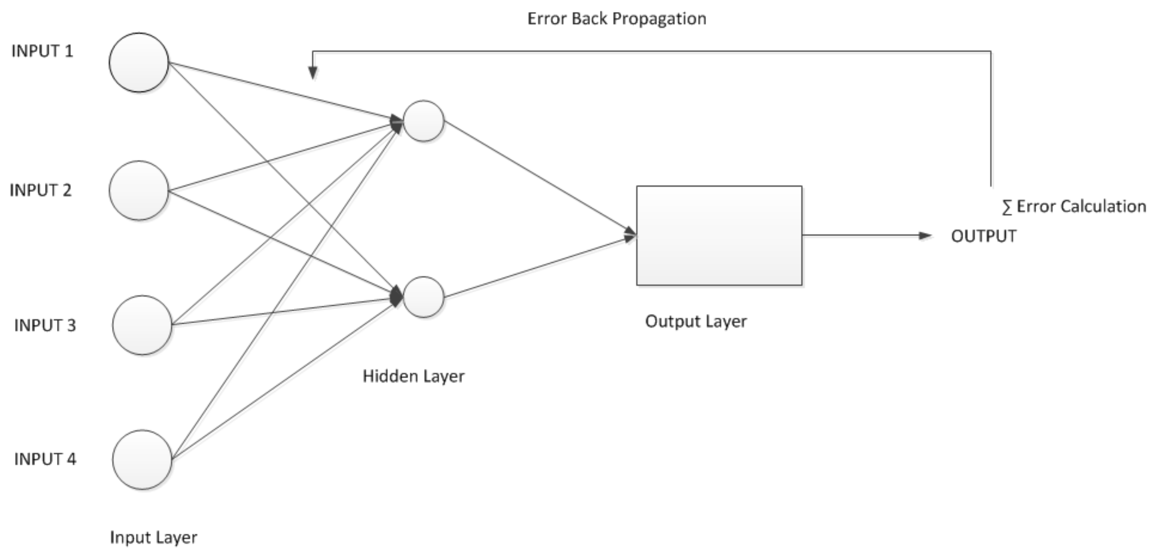


Figure 2.10 Schematic view of feed-forward MLP BP ANN model

2.2.5 Activation Functions and Backpropogation Algorithm

In this study, considering the best practices and literature survey; multi layer perceptron, feed forward backpropagation was selected as a topology and method for ANN model. The model is built considering the trial-error procedure. Considering Equation 2.1, the input variables and the corresponding actual output values are selected for the data domain. The importance of the input variables can be handled with connection weights. Information was stored in these weights and initially given as randomly. The intelligence and hence the performance of the neural network depends on the correct determination of the connection weights. Sum of the weighted input equation was given in Equation 2.1 and transformed to the output using activation function and/or other process elements. Activation function can be linear or non-linear. Sigmoid and hyperbolic- tangent activation functions are commonly used. (Figure 2.11)

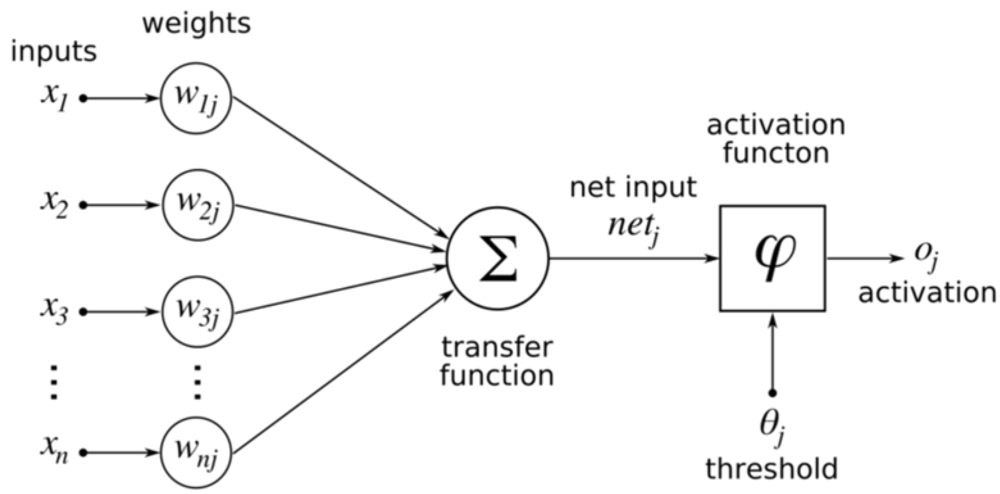
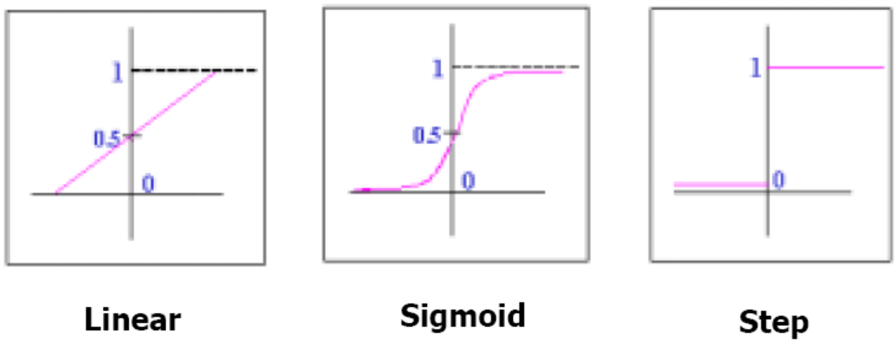


Figure 2.11 Schematic view of a sample ANN model



Name	Function $f(x)$	Codomain
linear	x	$]-\infty,+\infty[$
sigmoid	$\frac{1}{1+e(-x)}$	$[0,1]$
sigmoid1	$\frac{2}{1+e(-x)}-1$	$[-1,1]$
sigmoid2	$\frac{x}{1+\lvert x\rvert}$	$[-1,1]$
tanh	$tanh(x)$	$[-1,1]$

Figure 2.12 Typical activation functions (Lawrence, 1994)

Activation functions for the hidden units are needed to introduce nonlinearity into the network. Without nonlinearity, hidden units would not make neural networks more powerful than just plain perceptrons (which do not have any hidden units, just input and output units). The reason is that a linear function of linear functions is again a linear function. However, it is the nonlinearity (i.e. the capability to represent nonlinear functions) that makes multilayer networks so powerful. Almost any nonlinear function does the job, except for polynomials.

For BP learning, the activation function must be differentiable, and it helps if the function is bounded; the sigmoidal functions such as logistic and tanh and the Gaussian function are the most common choices. Functions such as tanh or arctan that produce both positive and negative values tend to yield faster training than functions that produce only positive values such as logistic, because of better numerical conditioning. For hidden layer, sigmoid activation functions are usually preferable to threshold activation functions. (Web 4)

Even for training methods that do not use gradients--such as simulated annealing and genetic algorithms--sigmoid units are easier to train than threshold units. With sigmoid units, a small change in the weights will usually produce a change in the outputs, which makes it possible to tell whether that change in the weights is good or bad. For the output units, a suitable activation function should be chosen for the distribution of the target values. (Web 4)

Total error at the output layer can be found by summation of all errors considering the following formula:

$$Total\ Error = \frac{1}{2}\sum_m E^2{}_m \quad (2.2)$$

$$E_m = \text{Error} = O_m - Ex_m \quad (2.3)$$

where;

Ex_m= expected output value

O_m= obtained output value

Once the total error is found, the designer should check the model and change the weight factors of the interconnections. This is called as the error back propagation process. This training process reduces the errors and teaches the cell for further calculations. Consider the following example;

A multilayer feed forward perceptron model was given with 3 inputs and 1 hidden layer with 2 neurons (Figure 2.13).

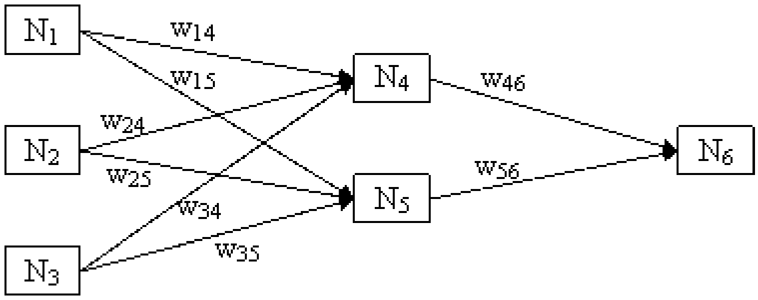


Figure 2.13 Example of a MLP network architecture

The feed forward neural network above has 6 neurons arranged in 3 layers. N_1, N_2 and N_3 are called input neurons as they receive data directly from the user, not other neurons. For input neurons the activation function is not used. N_4 and N_5 are part of what is called a hidden layer of neurons. They are hidden as the user can't set them a value or get their value directly, they only communicate with other neurons. N_6 is an output neuron. From the output neurons the users get the result of the neural network processing. W_{ij} are the weights of the connections between the neurons. In other words, weights can be defined as the value of how strong the connections are.

Hidden and output neurons apply an activation function to their sum of input data. The sum of input data is the sum of the products of the input neurons output values and the weights of the input connections from those neurons.

$$InputSumN_j = \sum(w_{ij} * N_i) \quad (2.4)$$

where N_i are the input neurons to neuron N_j

For the activation function F(x) the output of the neuron N_j:

$$N_j = F\left(InputSumN_j\right) = F(\sum\left(w_{ij} * N_i\right)) \quad \text{.......................} \ (2.5)$$

In order to be able to learn any pattern we need a non linear activation function. The most used activation function is the sigmoid function:

$$F(x) = \frac{1}{1+e^{-x}}) \quad \text{......................................} \ (2.6)$$

As seen from Figure 2.13; N_1, N_2 and N_3 are denoted as input values.

$N_4 = F(w_{14}*N_1 + w_{24}*N_2 + w_{34}*N_3)$

$N_5 = F(w_{15}*N_1 + w_{25}*N_2 + w_{35}*N_3)$

$\text{Output} = N_6 = F(w_{46}*N_4 + w_{56}*N_5)$

The purpose of learning is to determine the weights W_{ij} that allow us to reproduce the provided patterns of inputs and outputs (function of inputs). Basically, it learns a function of arbitrary complexity from examples. The complexity of the function that can be learned depends on the number of hidden neurons. Before starting the backpropagation learning iterations weights are initialized with random values, typically in the interval (-1, 1).

A backpropagation step for a specific input pattern and ideal output starts by calculating the error at the output neurons. This error is the difference between the provided ideal output and the calculated actual output multiplied with the activation function derivate on that output point. For the sigmoid function the derivate is

$$F'(x) = F(x)*(1 - F(x))$$

$$OutputError_j = (IdealOutput_j - Output_j) * F'(Output_j)$$

In this example, using the sigmoid as an activation function:

$$N_6\_Error = (N_6\_Ideal - N_6) * N_6 * (1-N_6)$$

After obtaining the error for the output layer, calculating an error for each neuron in the hidden layers, going backwards, layer by layer is important. The error for a neuron in a hidden layer is the sum of the products between the errors of the neurons in the next layer and the weights of the connections to those neurons, multiplied by the derivate of the activation function.

$$HiddenError_i = \sum(OutputError_j * w_{ij}) * F'(HiddenOutput_i)$$

In this example:

$$N_4\_Error = (N_6\_Error * w_{46}) * N_4 * (1 - N_4)$$

$$N_5\_Error = (N_6\_Error * w_{56}) * N_5 * (1 - N_5)$$

$$\Delta w_{ij} = Output_i * Error_j$$

In this example:

$$\Delta w_{46} = N_4 * N_6\_Error$$

$$\Delta w_{56} = N_5 * N_6\_Error$$

$$\Delta w_{14} = N_1 * N_4\_Error$$

$$\Delta w_{24} = N_2 * N_4\_Error$$

$\Delta w_{34} = N_3 * N_4\_Error$

$\Delta w_{15} = N_1 * N_5\_Error$

$\Delta w_{25} = N_2 * N_5\_Error$

$\Delta w_{35} = N_3 * N_5\_Error$

This process is repeated for all input patterns and the variations (deltas) are accumulated. At the end of a learning iteration actual weights were changed with the accumulated deltas for all the training patterns multiplied with a learning rate (a number typically between 0 and 1 which states how fast a network converges to a result).

$\Delta w_{ij}\_Final = \sum \Delta w_{ij}\_Input_k$

$w_{ij} = w_{ij} + (\Delta w_{ij}\_Final * LearningRate)$

In this example, considering 2 input patterns and a learning rate of 0.3:

$\Delta w_{46}\_Final = \Delta w_{46}\_Input1 + \Delta w_{46}\_Input2$

$New\ w_{46} = w_{46} + 0.3 * \Delta w_{46}\_Final$

Briefly, in order to teach a network using BP, the following steps are applied:

- Initialize weights with random values
- For a specified number of training iterations do:

a. For each input and ideal (expected) output pattern

   1. Calculate the actual output from the input
   2. Calculate output neurons error
   3. Calculate hidden neurons error

4. Calculate weights variations (delta): Δw_{ij}

5. Add the weights variations to the accumulated delta

b. Learn by using the accumulated deltas and adding them to the weights

On the other hand, the method for the training of network is rather important from architecture of the network for accurate forecast. The difference between output and the forecasted values is accepted as error and an iterative procedure in the model is applied in order to minimize this error. Consequently, the random connection weights are updated until the error is minimized in acceptable levels. This is known as “generalized delta learning rule” most often used for supervised learning algorithm of feed-forward multi-layer neural network. Although there are several learning algorithms, in this study Levenberg-Marquardt Algorithm (LM) was used according to the widely used and satisfactory studies.

The LM algorithm is the most widely used optimization algorithm which provides a numerical solution to the problem of minimizing a (generally nonlinear) function, over a space of parameters for the function. It is a popular alternative to the Gauss-Newton method of finding the minimum of a function. (Web 8, Web 9)

In this study, MATLAB-Neural Network Toolbox is used for ANN calculations and a built-in function, *trainlm*, is available for Levenberg-Marquardt Algorithm calculations. The methodology applied in this study will be given in Chapter 3 about the trial-error procedure, educating, validating and testing the model and related information. (Matlab 2008a, User’s Guide)

2.3 Performance Analysis

Evaluation of water distribution system performance depends on different and large number of parameters some of which are power outages, pipe failures, flow capacity of transmission lines, valve failures, and variation in daily demands. In a water distribution system valves are not necessarily located at the end of each pipe. When a pipe failure occurs due to inadequate valves more than one pipe is out of service. A system without a valve will be completely out of service during a pipe break or maintenance event requiring a shutdown. During the operation, the shutdown creates pressure drop on some of the nodes where available demand is lower than the required demand.

The performance can be calculated by various reliability factors, by forecasting the availability of water at deficient nodes. (Gupta and Bhave, 1991) Reliability, or more realistic name availability, should be regarded basically as the ratio of actual flow delivered to the required flow. While designing water distribution networks traditionally, it is important that the network supplies the forecasted demands with adequate pressures at all nodes of the network; these models assume fixed demands for nodes and they compute corresponding nodal pressures and also pipe flows. Deficient parts of the networks with nodal pressures lower than the minimum required pressures are then upgraded through necessary modifications.

However, there are no comprehensive and generally acceptable methods for calculating the quantity of flow actually delivered by water distribution systems with less pressure than the required. In this study, the relationship suggested by Germanopolos (1985) was used with some modifications (Nohutcu, 2002) to relate nodal demands and pressure heads. The modified relationship was included in linear theory for the solution of non-linear network equations. A computer program implemented by Nohutcu (2002) was used for both fixed-demand and pressure-dependent demand solutions. Basic reliability calculations (Gupta and Bhave, 1994) were carried out concerning this pressure zone taking into account various loading conditions and existing valving topology (Walski, 1993) using geographic information systems (GIS) (Yıldız,2002; Nohutcu,2002).

According to Gupta and Bhave (1994) there exist three reliability factors and performance analyses depend on these factors which are Node Reliability Factor, Volume Reliability Factor and Network Reliability Factor. In this study only the Network Reliability Factor is taken into consideration as a performance indicator (Yıldız, 2002).

2.4 Optimum Valve Settings for Pressure Management

As known from the literature and experience, water distribution networks (WDN) are planned and designed to forecast current and future demands. However it is inevitable that excessive pressure will exist and can lead to significant levels of leakage. In order to increase the efficiency of the WDN, leakage should be reduced to appropriate and acceptable levels. A study was applied to prescribed pressure zone by Özkan in 2001 and 2008. I In N8-3 pressure zone has 50.14% of total water used by the consumers was lost as leakage (Özkan, 2001).

Leakage is one of the major problems that a water utility should solve for economic and environmental purposes. Higher the pressure in the distribution network, higher the leakage from the system. Several researches studied about the pressure and leakage relationships and offers different solutions such as; usage of flow control valves to reduce leakage, optimization of variable pump schedule operation, valve and pumps speed optimization for minimizing leakage. Beyond the several techniques, Özkan (2008) used the optimal valve control which is still open to study with development in optimization models.

The valve optimization computer program was implemented by Özkan which is composed of two sub programs, CODE I and CODE II. The first code (CODE I) is the valve optimization program to find the optimal flow control valve settings minimizing the leakage volume by using pressure dependent leakage and pressure dependent demand terms. The second code (CODE II) is a static analysis program providing solution for all combinations of isolation valve settings defined in the network also by pressure dependent leakage and pressure dependent demand terms.

The main aim of the program is the determination of the flow control valve settings by optimization methods to minimize leakage. The inclusion of pressure dependent leakage and pressure dependent demand terms in the network analysis allows the application of optimization techniques to identify the most effective means of reducing water losses in distribution systems. The non-linear network equations are linearized using Linear Theory Method and the optimum flow control valve settings are determined by Linear Programming.

Flow control valve setting values are between 0 and 1 according to CODE I and 0 or 1 according to CODE II. CODE I take the valves as flow control valves while CODE II take the valves as isolation valves. The solution obtained from both codes may not be accepted as the effective way of leakage minimization but can help to reduce the pressure and so leakage. (Özkan, 2008)

CHAPTER 3

METHODOLOGY OF THE STUDY

3.1 Introduction

This chapter mainly focuses on the methodology for the forecasting daily demand curves (DDC) for a selected day using past SCADA records by Artificial Neural Network (ANN) theory. The results were compared with the actual recorded data for the selected day. Furthermore, the day before the selected day and seasonal average DDC data were also compared with the actual recorded day considering total volume and peak values.

On the other hand, the success of the ANN model may help the utility for forecasting the short term operational decisions. Pressure management by optimum valve setting operation and performance analysis of a pressure zone for each state were compared with recorded data. The main aim is to develop an operational schedule of the pressure zone for the short term period while satisfying the required demands and pressure for all nodes and minimizing leakage from the system considering pressure management.

3.2 Problem Formulation

Practically, hydraulic calculations are mainly based on the water consumption data with a successfully building of a DDC. As stated in the literature review (Chapter 2), the calculations are employed on the past data.

The unknown situation is the future water consumption and hence the related DDC. Although there are traditional methods that require specification of functional relationship (linear, polynomial, exponential or some other complex function) ahead of time, ANN is a powerful tool for approximating functional relationships that eliminated the need for knowing the shape of the functional relationship representing the phenomenon being modeled (Lingireddy, S and Brion G.M., 2005).

Using the forecasted DDC, performance analysis and optimum valve setting analysis for pressure management will be forecasted accordingly considering partially satisfied demand theory (Figure 3.1).

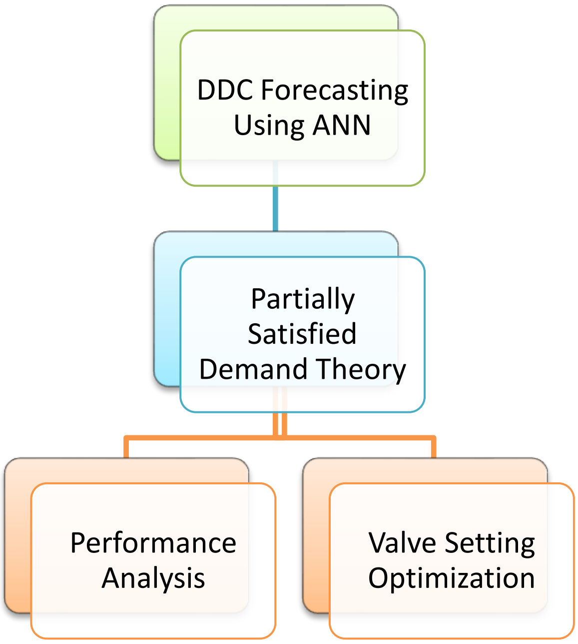


Figure 3.1 Scope of the study

Considering the theory of ANN (Chapter 2), the dependence of the variables has a great importance about the results. Variables should have a relationship with the output target. These variables may be relative humidity, temperature, population, rain period, number of storeys of the building, human behavior, sunshine hours for the prescribed pressure zone that affect the water consumption (Stark, 2002). In this study, temperature, relative humidity, season and the human behavior (weekday/weekend) were taken as the main dependent variable for building the ANN model.

ANN architecture was implemented considering the Ankara N8-3 pressure zone. On the other hand, same architecture was used for a sub-pressure zone of Antalya water distribution network to see whether the model forecast satisfactorily with the prescribed architecture. Consequently the comparison of water budget (Ankara) and direct measurement (Antalya) were evaluated.

3.3 Data Collection and Selection

Generally, data are one of the vital information for analysis process. All system characteristic information of pipes, pumps and tanks are taken from ASKI records for N8-3 pressure zone. Skeletonization procedure was applied for the selected pressure zone in order to simplify and accelerate the calculations (Yıldız, 2002).

SCADA stands for “Supervisory Control and Data Acquisition System.” The term supervisory indicates that there is at least a staff supervising the operation of the system and make decisions under different conditions. The purpose of SCADA is to compile data concerning the operation of the water system and to allow automated control of certain components of the water system. A SCADA system is composed of the following components; Field Instrumentation, Remote Stations, Communications Network, Central Monitoring Station, Data Storage Systems (Yıldız, 2002).

ASKI SCADA Center is responsible for collecting, transmitting and storing data from various control points of the network such as pump stations, storage tanks and some critical points on some pipes. SCADA system provides remotely operation and control of pumps and some control valves. There are actually 125 stations (73 storage tanks, 37 pumps stations and 15 other measuring points) monitoring for 7 days / 24 hours and all data received from these stations are stored in digital environment. For every second the information is transmitted from these stations to the SCADA Center and stored in the database via radio waves.

ASKI SCADA System can provide pump stations inlet and outlet pressures, discharge through pumps, control valves status, residual chlorine and alarms. At storage tanks, water levels, valve status and security alarms are real time controlled and monitored.

On the other hand, State Meteorological Service (DMI) has recording stations in all cities of Turkey. These stations measure air temperature, relative humidity, relative air pressure, wind speed, amount of rainfall, radiation, shining period and other meteorological information. Numerous stations are located through the country and especially in airports. Additionally, several radars are located and several stations are available for measuring and monitoring the seaside meteorological events. In this study, only temperature and relative humidity data are taken in to account for calculations. Related data was obtained from Keçiören station of DMI

Characteristics of the water distribution network and SCADA records were obtained from ASKI. Meteorological data were obtained from the DMI - TUMAS (Turkish Meteorological Archiving System) which includes the past 50 years of meteorological measurements for Turkey.

3.3.1 Building Daily Demand Curves (DDCs)

A Daily Demand Curve (DDC) is one of the operational characteristics of a pressure zone which reflects the water consumption in the network. DDCs are derived using the continuity equation. The continuity principle is based on the law of conservation of mass. Flow supplied by the pump is consumed at nodes as nodal consumptions and the remaining is stored at tank. The total flow consumed by the pressure zone is computed by Equation 3.1 (Mays, 1996).

$$\overline{I} - \overline{Q} = \frac{dS}{dt} \qquad (3.1)$$

$\overline{I}$: Average flowrate incoming to the system for a period of time dt, m^3 /hr

$\overline{Q}$: Average flowrate outgoing from the system for a period of time dt, m^3 /hr

dS : Storage in the tank for a period of dt, m^3

Selected pressure zone (N8-3) has one pump station and a prismatic tank therefore the calculations are easily conducted by using Equation 3.1. In this study hourly SCADA records were taken from ASKİ from the beginning of year of 2007 to the first quarter of 2010. As a result, nearly 1700 days of DDCs were built by a computer program using Equation 3.1.

3.3.2 Building Data Domain for ANN Model

Having adequate data is a vital step for the successful application of an ANN model and calculations and hence, selection of data domain has a significant importance. For this reason, every daily demand curve was investigated day by day considering the theoretical daily demand curves.

A theoretically acceptable DDC is given in Figure 3.2. Any unacceptable DDC was corrected if applicable. The correction was applied if the following value is changed drastically (Figure 3.3). The correction methodology is taking the average of the preceding and the following values and inserting the new value (Figure 3.4). However, if the DDC shape is not acceptable (Figure 3.5), it will not be taken in to account for ANN Data Domain.

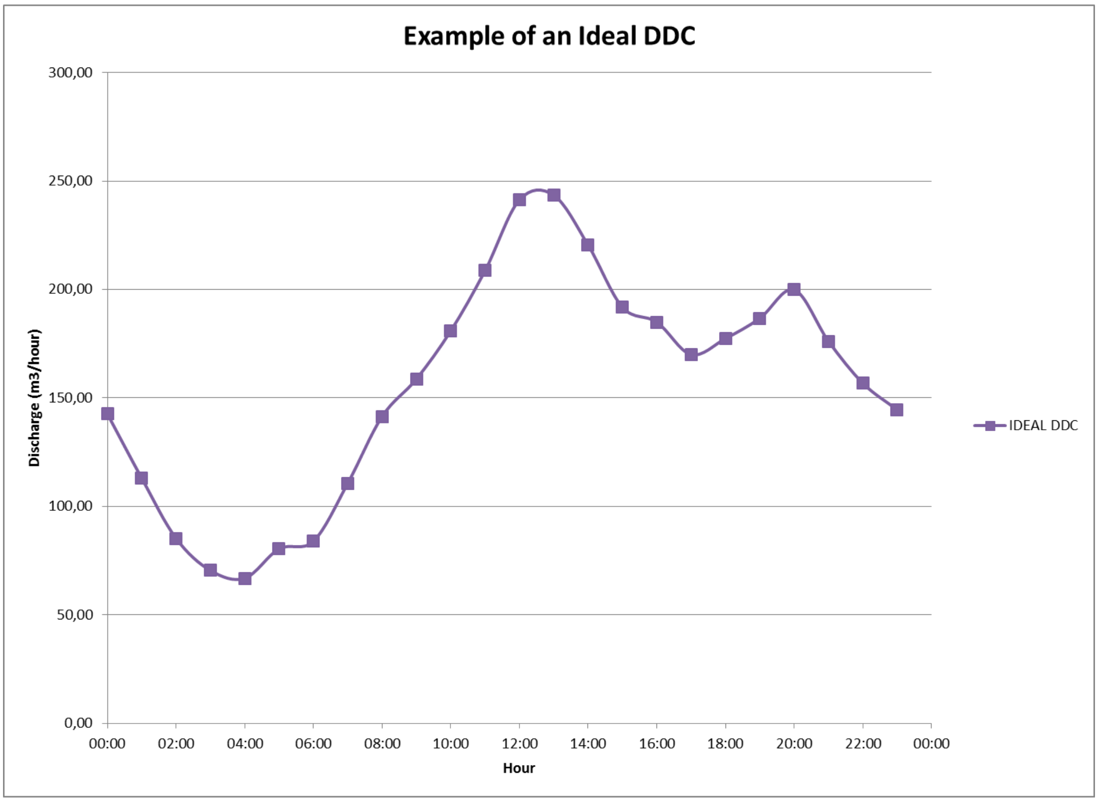


Figure 3.2 Theoretically ideal shape of a DDC for N8-3

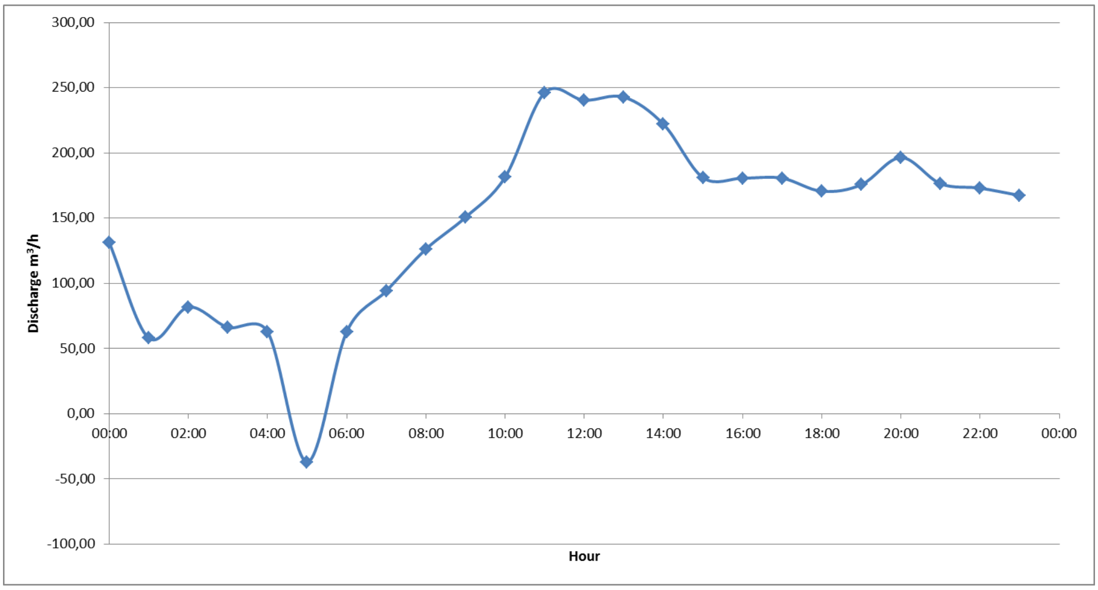


Figure 3.3 DDC of 14.09.2007 from recorded SCADA measurements of N8-3

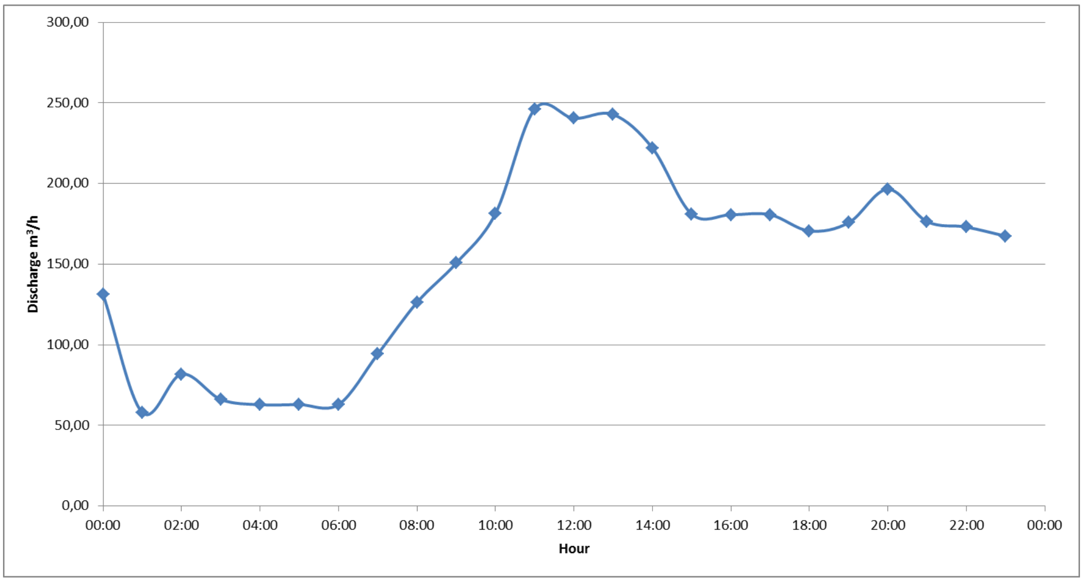


Figure 3.4 Corrected DDC of 14.09.2007 of N8-3

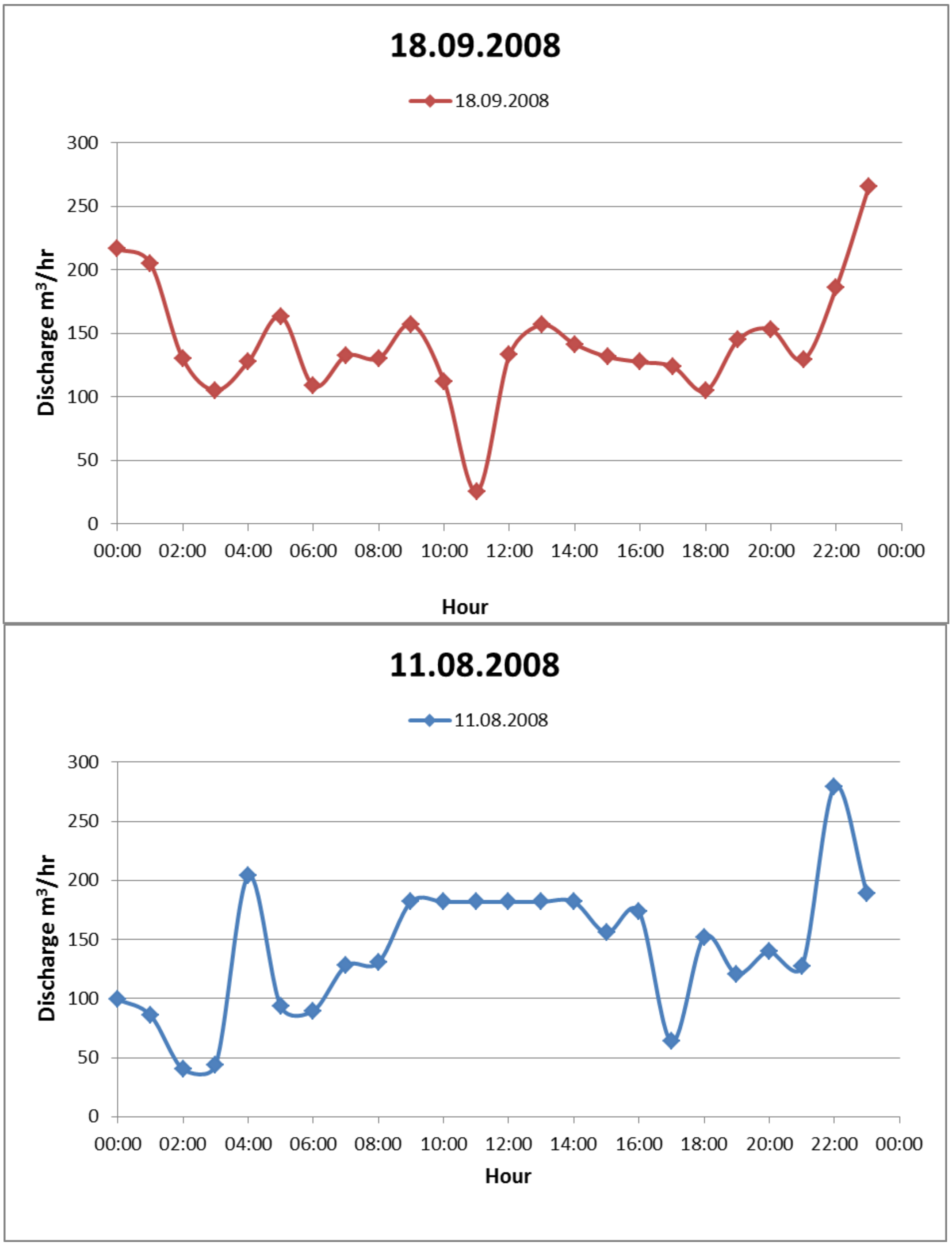


Figure 3.5 Unaccepted DDCs from SCADA records of N8-3

Selection criteria of the DDC are mainly based on the shape similarity of an ideal DDC as shown in Figure 3.2. A DDC which has the following was not selected for ANN domain.

- DDCs having more than 2 negative values,
- DDCs having steady and certain measurement for a period of time,
- DDCs having at least one zero, “N/A” or “error” value,
- DDCs having continuous fluctuation for a period of time.

After the completion of the selection of ANN model data domain, the other variables; temperature, relative humidity, human behavior (weekday/workday) and season are taken in to consideration for the input variables. As stated before, in this study, temperature, relative humidity, human behavior and season are the main factors that affect the water consumption. While temperature rises, generally water consumption rises on the other hand there is an inverse proportion with relative humidity and water consumption. As the humidity increases water consumption decreases. Considering the human behavior, at weekends more water is consumed rather than weekdays at this region.

As a result temperature and relative humidity will be accepted as an input variable for the ANN model. Hourly data of the Ankara Keçiören Meteorological Station was obtained from TUMAS (Turkish Meteorological Data Archiving System), DMI. A sample is given in Table 3.1.

Table 3.1 Meteorological data format (TUMAS)

Station #	City	Year	Month	Day	Hour	Temperature (°C)	Humidity (%)
17130	ANKARA	2007	6	16	0	20.1	55
17130	ANKARA	2007	6	16	1	20.0	54
17130	ANKARA	2007	6	16	2	19.0	59
17130	ANKARA	2007	6	16	3	18.9	64
17130	ANKARA	2007	6	16	4	20.7	58
17130	ANKARA	2007	6	16	5	22.9	49
17130	ANKARA	2007	6	16	6	23.2	52
17130	ANKARA	2007	6	16	7	25.5	44
17130	ANKARA	2007	6	16	8	28.3	34
17130	ANKARA	2007	6	16	9	28.8	32
17130	ANKARA	2007	6	16	10	32.1	25
17130	ANKARA	2007	6	16	11	31.1	25
17130	ANKARA	2007	6	16	12	30.8	26
17130	ANKARA	2007	6	16	13	30.8	24
17130	ANKARA	2007	6	16	14	22.0	60
17130	ANKARA	2007	6	16	15	23.7	52
17130	ANKARA	2007	6	16	16	22.8	51
17130	ANKARA	2007	6	16	17	22.1	50
17130	ANKARA	2007	6	16	18	21.8	51
17130	ANKARA	2007	6	16	19	21.7	50
17130	ANKARA	2007	6	16	20	20.9	59
17130	ANKARA	2007	6	16	21	20.0	63
17130	ANKARA	2007	6	16	22	19.1	66
17130	ANKARA	2007	6	16	23	19.4	61

Considering the literature (Stark, 2002) human behavior is one of the important factors that affect the water consumption of a distribution network. For this reason, weekdays and weekends were separated considering the data domain (Table 3.2). Also, seasons are coded as seen in Table 3.3.

Table 3.2 Human behavior mode

Day	Mode
Work Day / Weekday (Mon/Tue/Wed/Thu/Fri)	1
Weekend / Holidays (Sat/Sun and official holidays of Turkey)	2

Table 3.3 Season mode

Season	Mode
Spring	1
Summer	2
Autumn	3
Winter	4

At the end of this processing, the input file is as follows: (one of the selected day from the data domain, 06.08.2007, is given in Table 3.4)

Table 3.4 Sample input data for a selected day (06.08.2007)

Hour	Season Mode	Day Mode	Temperature (C^o)	Humidity (%)	Discharge (m^3/hr)
0	2	1	24	34	268.22
1	2	1	23.5	39	296.25
2	2	1	23	45	35.28
3	2	1	21.8	50	119.73
4	2	1	23.8	46	168.85
5	2	1	26.9	38	161.53
6	2	1	29.8	30	191.94
7	2	1	32.7	23	154.42
8	2	1	33.6	19	186.00
9	2	1	34.9	16	220.14
10	2	1	35.8	10	202.65
11	2	1	36.3	11	215.22
12	2	1	36.3	10	605.10
13	2	1	36.7	10	518.92
14	2	1	36.8	9	208.73
15	2	1	36.3	9	218.27
16	2	1	34.8	10	184.52
17	2	1	33.2	12	238.14
18	2	1	31.3	13	217.81
19	2	1	29.5	12	228.81
20	2	1	26.7	15	358.69
21	2	1	26	18	371.63
22	2	1	25.6	17	73.25
23	2	1	25.3	20	40.36

171 days were selected from the 1700 SCADA days as the data domain of the ANN model due to erroneous SCADA measurements. On the other hand, temperature and relative humidity has a direct relationship with the season therefore season mode was removed from the data domain in order to apply seasonal analysis. Therefore, every season has its own data domain for the building of ANN model. For every season 4 days were randomly selected (totally 16 days) and related seasonal data domain was selected as training, validating and testing of ANN model.

3.3.3 Building ANN Model Architecture

As stated in Chapter 2.2.5, Feed Forward Multi-Layer Perceptron (MLP) Architecture with Levenberg-Marquardt Backpropagation training algorithm was used for the ANN model. A schematic view for the MLP architecture is presented in Figure 3.6.

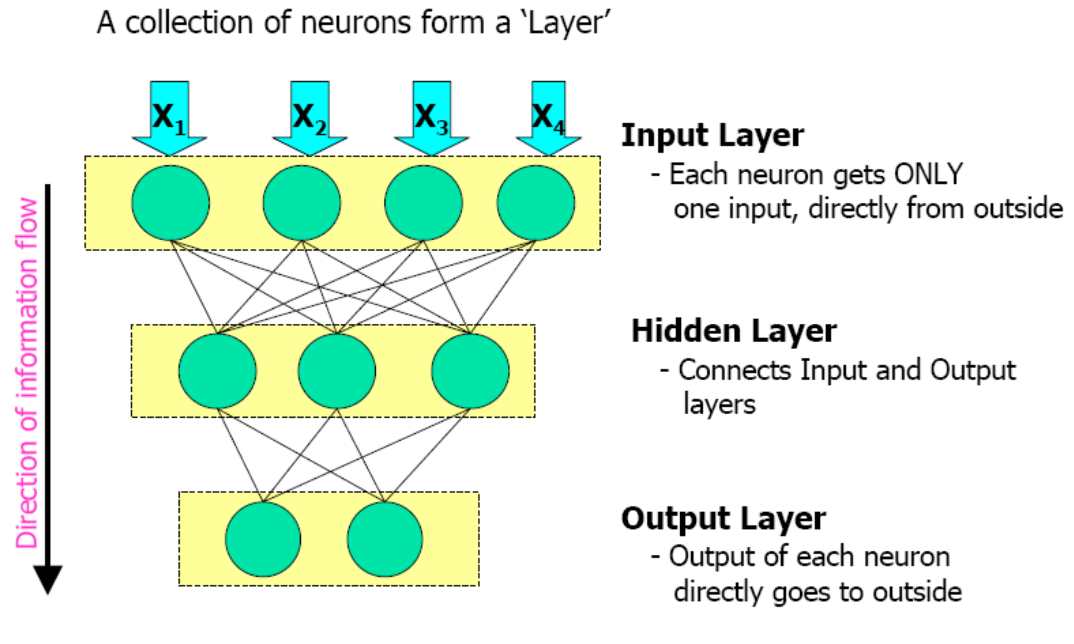


Figure 3.6 A sample schematic view of MLP architecture

Input layer is the receiver of the neural network and takes all raw data. Hidden layer may compose of several layers composed of several neurons and all data are processed at this layer. Output layer takes all processed data from the hidden layer and gives the related output value.

Data-driven modeling approaches are becoming more popular due to the increasing availability of data in the water industry. Water utilities possess large quantities of data derived from control and monitoring facilities. Rather than devising data collection schemes to collect the large amounts of data required to develop a process-based model, statistical techniques can be applied to extract useful relationships from existing data sets, thus making maximum use of the data that are already available. A neural network is a powerful data modeling tool that is able to capture and represent complex input/output relationships. The motivation for the development of neural network technology stemmed from the desire to develop an artificial system that could perform “intelligent” tasks similar to those performed by the human brain. In more practical terms neural networks are non-linear statistical data modeling tools that can be used to model complex relationships between inputs and outputs or to find patterns in data. ANN are used due to their ability to handle nonlinearity and large amounts of data, as well as their fault and noise tolerance and their learning and generalization capabilities (Lawrence, 1994). The ANN model architecture used in this study is presented in Figure 3.7.

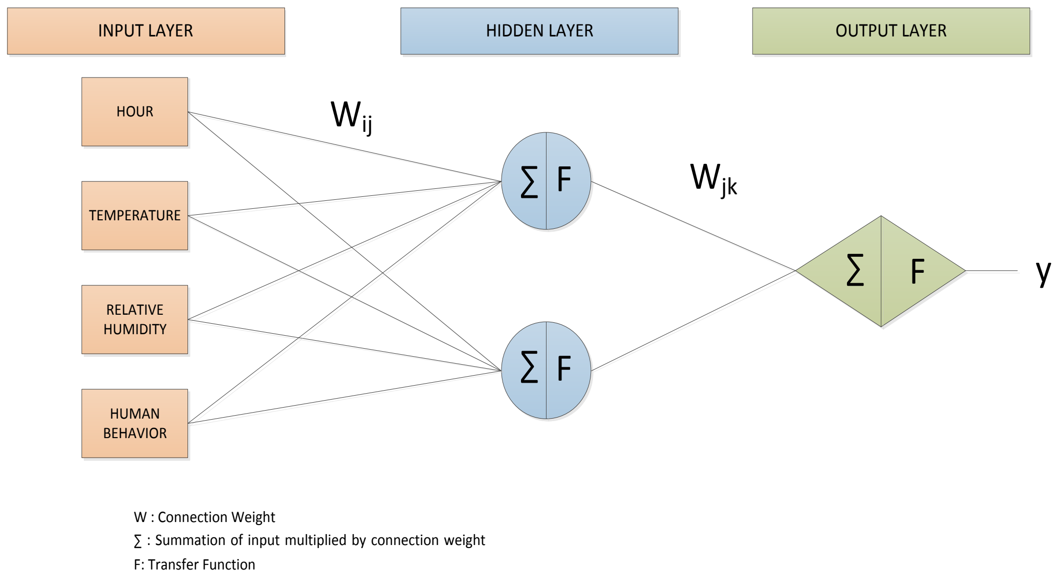


Figure 3.7 General ANN architecture of the study

As seen from Figure 3.7 the model has 3 layers as input, hidden and output. Each layer consists of nodes or neurons, which are connected to nodes in the previous and following layers by connections. The strength of each connection, referred to as its connection weight, can be adjusted through the training process.

Considering Table 3.4, season code is removed from the input variables after the results for the initial calculations. Furthermore, temperature and relative humidity have a direct dependency with the season. After the removal of the season code the following sample input table is given in Table 3.5.

Table 3.5 Sample input data for a selected day (06.08.2007)

Hour	Day Mode	Temperature (C^o)	Humidity (%)	Discharge (m^3/hr)
0	1	24	34	268.22
1	1	23.5	39	296.25
2	1	23	45	35.28
3	1	21.8	50	119.73
4	1	23.8	46	168.85
5	1	26.9	38	161.53
6	1	29.8	30	191.94
7	1	32.7	23	154.42
8	1	33.6	19	186.00
9	1	34.9	16	220.14
10	1	35.8	10	202.65
11	1	36.3	11	215.22
12	1	36.3	10	605.10
13	1	36.7	10	518.92
14	1	36.8	9	208.73
15	1	36.3	9	218.27
16	1	34.8	10	184.52
17	1	33.2	12	238.14
18	1	31.3	13	217.81
19	1	29.5	12	228.81
20	1	26.7	15	358.69
21	1	26	18	371.63
22	1	25.6	17	73.25
23	1	25.3	20	40.36

As stated earlier, 171 days of hourly values are available for input values and 4104 rows of data are available for ANN data domain. In order to prevent generalization error all data are randomized using random number generator (Soyupak, 2003). Before proceeding to the next step the number of hidden layers and the including neurons should be determined. However, this can only be applied by trial and error process. Therefore, initially one hidden layer with 3 neurons was selected as the initial run. The other trials were presented in Table 3.6.

Neural Network calculations can be applied using several programming techniques. Although there are package software programs MATLAB is used for the ANN Calculations. A simple toolbox is built-in in MATLAB package program called Neural Network Toolbox. Before running the application the final checklist is summarized as follows:

1. The structure of the network should be defined, activation functions, biases, weights should be initialized,
2. The parameters associated with the training algorithm like error goal, maximum number of epochs (iterations) should be defined,
3. The training algorithm should be selected,
4. After the neural network has been determined, the result is first tested by the simulating the output of the neural network with the measured input data and compared with the calculated data. Final validation must be carried out with independent data.

The MATLAB commands used in this study are *newff*, *train* and *sim*. *Newff* command generates a feed forward neural network which is called *net*.

$$net = newff(input, output, \{HL_i, O\}, \{AF_i\}, \{TA\}) \quad \text{.............} \quad (3.2)$$

where;

input: input matrix as presented in Table 3.5 (hour, day mode, temperature, humidity columns)

output: output matrix as presented in Table 3.5 (only discharge column)

HL_i : number of hidden layers

O: number of output layer

AF_i : Activation function of i^{th} layer, (default='tansig')

TA: Training Algorithm (default='trainlm')

The default algorithm of command *newff* is Levenberg-Marquardt, *trainlm.* Default parameter values for the algorithms are assumed and are hidden from the user. They need not be adjusted in the first trials. Initial values of the parameters are automatically generated by the command. It was observed that their generation is random and therefore the answer might be different if the algorithm is repeated.

After initializing the network, the network training is originated using *train* command. The resulting MLP network is called *net*1. (Equation 3.3)

$$net1 = train(net, input, output) \quad \text{..........................} \quad (3.3)$$

To test the result sim command is applied. The output of the MLP network is called a. (Equation 3.4)

$$a = sim(net1, input) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

The measured output and the output of the MLP network a can now be compared using different statistical methods.

ANN modelling is an extensive trial and error process and several calculations for the best result are applied in this study. The main criterion of a successfully built ANN model is plotting the regression. Single layer architecture trials were given in Table 3.6.

Table 3.6 ANN modeling trials with one hidden layer

Trial #	Architecture (number of neurons in hidden layer)
1	3-1
2	5-1
3	7-1
4	10-1
5	15-1
6	20-1

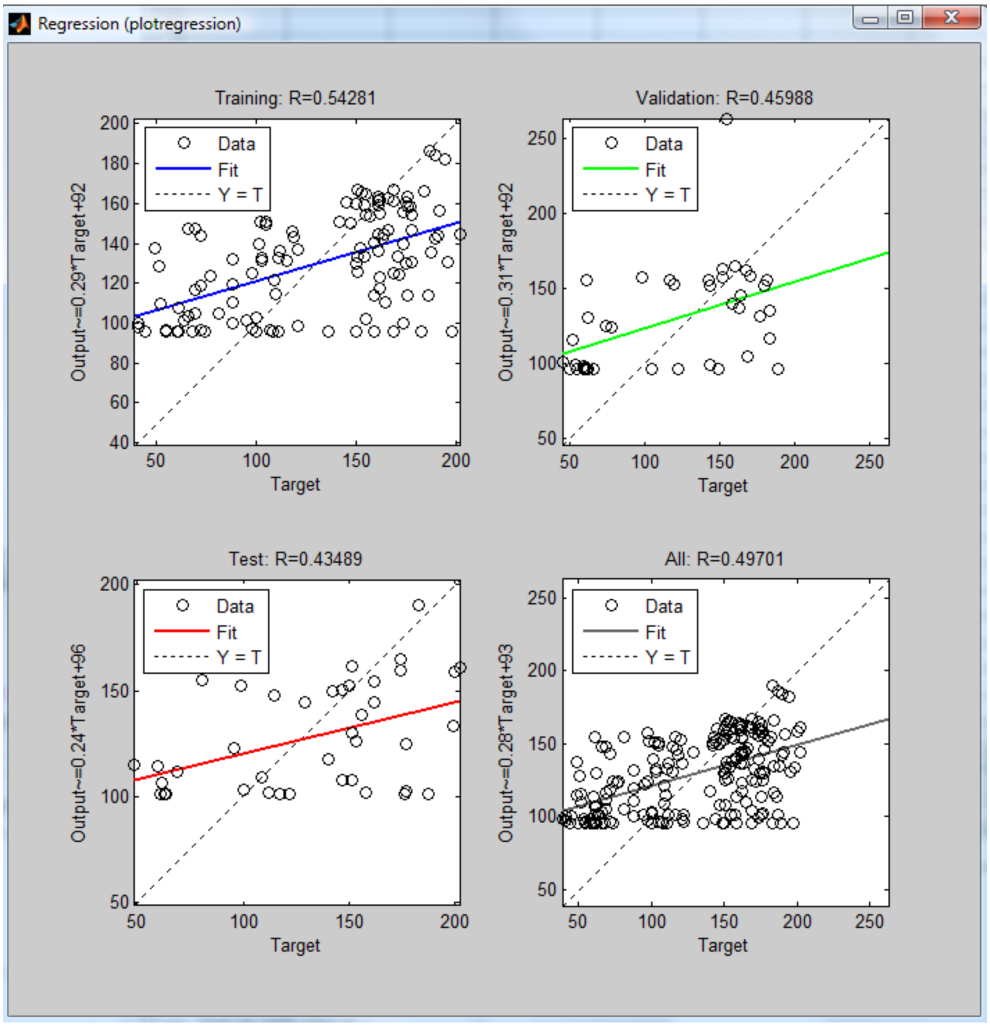


Figure 3.8 Regression plot for Trial #4

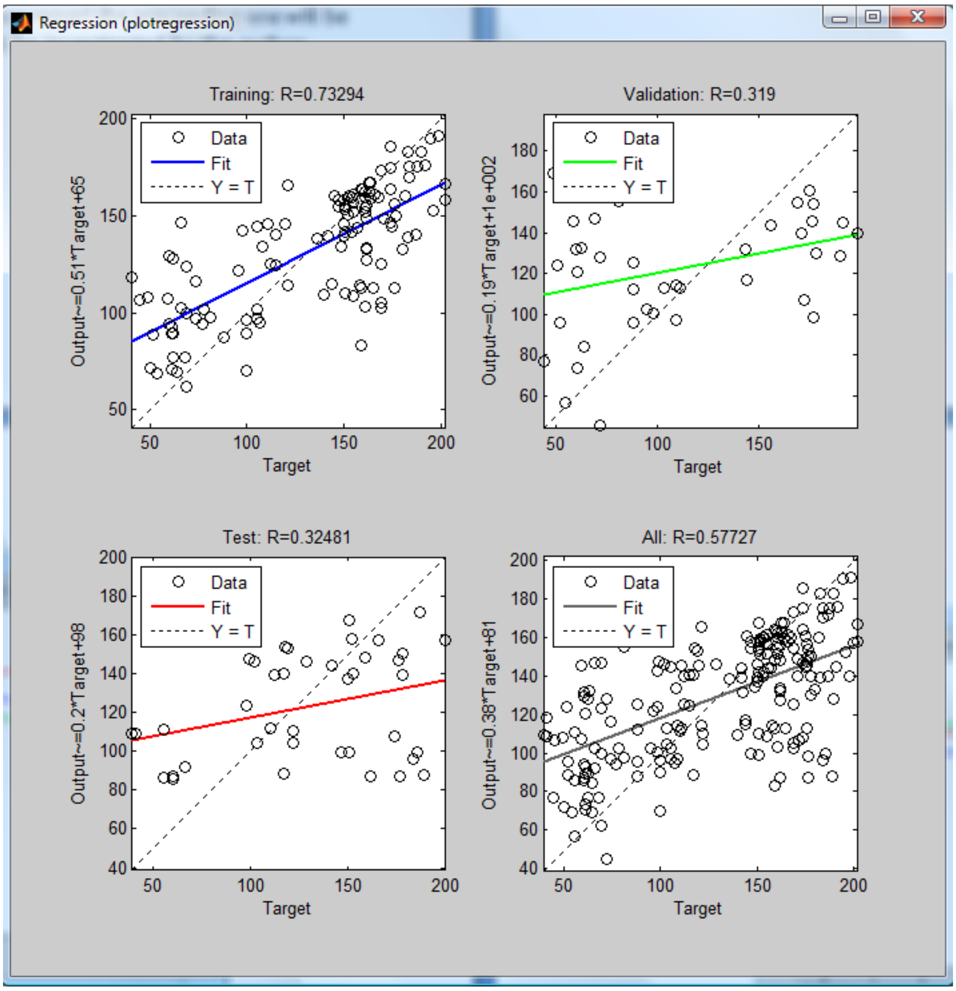


Figure 3.9 Regression plot for Trial #3

After the training, plotregression command is automatically executed by the neural network toolbox program and Figure 3.8 and 3.9 were obtained for related trials. It was seen from the figures that the neural network could not build the relationships between the input and output variables. During the trial an error process, increasing the number of neurons in the hidden layer gives the better results. However, in one of the trials, the number of neurons in hidden layer were decided to be 100 and the program hangs therefore a divergence of the calculation was occurred.

Table 3.7 ANN modeling trials with two hidden layers

Trial #	Architecture (number of neurons in hidden layer)
7	3-3-1
8	5-5-1
9	7-7-1
10	10-10-1
11	15-15-1
12	20-20-1

During the trials, number of hidden layers was decided to be 2 and the related calculations with respect to number of neurons were executed (Table 3.7). Data domain is divided in to 60% for training, 20% for testing and 20% for validating in the neural Network Tool Box by default. The following table gives the other constraints that were continuously set during the trial and error process (Table 3.8).

Table 3.8 Other constraints in ANN model

Constraint Name	Value
Maximum Number of Epochs	200
Error Goal	0.01
Bias (threshold)	0

Consequently, optimization of the number of neurons in the hidden layer and as a result number of neurons in the hidden layer is found as 12 after the comparison of measured and forecasted data considering regression plot and value. During trial and error process, the model architecture having a regression value (best curve fit) of 0.60 and higher can be classified as satisfactory. The final demonstration of the ANN architecture is presented in Figure 3.10. Performance and correlation regression plots are given in Figure 3.11 and 3.12.

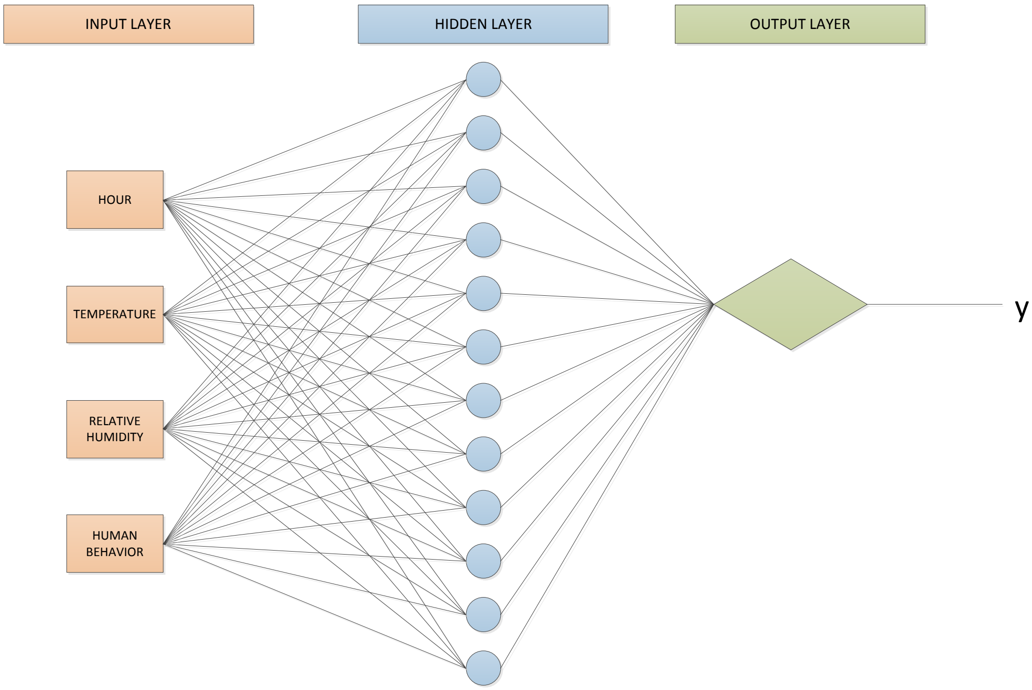


Figure 3.10 Final ANN architecture of the study

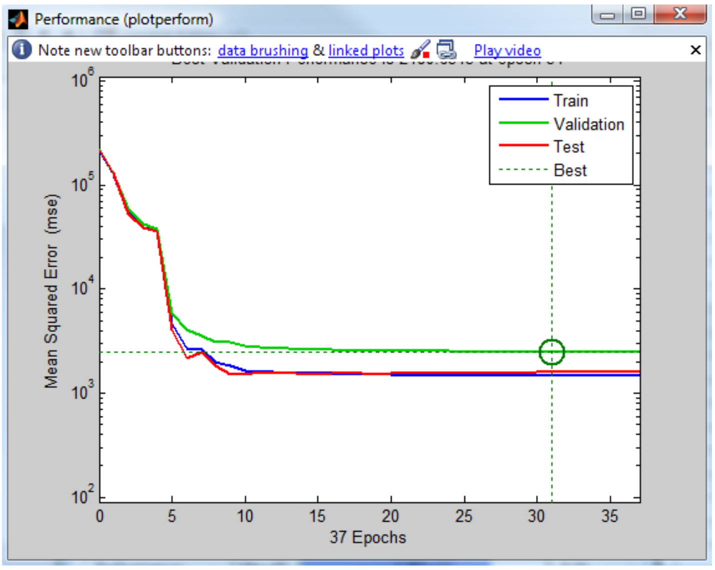


Figure 3.11 Performance plot of the ANN

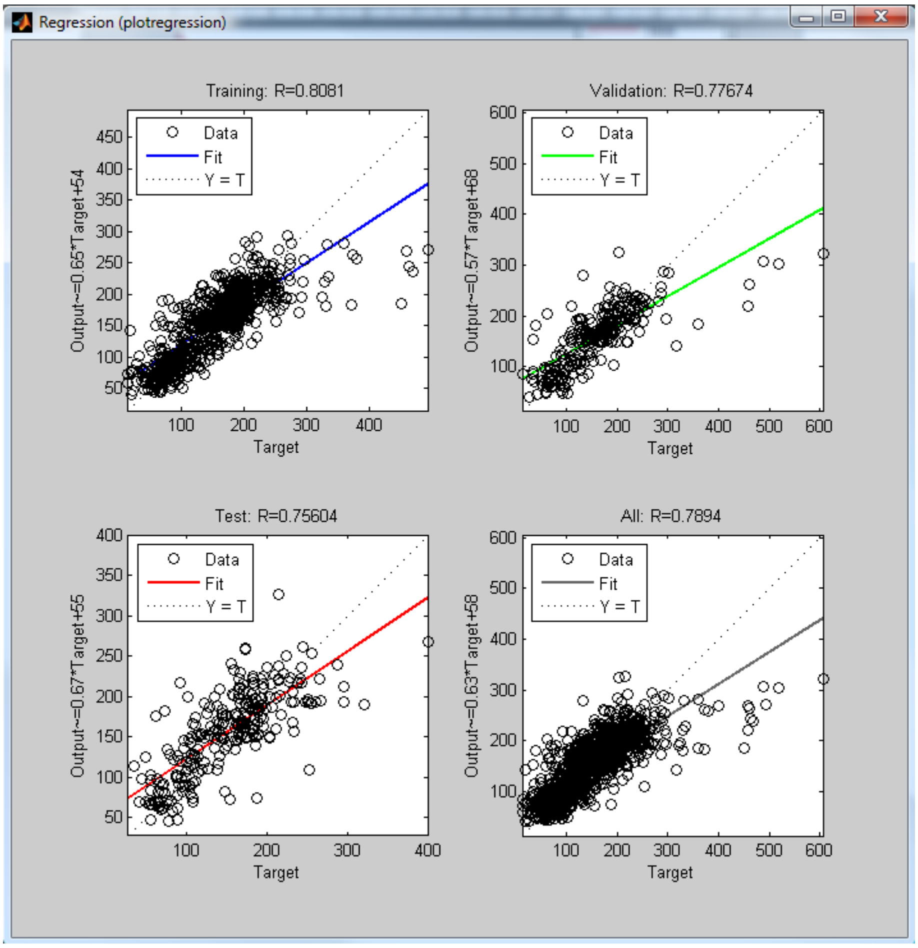


Figure 3.12 Regression plot of the ANN

Final validation of the ANN Model should be done after the successive results of the current model. Therefore a pressure zone of the Antalya Water Distribution Network was analyzed with this model. A general flowchart is given in Figure 3.13 and the neural network flowchart calculations in Figure 3.14.

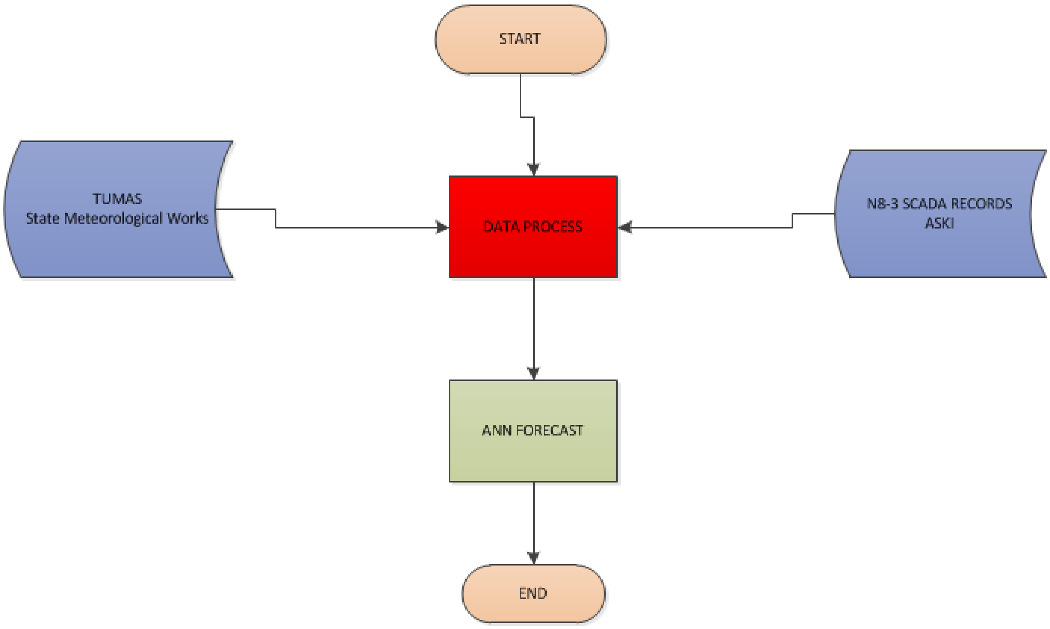


Figure 3.13 General flowchart of DDC forecasting with ANN

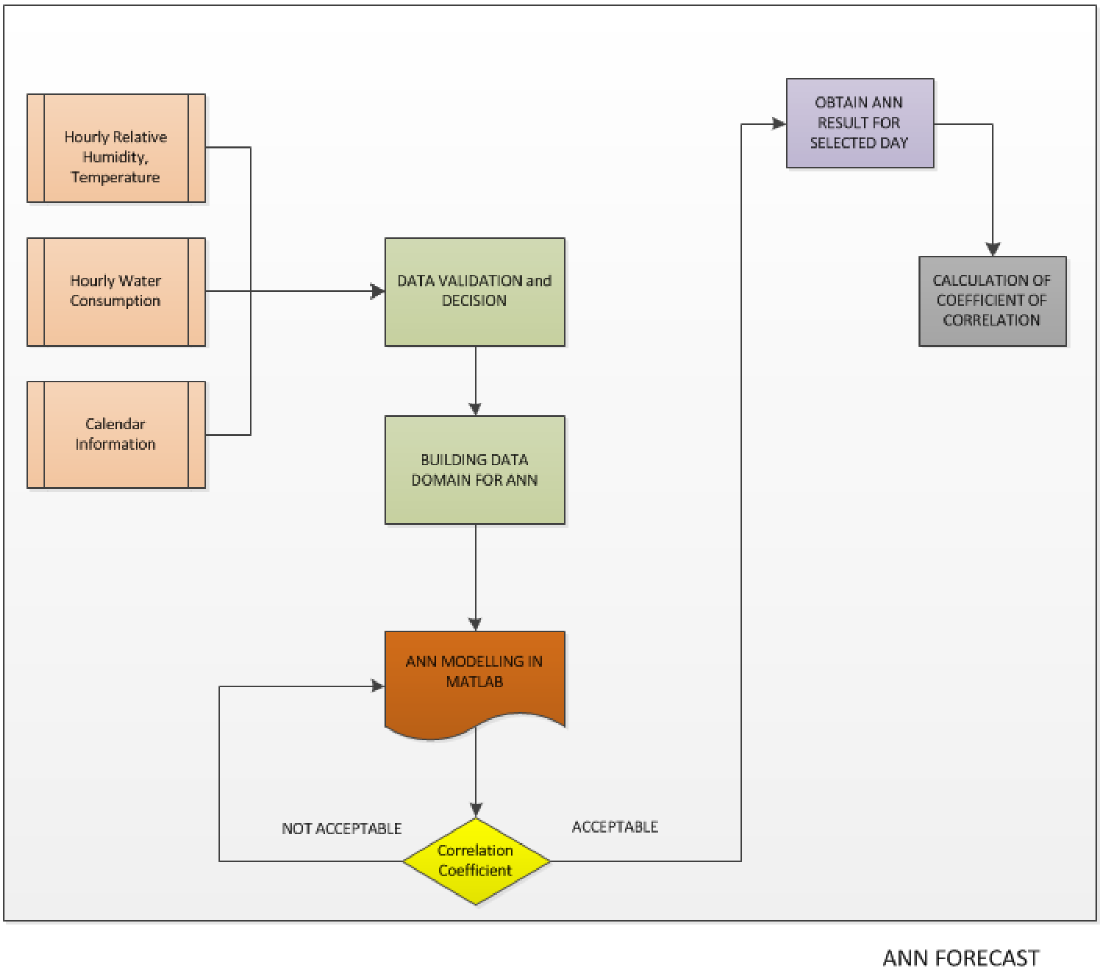


Figure 3.14 Flowchart of ANN calculations

Correlation coefficient, r, measures the strength and direction of a linear relationship between two variables; actual recorded and forecasted. The mathematical formula for computing r is given in Equation 3.5.

$$r = \frac{\sum_{i=1}^{n}(A_i - \overline{A})(F_i - \overline{F})}{\sqrt{\sum_{i=1}^{n}(A_i - \overline{A})^2}\sqrt{\sum_{i=1}^{n}(F_i - \overline{F})^2}} \qquad (3.5)$$

where;

A: actual recorded values

F: forecasted values

$\overline{A}$: average of actual recorded values

$\overline{F}$: average of forecasted values

n: number of records in a day (n=24)

Meanwhile, coefficient of determination R^2 gives the proportion of the variance (fluctuation) of one variable that is forecastable from other variable. It is a measure that allows us to determine how certain forecast from a certain model is. Coefficient of determination varies between 0 and 1 and denotes the strength of the linear association between x and y. In other words, R^2 represents the percent of data that is closest to the line of best fit.

For all selected days, coefficient of determination was calculated as explained above considering the recorded and forecasted DDC values. High R^2 value represents success of ANN forecast.

3.4 Hydraulic Analyses

3.4.1 Performance Analysis

Using the ANN model DDC forecast was calculated and compared with the actual recorded for a selected day, the day before for the selected day and seasonal average. Total volume and peak values were compared for the performance of DDC forecasting. Besides, performance and valve optimization analysis for pressure management are compared for these states.

In the design stage of a Water Distribution Network, it is important that the network supplies the forecasted demands with adequate pressure at all nodes. Traditionally, for all kinds of network models, it is assumed that a fixed-demand assigned to the node is consumed successfully and corresponding nodal pressures and pipe flows are obtained accordingly. These models investigate that what should be the nodal pressures and pipe flows if the predetermined nodal demands are consumed in the network.

Performance analysis of a distribution network can be calculated by using the methods that was introduced in Nohutcu (2002) and Yıldız (2002). The definition of the performance of the system can be “the probability that the system performs within specified limits for a given period of time” (Bhave, 1991).

Bhave (1991) proposed a technique that determines the available nodal flows considering the minimum required nodal heads and termed it as “node flow analysis” (NFA).

When available nodal head is greater than minimum required, there is no problem, the node can be classified as “adequate flow node”. However, if available nodal head is equal to minimum required then the node is classified as “partial flow node”. A partial flow node supply less water than the required demand to the consumers. Consequently, if available nodal demand is less than the minimum required then there is no flow.

At any instant a node is in one of the following three conditions:

When $H_j^{avl} > H_j^{\min}$ (supercritical node), $q_j^{avl} = q_j^{req}$ (adequate flow node);

When $H_j^{avl} = H_j^{\min}$ (critical node), $0 < q_j^{avl} < q_j^{req}$ (partial flow node);

When $H_j^{avl} < H_j^{\min}$ (subcritical node), $q_j^{avl} = 0$ (no flow node);

The available nodal flow is a function of demand pattern and the condition of the distribution network. A time interval, “state”, is considered during which the nodal demands and condition of the network remains constant. The number of states during the period of analysis depends on the number of demand patterns and the number of different combinations of pipes in working or failure conditions.

Three reliability factors, defined by Gupta and Bhave (1994), are described for the performance of water distribution system over the analysis period

- Node Reliability Factor
- Volume Reliability Factor
- Network Reliability Factor

- Node Reliability Factor

Node Reliability Factor (R_n) can be defined as the ratio of the total available outflow volume at a node to the required outflow volume at that node for all states during the period of analysis.

For node j,

$$R_{nj} = \frac{\sum_{s} V_{js}^{avl}}{\sum_{s} V_{js}^{req}} = \frac{\sum_{s} q_{js}^{avl}.t_s}{\sum_{s} q_{js}^{req}.t_s} \quad \text{..........................(3.6)}$$

where;

V^{avl} : available outflow volume

V^{req} : required outflow volume

q^{avl} : available discharge

q^{req} : required discharge

t_s : time duration of state (same for all nodes)

j: subscript denoting demand node

s: subscript denoting state

- Volume Reliability Factor

Volume Reliability Factor R_v can be defined as the ratio of total available outflow volume to the required outflow volume for the entire network for all states during the period of analysis.

$$R_v = \frac{\sum_s \sum_j V_{js}^{avl}}{\sum_s \sum_j V_{js}^{req}} = \frac{\sum_s \sum_j q_{js}^{avl} . t_s}{\sum_s \sum_j q_{js}^{req} . t_s} \quad \text{……………………….(3.7)}$$

where;

V^{avl} : available outflow volume

V^{req} : required outflow volume

q^{avl} : available discharge

q^{req} : required discharge

t_s : time duration of state (same for all nodes)

j: subscript denoting demand node

s: subscript denoting state

- Network Reliability Factor

Node Reliability Factor and Volume Reliability Factor describe the performance of a distribution network considering the total volume that is available at individual nodes and for the entire network respectively. However these ratios do not completely reflect the reliability of the network.

Consider these three situations (Bhave and Gupta, 1994):

- 90% of demand is satisfied for 100% nodes of time 100%. In other words there is a 10% of shortfall at each node during the entire period of analysis.
- 100% of demand is satisfied for 90% of time of nodes 100%. In other words there is no supply at all the nodes during 10% of the time period of analysis
- 100% of demand is satisfied for 100% of time at 90% of nodes. In other words there is no supply for 10% of nodes during the entire period of analysis.

For all these situations R_v = 0.9. For 1 and 2 R_n=0.9 at all nodes while for 3 R_n=1 for 90% of nodes and R_n=0 for 10% of nodes. Although R_v and R_n values are the same for situation 1 and situation 2 their performances are not the same. Similarly, the value R_v is also same for situation 3; however the values of R_n are different.

Therefore R_v and R_n values together indicate the reliability of network for situation 3 but it is preferable to have single reliability factor that can describe situation 3 and also can properly distinguish between the situations 1 and 2.

Because of all these, R_{nw} is defined as;

$$R_{nw} = R_V . F_t . F_n \quad \text{..........................(3.8)}$$

in which $F_{t=}$ time factor and F_n= node factor. Time factor is defined as;

$$F_t = \frac{\sum_s \sum_j a_{js} . t_{js}}{J . T} \quad \text{..........................(3.9)}$$

where;

J = total number of demand nodes

T = period of analysis (= Σ t_s)

a_{js} = 1 if discharge ratio q_j^{avl} / q_j^{req}, at a node for a particular state is equal or more than an acceptable value, and a_{js} = 0, otherwise.

For example; if this acceptable value of discharge ratio is 0.5, a node included in evaluating the time factor if it satisfies at least 50% of demand during the state.

Node factor (F_n) is the geometric mean of the node reliability factors.

$$F_n = \left[\prod_{j=1}^{J} R_{nj} \right]^{1/J} \qquad \text{..........................(3.10)}$$

If the network is unacceptable when the flow available at a node is less than a desired value, R_{nj} is set to zero in equation 3.10 thus F_n and therefore R_{nw} would be zero and the network would be unacceptable. It is obvious that R_{nw} values can properly depict the reliability for the three situations. Situation 3, which is unacceptable, has zero network reliability.

For the assessment of the performance of distribution network, Network Reliability Factor was selected as the indicator. The calculation of performance indicator of the network is based on the Yıldız (2002). Performance analysis were calculated for recorded and forecasted cases for selected 16 days and compared.

3.4.2 Optimum Valve Setting Analysis

Furthermore, as known from the literature and experience, water distribution networks (WDN) are planned and designed to forecast current and future demands. However it is inevitable that excessive pressure will exist and can lead to significant levels of leakage. In order to increase the efficiency of the WDN, leakage should be reduced to appropriate and acceptable levels. There exist a nonlinear relationship between the leakage and average pressure. Any increase in the pressure increases the amount of leakage from the system. There are several methods for minimizing leakage one of which is setting the openings of isolation valves of the network. Valve setting optimization for minimizing the leakage study was conducted by

Ozkan (2008). Ozkan’s code was implemented for minimizing the leakage, satisfying the minimum required heads at nodes by optimizing the opening of necessary flow control valves.

A computer program was implemented by Ozkan (2008), LEAKSOL, which is composed of two components, CODE I and CODE II. CODE I is the valve optimization program to find the optimal flow control valve settings minimizing the leakage volume by using pressure dependent leakage and pressure dependent demand terms. CODE II is a static analysis program providing solution for all combinations of isolation valve settings defined in the network also by pressure dependent leakage and pressure dependent demand terms (Ozkan,2008). All the valve settings were compared with recorded selected day and the percentage of the difference is evaluated. The flowchart of the study was briefly given in Figure 3.15.

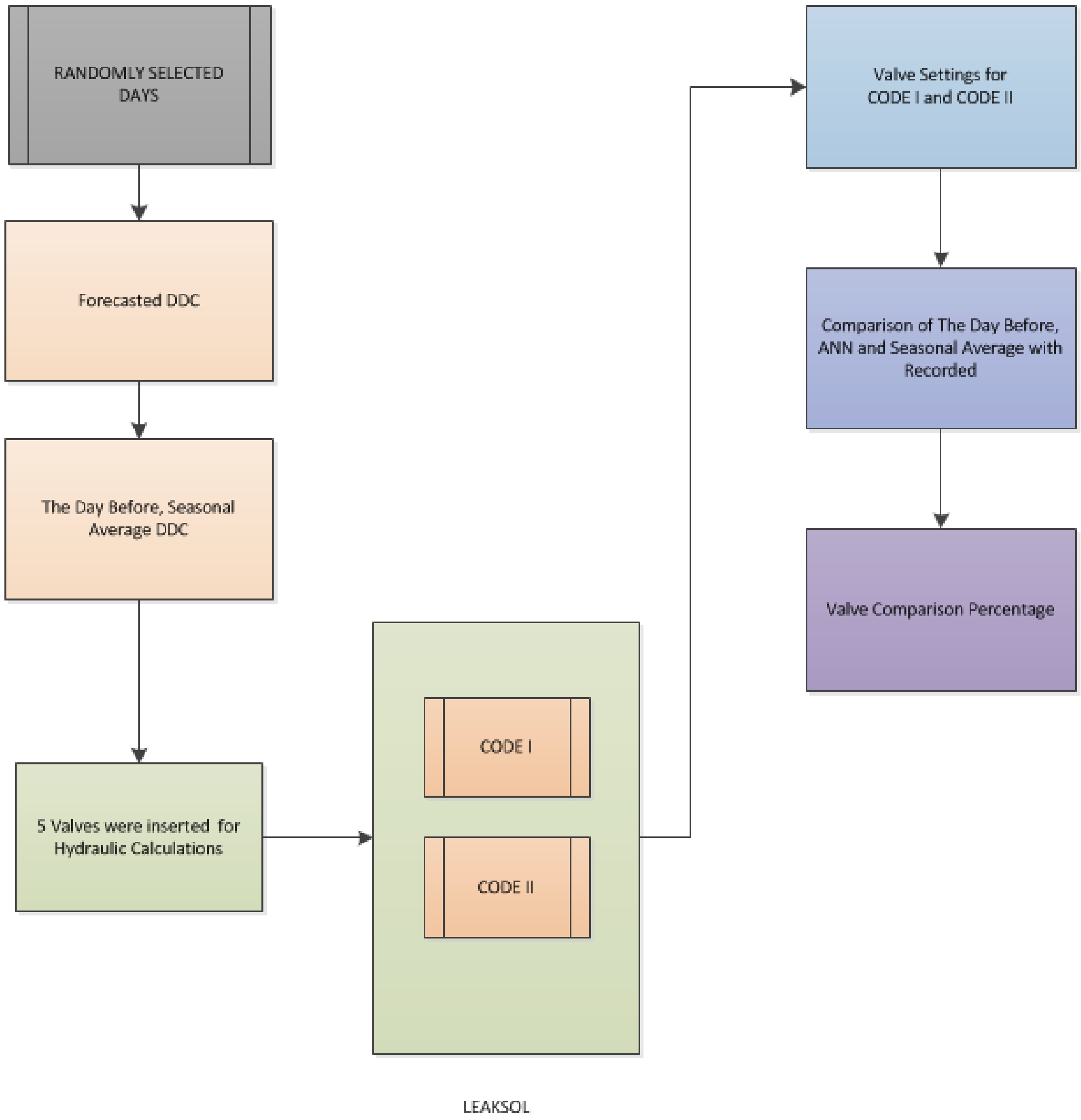


Figure 3.15 Flowchart of Optimum Valve Setting Analysis calculations

CHAPTER 4

CASE STUDY

4.1 Introduction

Hydraulic calculations of water distribution network are mainly based on the physical network characteristics and statistical SCADA records. Using SCADA records and continuity equation, Daily Demand Curve (DDC) and as a result water consumption of the pressure zone of the network can easily be obtained. However, any hydraulic calculation using statistical SCADA records only reflects the past analysis of the network.

As stated briefly in Chapters 2 and 3, the basic aim is to determine the short-term forecast of the DDC for a prescribed pressure zone using Artificial Neural Networks (ANN). After obtaining the forecasted DDCs, performance of the pressure zone considering several different pipe break and fire scenarios throughout a specified time period is calculated and compared with the recorded DDCs. Finally, optimal valve settings for minimizing leakage using pressure dependent demand theory is obtained and compared with recorded values. For this scope, Ankara Municipality Water distribution Network, N8-3 pressure zone was selected for the analysis. Also, a sub-pressure zone of Antalya water distribution network was analyzed in order to compare the effect of water budget and direct measurement.

4.1.1 Ankara Water Distribution System

Ankara Water Distribution Network roughly serves 3.500.000 people by providing approximately 960.000 m^3 of potable water per day from two treatment plants; İvedik and Pursaklar (Official Records from ASKİ and NVİ, General Directorate of Civil Registration and Nationality). This value stands approximately 274 lt/day/capita.

The network of Ankara is divided into five main pressure zones:

- Central and Western Supply Zone (e.g. Sincan, Etimesgut, Eryaman)
- Northern Supply Zone (e.g. Keçiören)
- Eastern and South-Eastern Supply Zone (e.g. Mamak)
- Southern Supply Zone (e.g. Çankaya)
- South Western Supply Zone (e.g. Çayyolu, Ümitköy)

Each main pressure zone has its own sub-pressure zones, which have been divided according to the elevations of the concerned areas. Study area is approximately located in red circle. (Figure 4.1)

4.1.2 Study Area

N8-3 Pressure Zone, which is the zone at the end of north line of Ankara Municipal Water Supply System, was chosen as the study area. It is laterally distributed on two adjacent hills and includes Çiğdemtepe Şehit Kubilay, Sancaktepe, Yayla districts (Yenimahalle County and Keçiören County). There are approximately 45.000 people consuming municipal water from this zone. The network is consisting of 465 links and 373 junction nodes. There exists one storage tank, T53, and one pump station, P23, having three identical parallel pumps. Tank T53 is rectangular in cross section with a height of 6.5 m and has a volume of 5000 m^3. (Figure 4.2)

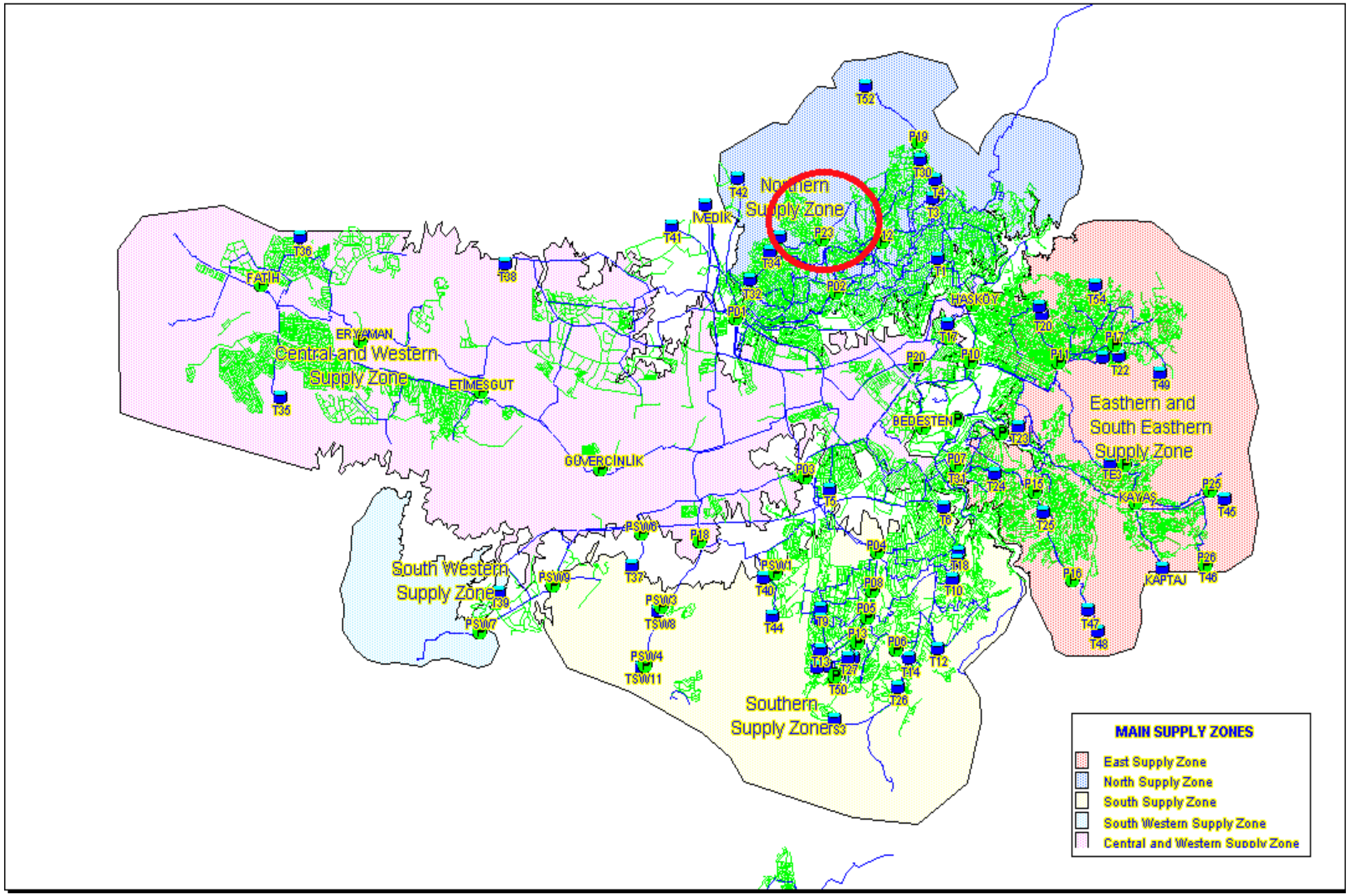


Figure 4.1 Main pressure zones of Ankara and study area (Yıldız, 2002)

There are several reasons for selecting N8 Pressure Zone as study area. This zone is a residential area and water consumption in this zone is nearly homogeneous except for the mosques and the schools around, there is nothing disturbing this homogeneity (Merzi et al., 1998a). The consumers have the same socioeconomic status. There exits very few commercial and industrial customers. Since the system is fed by one pump station and has one tank, the monitoring of this network is relatively easy. The flow rate passing through the pump, input and output pressure head values and tank levels can be easily observed and recorded by the help of Supervisory Control and Data Acquisition System (SCADA).

Furthermore, the skeletonization process is much easier than other network portions. Skeletonization was applied to the current N8-3 pressure zone for fastest hydraulic calculations. The theory was given in the M. Sc. Study of Yıldız (2002).

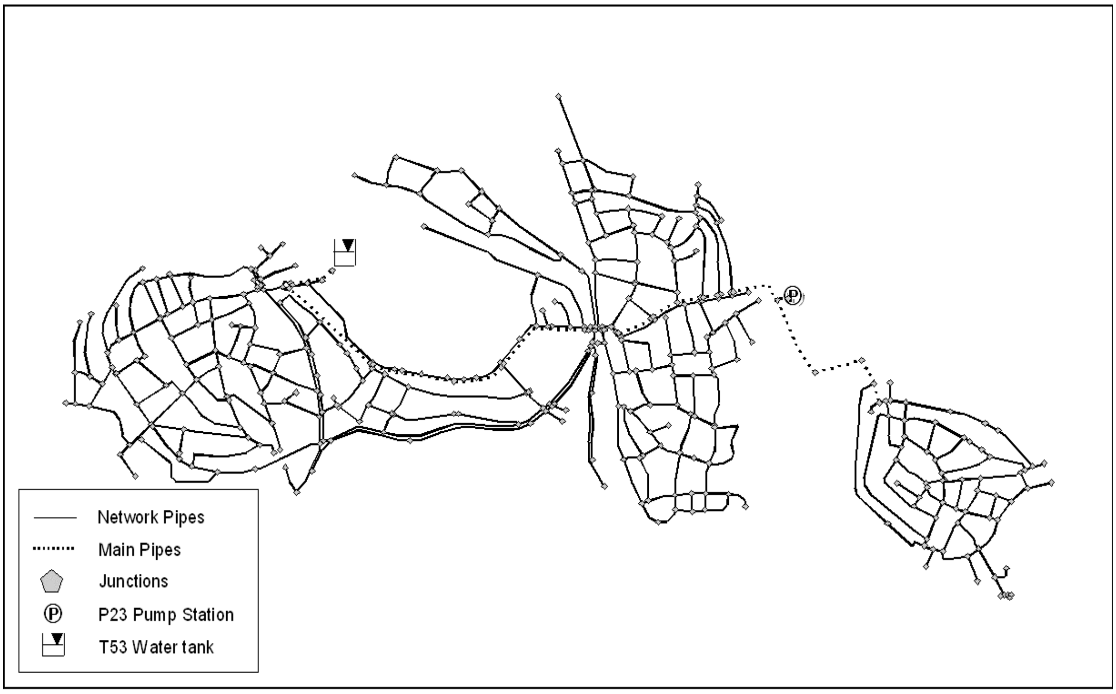


Figure 4.2 N8-3 pressure zone plan view (Yıldız, 2002)

4.1.3 Antalya Water Distribution Network

Antalya is Turkey's seventh biggest city in terms of population. The total population of the city is nearly 2 million and about half of them are living in central counties (Aksu, Döşemealtı, Kepez, Konyaaltı, and Muratpaşa). As the city is one of the major tourism cities of Turkey, its population increases considerably in summer. Water consumption of Antalya's central counties stated above, is around 180,000 m^3/day during the tourism season according to the records at the SCADA centre. Antalya Water and Wastewater Administration (Antalya Su ve Atıksu Ddaresi, ASAT) is the organization, which is responsible for all of the water and wastewater issues in the central counties. Selected study area, Zone 6, was located in Konyaaltı region. A schematic view was demonstrated in Figure 4.3 (Bektas, 2010).

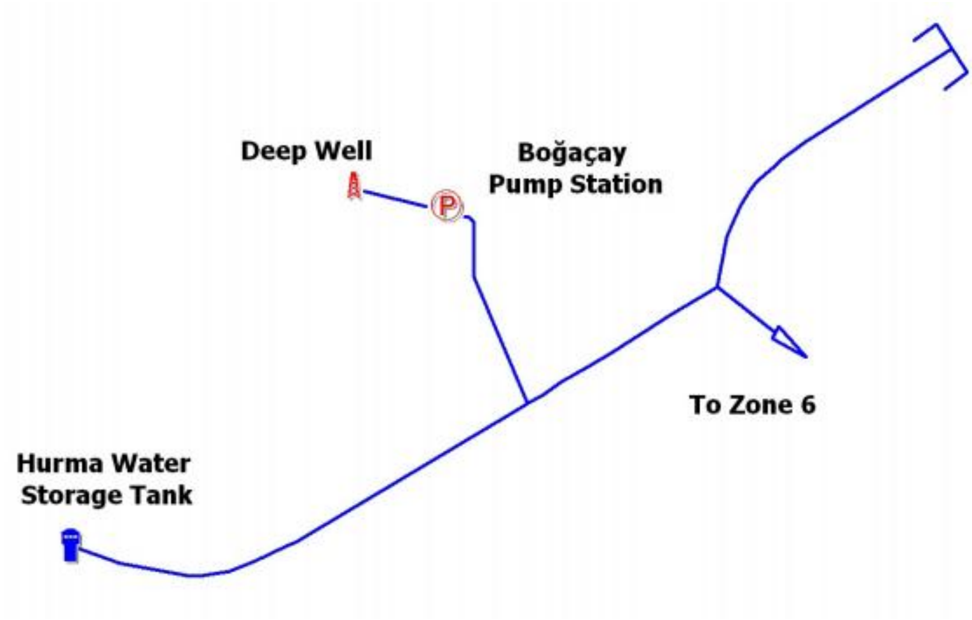


Figure 4.3 Simplified Schematic Drawing of Konyaaltı Water Transmission System and Zone 6 Entrance (Bektas, 2010)

Corresponding consumption values were obtained from direct measurement from the entrance of Zone 6.

4.2 Forecast of Daily Demand Curves (DDCs)

The core of this study is based on the forecasting of DDCs using ANN. This was held by obtaining statistical data from the SCADA Center of the Ankara N8-3 and Antalya Zone 6 pressure zone and creating the statistical DDC for selecting the data domain of the ANN architecture.

4.2.1 Building DDCs using SCADA Records

Daily Demand Curves were derived using continuity equation, Equation 3.1 (Mays, 1996). Flow supplied by the pump P23 is consumed at nodes as nodal consumptions and the remaining is stored at tank T53; under high nodal demands, if P23 could not give adequate water to the system, T53 will feed the system. Theoretical information for the building the diurnal curve of N8-3 pressure zone was given in Chapter 3 (Equation 3.1). Hourly flowrate of P23 and water elevation of T53 was taken from the SCADA records and corresponding DDCs were obtained. On the other hand, Antalya pressure zone does not have any storage and pump station and thus flowmeter on the entrance of the zone gave the actual consumption.

In the following figure, data format obtained from ASKI was presented in Figure 4.4.

P23				T53					
TARİH		DEBİ		TARİH		GÖZ 1		GÖZ 2	
01.08.2007 00:00	p23	z1flow	-0,22	01.08.2007 00:00	t53	lev1	0,11	lev2	0,10
01.08.2007 01:00	p23	z1flow	-0,22	01.08.2007 01:00	t53	lev1	0,11	lev2	0,10
01.08.2007 02:00	p23	z1flow	-0,22	01.08.2007 02:00	t53	lev1	0,11	lev2	0,10
01.08.2007 03:00	p23	z1flow	-0,22	01.08.2007 03:00	t53	lev1	0,11	lev2	0,10
01.08.2007 04:00	p23	z1flow	-0,22	01.08.2007 04:00	t53	lev1	0,11	lev2	0,10
01.08.2007 05:00	p23	z1flow	38,35	01.08.2007 05:00	t53	lev1	0,11	lev2	0,10
01.08.2007 06:00	p23	z1flow	265,04	01.08.2007 06:00	t53	lev1	0,11	lev2	0,10
01.08.2007 07:00	p23	z1flow	474,08	01.08.2007 07:00	t53	lev1	0,11	lev2	0,10
01.08.2007 08:00	p23	z1flow	450,89	01.08.2007 08:00	t53	lev1	0,11	lev2	0,10
01.08.2007 09:00	p23	z1flow	352,39	01.08.2007 09:00	t53	lev1	0,34	lev2	0,34
01.08.2007 10:00	p23	z1flow	225,09	01.08.2007 10:00	t53	lev1	0,59	lev2	0,59
01.08.2007 11:00	p23	z1flow	225,83	01.08.2007 11:00	t53	lev1	0,73	lev2	0,73
01.08.2007 12:00	p23	z1flow	248,23	01.08.2007 12:00	t53	lev1	0,77	lev2	0,78
01.08.2007 13:00	p23	z1flow	249,53	01.08.2007 13:00	t53	lev1	0,77	lev2	0,88
01.08.2007 14:00	p23	z1flow	241,93	01.08.2007 14:00	t53	lev1	0,81	lev2	0,88
01.08.2007 15:00	p23	z1flow	199,32	01.08.2007 15:00	t53	lev1	0,88	lev2	0,88
01.08.2007 16:00	p23	z1flow	202,40	01.08.2007 16:00	t53	lev1	0,80	lev2	0,83
01.08.2007 17:00	p23	z1flow	207,26	01.08.2007 17:00	t53	lev1	0,72	lev2	0,72
01.08.2007 18:00	p23	z1flow	202,65	01.08.2007 18:00	t53	lev1	0,66	lev2	0,67
01.08.2007 19:00	p23	z1flow	167,39	01.08.2007 19:00	t53	lev1	0,55	lev2	0,55
01.08.2007 20:00	p23	z1flow	318,78	01.08.2007 20:00	t53	lev1	0,35	lev2	0,36
01.08.2007 21:00	p23	z1flow	314,55	01.08.2007 21:00	t53	lev1	0,47	lev2	0,47
01.08.2007 22:00	p23	z1flow	314,55	01.08.2007 22:00	t53	lev1	0,58	lev2	0,58
01.08.2007 23:00	p23	z1flow	314,55	01.08.2007 23:00	t53	lev1	0,69	lev2	0,70

Figure 4.4 ASKI SCADA record format

Using Equation 3.1, nearly 1700 DDCs were extracted for candidates of ANN data domain for N8-3 pressure zone. Unfortunately, half of the obtained data were useless due to low data quality, mostly misreading of data from the field and SCADA problems. As stated the selection criteria in Chapter 3.3.2, 171 out of 1700 DDCs were selected as data domain.

4.2.2 Forecasting of DDCs using ANN

As the number of days for the data domain was obtained as 171, randomly selected 16 days were taken as the sample domain. Using the seasonal ANN model comparison of recorded DDC and forecasted DDC were compared. Randomly selected days are given in Table 4.1.

Table 4.1 Dates of randomly selected days

Season	Randomly Selected Days
Autumn	September 6th, 2008 October 11th, 2008 October 25th, 2007 November 16th, 2008
Winter	December 13th, 2008 January 10th, 2009 January 15th, 2009 February 23rd, 2009
Spring	March 8th, 2009 April 23rd, 2008 May 11th, 2009 May 14th, 2008
Summer	June 29th, 2008 July 18th, 2008 August 21st, 2008 August 3rd, 2008

The performance of the ANN was calculated using Coefficient of Determination (Chapter 3.3.3). Coefficient of determination, known as R^2 the forecast of future outcomes on the basis of other related information, is an important indicator and provides a measure of how well future outcomes are likely to be forecasted by the model. Coefficient of determination is used in trend analysis. It is computed as a value between 0 (0 percent) and 1 (100 percent). High value represents better fit. Coefficient of determination is symbolized by R^2 because it is square of the coefficient of correlation symbolized by r. The coefficient of determination is an important tool in determining the degree of linear-correlation of variables ('goodness of fit') in regression analysis. (Web 5) The corresponding values for the selected days were represented (Table 4.2).

Table 4.2 Average seasonal forecast performance and corresponding number of records

Season	Autumn	Winter	Spring	Summer
Average R^2	0.65	0.74	0.81	0.84
Number of records	504	552	864	600

Considering the results given in Table 4.2, it can be said that ANN forecast is more successful in summer season with respect to R^2 analysis. The graphical representations of relatively worse, medium and best forecasted days were given with related R^2 values in Figures 4.5, 4.6 and 4.7 respectively. The graphics for other days were given in Appendix A.

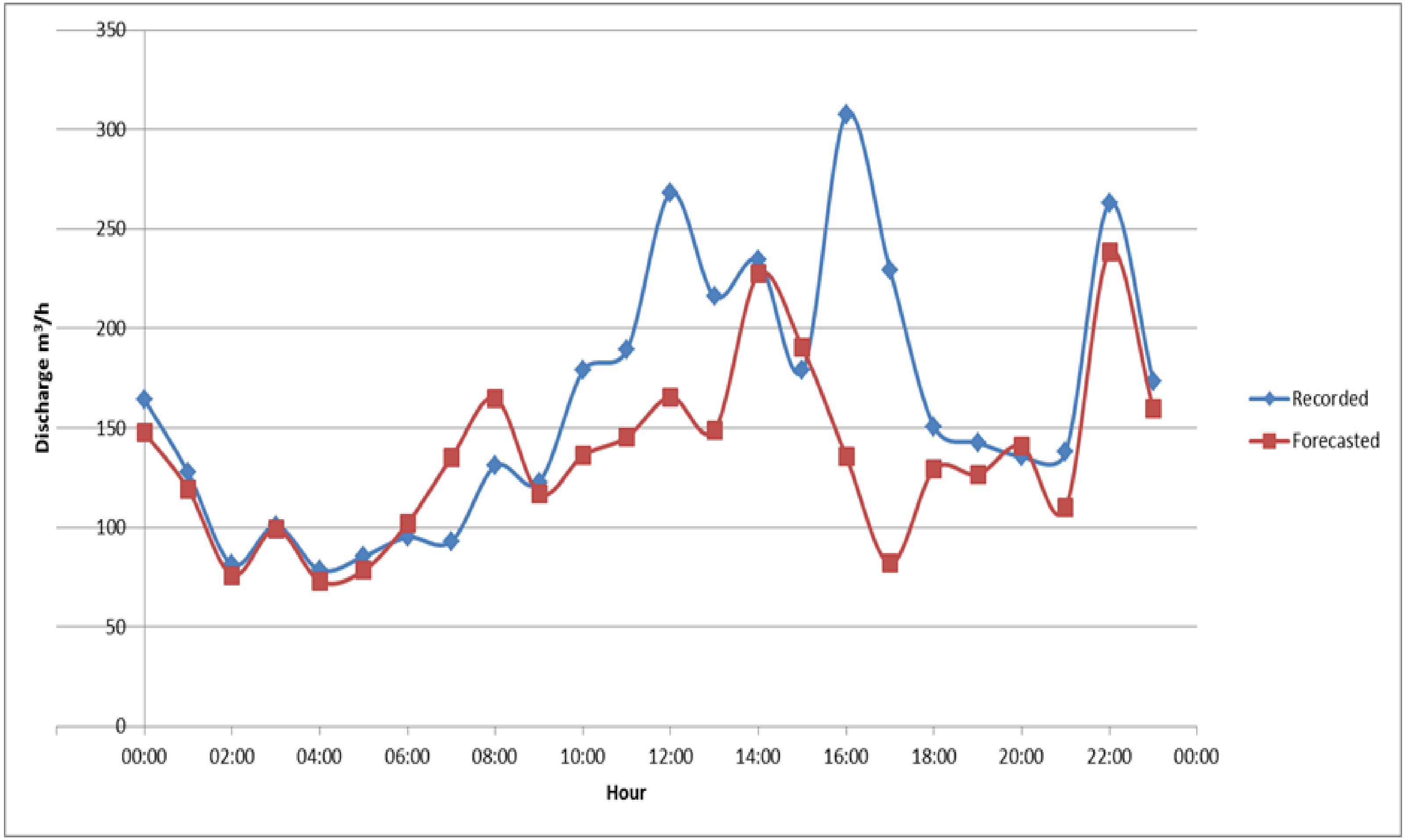


Figure 4.5 DDCs of 16.11.2008 (R^2=0,38)

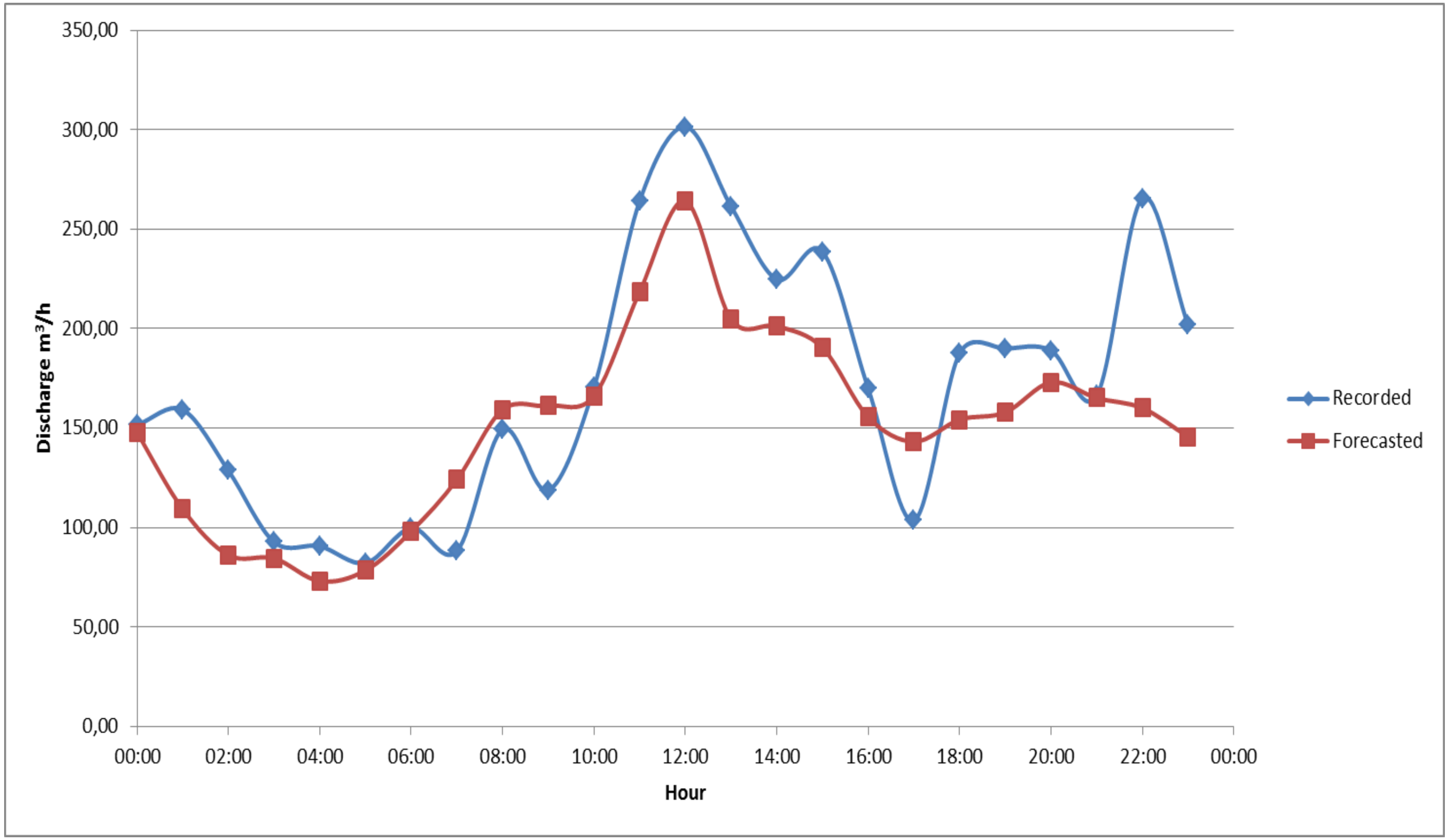


Figure 4.6 DDCs of 08.03.2009 (R^2=0,73)

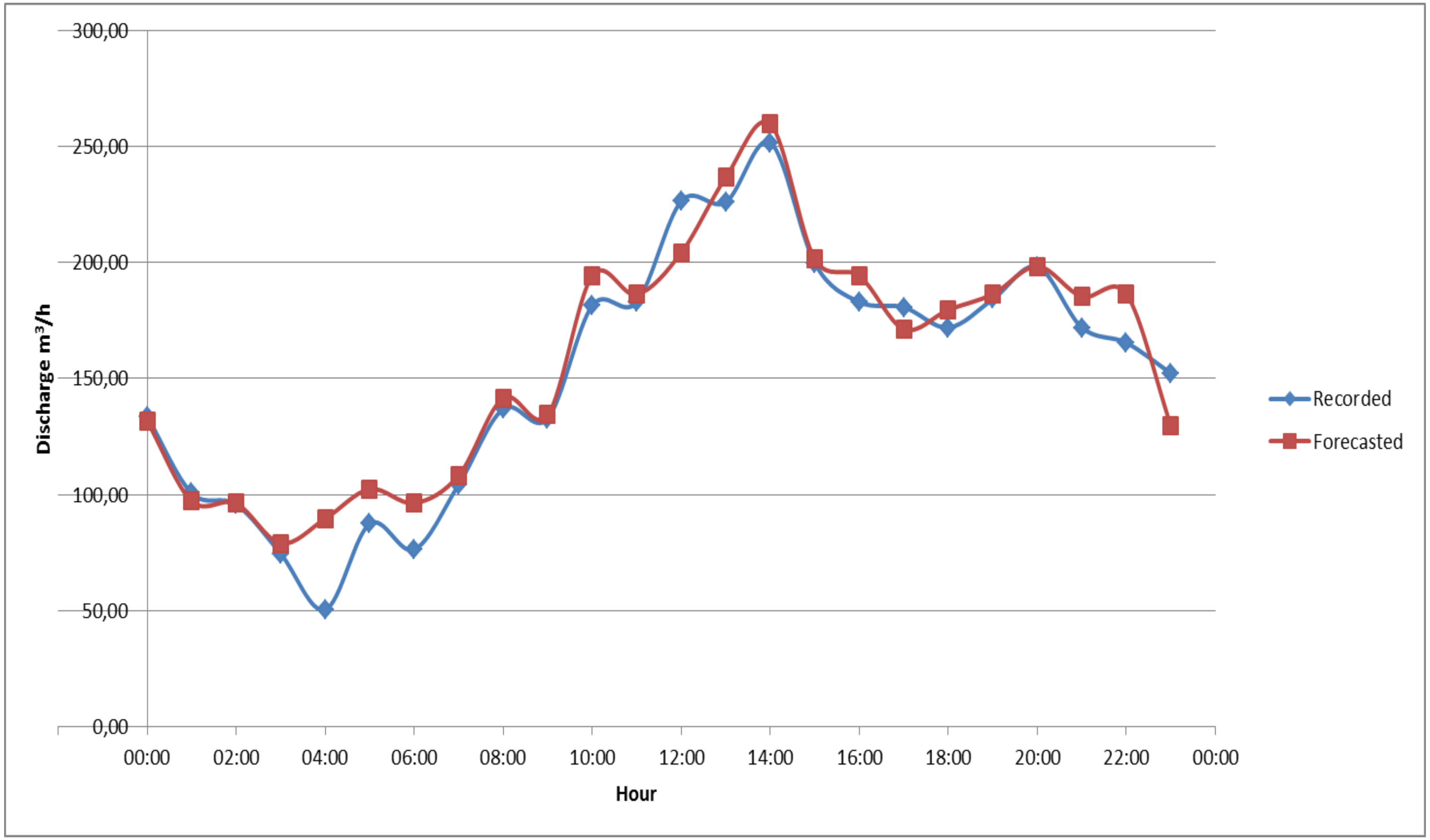


Figure 4.7 DDCs of 03.08.2008 (R^2=0,94)

As seen from the Figure 4.5, the model predicts two of three peaks of the recorded DDC; however forecasted values are not close to recorded values thus it is not a satisfactory forecast. Apparently, there is an increase in water consumption at 22:00. Considering the training set of autumn values, nearly all DDCs have the same peak at that time. As a result, the explanation may be a erroneous readings of the devices and constant water consumption due to an extraordinary situation during this period. Considering other figures (4.6 and 4.7) the forecasted values are close to recorded values and according to R^2 values, forecasted DDCs may be accepted as satisfactory.

The other selected days were presented in Appendix A as stated before. It was seen that the forecasted values are close to the recorded values especially in summer season. Considering the shape of the DDCs, most of the peaks are forecasted successfully as the R^2 value is high. (Figure 4.7) Consequently, summer is selected as the best season for the forecast of the DDCs using ANN while autumn is the worst one.

Considering the 24 hours of forecast, hourly DDC forecasting will help utility for the short operational schedule management of a water distribution network. On the other hand, short-term forecasting, like 6-hours period will guide utility to take necessary precautions such as pump operation schedule, valve setting management. The model was used for the very short term forecast, next 6-hours, and the following results were obtained for randomly selected 2 days (Table 4.3).

Table 4.3 Hourly short term forecast

Hours	21.08.2008 recorded (m^3/hr)	21.08.2008 forecasted (m^3/hr)	02.02.2009 recorded (m^3/hr)	02.02.2009 forecasted (m^3/hr)
18:00	155.98	147.31	153.65	171.12
19:00	195.44	184.69	149.93	174.55
20:00	165.02	168.14	141.81	175.94
21:00	152.51	153.27	139.17	174.14
22:00	133.40	134.69	135.74	174.82
23:00	215.81	226.98	137.13	173.36

Table 4.4 Short term forecast performance

Days	21.08.2008	02.02.2009
Average R^2	0.94	0.51

As seen from Table 4.4, 21.08.2008 gave successive short term forecast compared with the recorded values.

4.2.3 Total Volume and Peak Values

Water utilities use hourly DDC data for the operational management of distribution networks. On the other hand, Total Volume, Average Volume and Peak values help utilities for planning stage of the network. A comparison is presented using recorded, forecasted, the day before recorded and seasonal average values considering randomly selected days (Table 4.1).

Related results are given in Tables 4.5-4.8. As seen from the Table 4.8 forecasted values of summer season are more close to recorded values. thus 18.07.2008 is the most successful day rather than others comparing recorded and forecasted values. However, generally seasonal average forecasted values are close to the recorded values. As a result, seasonal average values reflect the trend and behaviors of the water consumption for a selected day.

Table 4.5 Comparison of total volume and peak values for autumn days

Autumn	16.11.2008		11.10.2008		06.09.2008		25.10.2008	
	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)
Recorded	3886.59	307.68	3664.13	224.04	3664.13	249.36	4077.52	295.49
The Day Before	3714.72	343.90	4067.26	220.86	4067.26	230.38	3292.35	217.22
Forecasted	3251.09	238.58	3773.30	198.18	3773.30	235.77	3863.72	245.64
Season Average	3579.90	247.75	3579.90	247.75	3579.90	247.75	3579.90	247.75

Table 4.6: Comparison of total volume and peak values for winter days

Winter	23.02.2009		10.01.2009		13.12.2008		15.01.2009	
	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)
Recorded	3538.34	335.84	4063.81	298.22	3291.11	252.38	4077.52	295.49
The Day Before	4098.02	276.74	3530.48	225.69	3386.99	249.56	3612.28	249.09
Forecasted	3491.60	248.33	3524.14	251.97	3512.40	245.37	3565.04	254.68
Season Average	3620.03	233.84	3620.03	233.84	3620.03	233.84	3620.03	233.84

Table 4.7 Comparison of total volume and peak values for spring days

Spring	08.03.2009		11.05.2009		23.04.2008		14.05.2008	
	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)
Recorded	4096.56	301.50	3925.80	282.08	3634.13	247.20	3449.81	224.02
The Day Before	3897.51	261.01	3646.26	257.38	4067.26	230.38	3386.71	226.18
Forecasted	3622.80	264.14	3553.77	241.17	3718.50	255.28	3327.43	201.37
Season Average	3654.90	233.01	3654.90	233.01	3654.90	233.01	3654.90	233.01

Table 4.8 Comparison of total volume and peak values for summer days

Summer	29.06.2008		18.07.2008		21.08.2008		03.08.2008	
	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)	Total Volume (m^3)	Peak (m^3/h)
Recorded	3858.54	244.28	3480.80	230.78	3781.85	243.84	3667.68	251.63
The Day Before	3972.87	275.78	3594.16	238.35	3532.79	242.66	3595.85	253.98
Forecasted	3616.36	235.77	3455.71	231.57	3517.08	233.51	3789.11	259.57
Season Average	3736.15	243.43	3736.15	243.43	3736.15	243.43	3736.15	243.43

4.2.4 Case Study of Antalya Water Distribution Network

The ANN architecture developed for N8-3 network is applied to one of the sub-zones of the Antalya Water Distribution Network. Completely the same procedure was applied and 2 days for each season were randomly selected from the data domain (Table 4.5). From TUMAS, data from the Antalya meteorological station were obtained. The graphical representations of relatively worse, medium and best forecasted days were given with related R^2 values in Figures 4.8, 4.9 and 4.10 respectively. Graphical results of the other selected days were given in Appendix B.

Table 4.9 Randomly selected days for each season

Season	Randomly Selected Days for Antalya
Autumn	October 25th, 2009 November 30th, 2009
Winter	December 6th, 2009 January 31st, 2009
Spring	March 8th, 2010 May 22nd, 2010
Summer	July 15th, 2009 August 8th, 2009

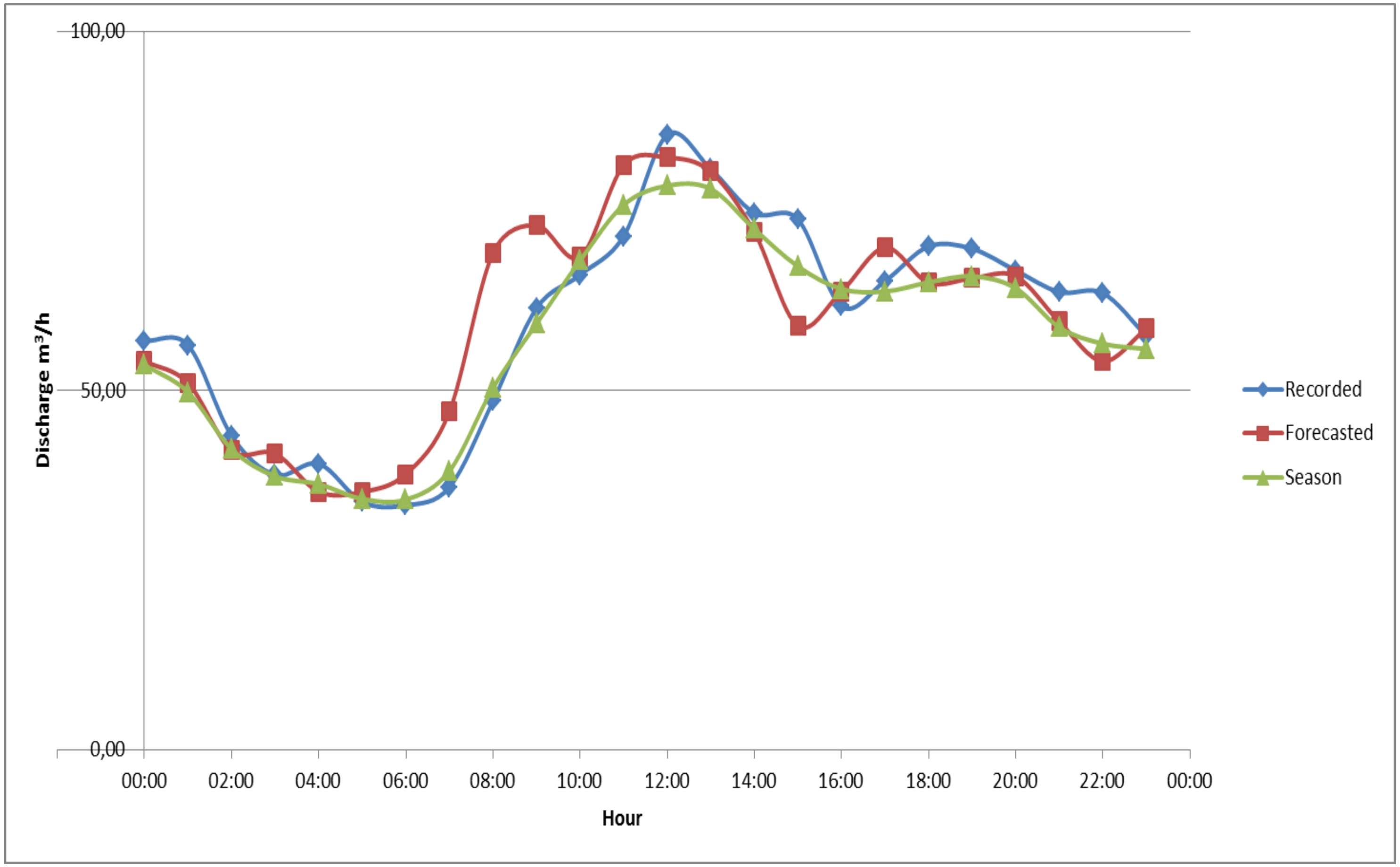


Figure 4.8 DDCs of 06.12.2009 (R^2=0,76)

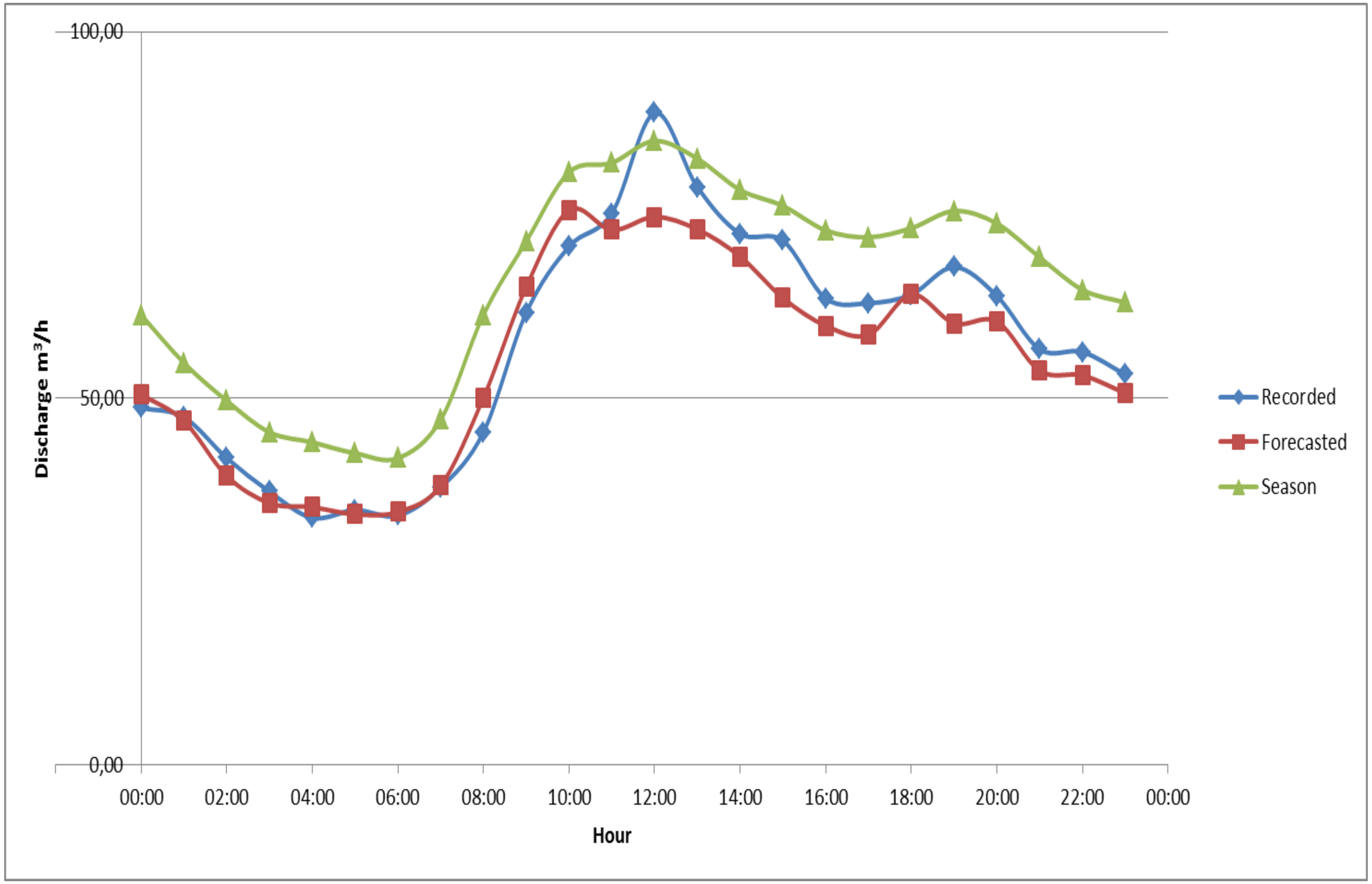


Figure 4.9 DDCs of 30.11.2009 (R^2=0,85)

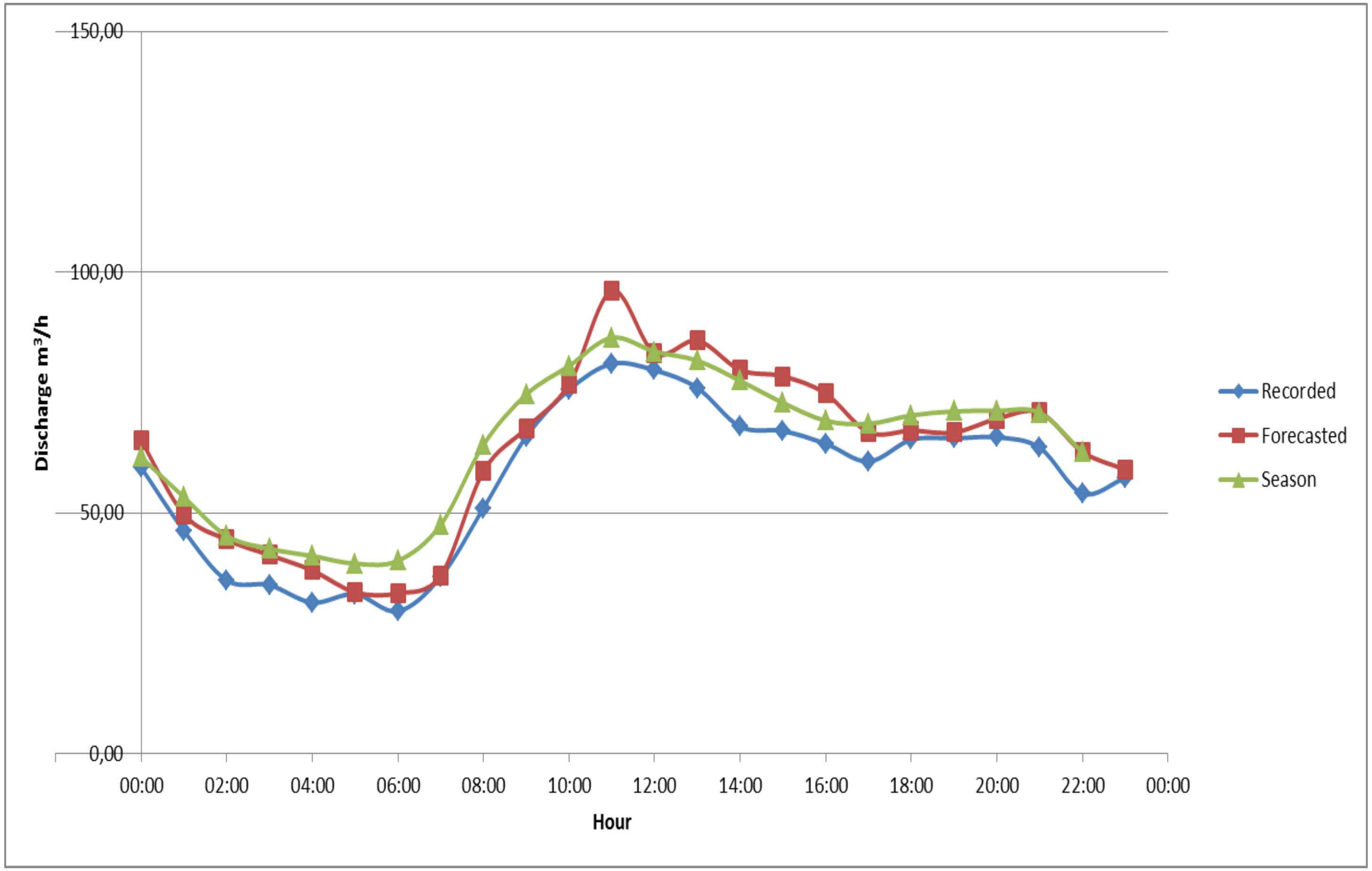


Figure 4.10 DDCs of 22.05.2010 (R^2=0,94)

Table 4.10 Average seasonal forecast performance and corresponding number of records

Season	Autumn	Winter	Spring	Summer
Average R^2	0,84	0,78	0,91	0,88
Number of records	912	984	1272	1392

From the table 4.10, obviously, spring has the best performance for forecasting the hourly DDC. ANN model works better in this study rather than N8-3 pressure zone. The main reason of this success is the availability and reliability of the training data domain for ANN.

4.3 Performance Analysis

As stated in Chapter 3.4.1, in the design stage of a Water Distribution Network, it is important that the network supplies the forecasted demands with adequate pressure at all nodes. Traditionally, for all kinds of network models, it is assumed that a fixed-demand assigned to the node is consumed successfully and corresponding nodal pressures and pipe flows are obtained accordingly. Necessary modifications are applied to the network when an insufficient nodal pressure is detected on any node.

The definition of the performance of the system can be "*the probability that the system performs within specified limits for a given period of time*" (Bhave, 1991). Yıldız (2002) introduced reliability analysis of a water distribution network. The study presented 50 pipe break scenarios for the skeletonized network of the N8-3 pressure zone considering actual valve locations and five fire conditions. Calculations were applied with the theoretical considerations given in the study and related reliability factors according to Gupta and Bhave (1994) were calculated.

However, the reliability analysis was applied using past SCADA records. In this study, as stated in Chapter 3.4.1, network reliability factor was selected as a performance indicator and calculated for recorded and forecasted days as given in Table 4.7.

Table 4.11 Results of performance indicators for recorded and forecasted cases

Randomly Selected Days	Recorded Performance	Forecasted Performance
06.09.2008	0.896	0.902
11.10.2008	0.877	0.866
25.10.2008	0.868	0.876
16.11.2008	0.893	0.848
13.12.2008	0.878	0.893
10.01.2009	0.904	0.897
15.01.2009	0.913	0.896
23.02.2009	0.912	0.904
08.03.2009	0.902	0.895
23.04.2008	0.894	0.886
11.05.2009	0.897	0.892
14.05.2008	0.904	0.898
29.06.2008	0.931	0.928
18.07.2008	0.916	0.914
21.08.2008	0.898	0.902
03.08.2008	0.921	0.917

4.4 Optimum Valve Setting Analysis for Pressure Management

Optimum valve setting analysis for pressure management considering the minimum head requirement 20 m for each node was applied according to the method that was presented by Ozkan (2008). A preliminary study was conducted in 2001 for determining the sub-sections of N8-3 pressure zone (Ozkan, 2001). The valves were located at these determined points respectively.

As stated in Chapter 3.3, seasonal forecast method was applied using ANN for randomly selected days (Table 4.1). Recorded, forecasted, the day before recorded day and seasonal average data were introduced and corresponding hourly valve status was compared with recorded results. Valve locations were selected as follows for the prescribed N8-3 skeletonized network considering the subzones (Ozkan, 2001) (Figure 4.11).

Ozkan (2008) implemented a computer program which optimizes the openings of the valves for minimizing leakage and thus pressure management. CODE I takes the valves as flow control while CODE II takes them as isolation valves. In other words, the settings of the valves for CODE I represents the percentage of the opening while CODE II gives zero (0) as closed and one (1) as opened.

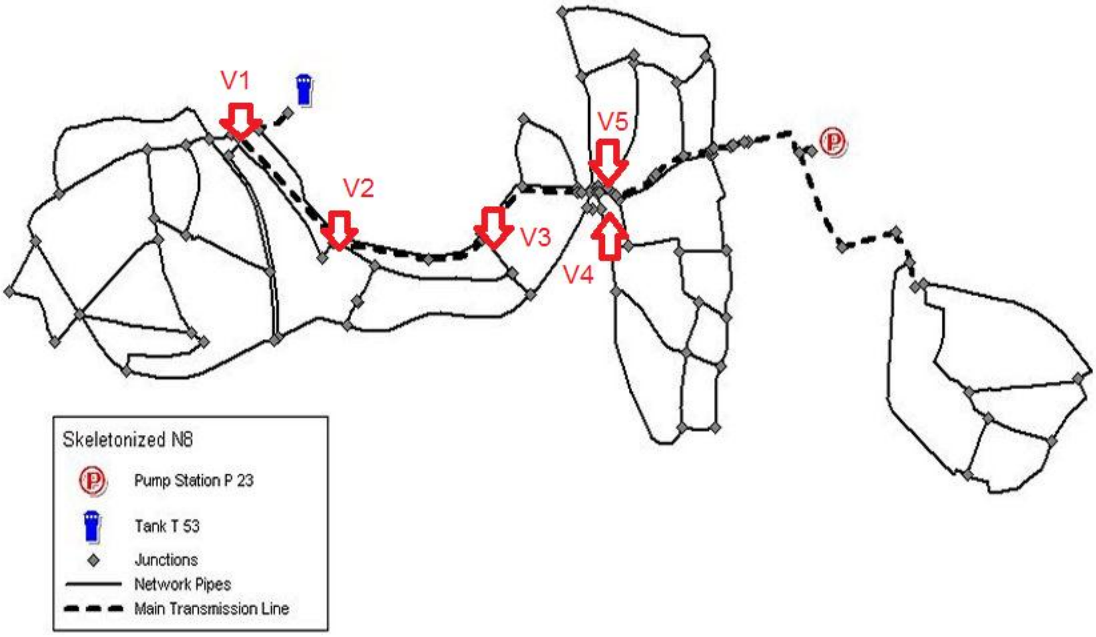


Figure 4.11 Locations of valves on skeletonized N8-3 pressure zone (Yıldız, 2002)

Valve setting analysis was applied for recorded, the day before recorded, forecasted and seasonal average for the days listed in Table 4.8. Valve settings for each day were compared with the related recorded settings and the percentage match was calculated. Results were demonstrated in Appendix C.

Valve 3 may be accepted as the most successful valve which means that whatever the DDC it is always opened for all cases. The status of other valves varies considering the change in pressure in the system.

Between 16:00 – 24:00 no valve setting was changed unless there is a sharp drop of pressure. In the morning through midday, between 06:00-12:00, the states of Valve 2 and Valve 5 change only. Comparison of the valve status of forecasted, the day before and seasonal average the following results were obtained. (Table 4.8)

The procedure is as follows, for CODE I, since the settings of the valves reflect the percentage of the opening, the difference was calculated for each valve and percentage of the average of this difference gives the similarity of valve setting. In other words, if the average of the difference is calculated as 0, 05 the comparison percentage is 95%.

On the other hand for CODE II, there are 5 valves and 24 hours as a result 120 cells were compared for every different situation. (the day before, forecasted and seasonal average individually). The different situations were counted and divided to 120 and multiplicated by 100 and related percentage was found (Appendix C).

Table 4.12 Valve comparison percentage with respect to recorded valve settings

Selected Days	Situation	CODE I (%)	CODE II (%)
16.11.2008	Forecasted	97.00	98.33
	The Day Before	96.00	99.17
	Seasonal Average	98.00	99.17
11.10.2008	Forecasted	96.00	95.00
	The Day Before	97.00	97.50
	Seasonal Average	99.00	99.17
25.10.2008	Forecasted	96.00	97.50
	The Day Before	98.00	98.33
	Seasonal Average	95.00	96.67
06.09.2008	Forecasted	97.00	96.53
	The Day Before	97.00	96.67
	Seasonal Average	98.00	99.17
23.02.2009	Forecasted	98.00	95.00
	The Day Before	96.00	94.17
	Seasonal Average	98.00	95.83
10.01.2009	Forecasted	92.00	97.50
	The Day Before	97.00	95.00
	Seasonal Average	96.00	95.83
15.01.2009	Forecasted	94.00	97.50
	The Day Before	97.00	95.83
	Seasonal Average	97.00	96.67
13.12.2008	Forecasted	98.00	98.33
	The Day Before	97.00	96.67
	Seasonal Average	99.00	95.83

Table 4.12 (continued)

08.03.2009	Forecasted	99.00	97.50
	The Day Before	98.00	97.50
	Seasonal Average	99.00	96.67
10.05.2008	Forecasted	98.00	97.50
	The Day Before	96.00	97.50
	Seasonal Average	97.00	96.67
14.05.2008	Forecasted	97.00	96.67
	The Day Before	95.00	97.50
	Seasonal Average	98.00	96.67
23.04.2008	Forecasted	99.00	100
	The Day Before	97.00	99.17
	Seasonal Average	95.00	96.67
21.08.2008	Forecasted	99.00	98.33
	The Day Before	98.00	95.00
	Seasonal Average	99.00	98.33
03.08.2008	Forecasted	98.00	98.33
	The Day Before	97.00	99.17
	Seasonal Average	99.00	98.33
18.07.2008	Forecasted	99.00	99.17
	The Day Before	97.00	98.33
	Seasonal Average	98.00	98.33
29.06.2008	Forecasted	98.00	99.17
	The Day Before	97.00	98.33
	Seasonal Average	98.00	98.33

CHAPTER 5

DISCUSSION OF RESULTS

This chapter summarizes the main results of the case study presented in Chapter 4; furthermore implications of the results are discussed.

The main objective of this research was to develop a new methodology for short-term forecasting of hourly Daily Demand Curves (DDC) using Artificial Neural Networks (ANN). Forecasting of DDCs are necessary for short term planning and operation of water distribution networks. As employed in Case Study (Chapter 4) performance analyses under predefined scenarios were realized; furthermore comparisons of optimum valve settings for pressure management were calculated using the forecasted DDCs.

The study is applied for randomly selected four days for each season. Recorded DDCs were compared with forecasted DDCs and seasonal average DDCs. Also, hourly short-term forecast and total volume with peak values were evaluated in order to see whether the model is successful or not. As the model gives relatively satisfactory results, performance analysis and optimum valve settings for pressure management were calculated for the comparison with the recorded values. Besides, optimum valve settings were evaluated for (i) the day before recorded day and (ii) seasonal average.

Apparently, the forecasted values are to be close to the recorded values which lead the performance and the success of the ANN model. On the other hand, estimation of network performance analyses and valve settings employed key role to a utility for customer conformity and pressure management in order to reduce leakage from the system.

The important outcome of this study can be briefly outlined as follows:

1. Forecasting the daily demand curves assumes that there is no extraordinary situation such as fire-fighting and any incident on distribution network (pipe, pump, tank failures) etc.

2. Results demonstrated in Chapter 4 and Appendices, show that the ANN model works satisfactorily with an average of 75% success in Ankara N8-3 pressure zone according to R^2 values. Summer season is more satisfactory than other seasons for forecast since it has the maximum R^2 value and (Chapter 3.3.3) data domain is more accurate than other seasons considering the frequent repair and calibration opportunities of devices in field visits by the staff.

3. Results of the Antalya pressure zone were better than the results of Ankara pressure zone. DDC values of Ankara pressure zone were extracted considering the water budget; however DDC values for Antalya case were extracted using direct measurement since the calculations were applied to a sub-pressure zone. Besides, weather conditions of Antalya give more opportunities to technical staff for re-visiting field operations for the repair, check and calibration of the monitoring devices.

4. Considering the DDC shapes, forecasted values were close to recorded values however shape of the forecasted DDCs was different from the recorded especially in winter and spring seasons (Appendix

A) for selected days (Table 4.1). This is probably the unavailable data for related seasons and inaccurate measurements.

5. Comparison of Total Volume and Peak Value shows that only peak values of ANN are close to the peak values of recorded values. Generally, seasonal total volume is more close to the recorded values. Only ANN values of 18.07.2008 (Figure A-15; Table 4.8) are close to recorded values for Total Volume and Peak Values. In other days, generally average and the day before values were closer to the recorded ones.

6. Short-term forecast (e.g. 3 hours, 6 hours etc.) of water consumption and valve setting can be applied using the procedure and methodology given in Chapter 4.2.2 and gives the similar results as compared with the 24-hr analysis since it uses the same model. As a result, hourly short-term forecast can be evaluated using the model for the utility to take necessary guidance for the operation management of pressure zone (Table 4.3).

7. Model architecture developed for N8-3 pressure zone was applied for a pressure zone of Antalya and better results were obtained since the training data is mostly available since the network is a closed sub-zone and DDC values were directly measured. Consequently, Antalya forecast is more successful than Ankara forecast for randomly selected days considering the average R^2 values calculated as 85%. This shows that Antalya data is more accurate than the Ankara data.

8. Valve optimization analysis for pressure management was implemented by Ozkan (2008) and the results reflect the configuration of the valves that reduces the leakage relatively. Five valves which reflect the sub-zones of the pressure zone according to Ozkan (2001) were employed in this study (Figure 4.10). According to the results

demonstrated in Appendix C; forecasted valve settings were compared with recorded valve settings and generally seasonal average valve settings were closer to the recorded valve settings.

9. On the other hand, the day before recorded day valve settings and seasonal average valve setting were compared with the recorded valve settings. Generally, forecasted and seasonal average results were close to recorded settings.

10. According to the results presented in Appendix C, Valve 3 may be accepted as the most successful valve since it is opened in all cases for every hour. Besides, pressure is needed at the point where V3 is located for regular network operation. V1, V2, V4 and V5 status varies as the change of the pressure for different situations according to the CODE I and CODE II (Tables C1-C52). Between 16:00 – 24:00 no valve configuration was changed unless there is a sharp drop of pressure of the pressure zone. In the morning through midday, 06:00 – 12:00, V2 and V5 changes according to the change in pressure. (Tables C1-C52). This is due to the characteristic of the water consumption in the pressure zone whether there is no extraordinary condition.

11. Forecasted values of the valve settings are better than the day before records.

12. Considering valves individually; V3 is almost the same with the recorded one comparing with The Day Before, Forecasted and Seasonal Average. V1 is in the second rank. V4, V2 and V5 is in the other ranks (3, 4, 5) respectively. (Tables C1-C52).

13. Valve settings of the N8-3 may be affected with the topography of the valve location and, thus, required pressure. As stated before, V3 was always open because of H_{min} requirements. On the other hand, other

valves settings may be affected depending on the pressure change in the network.

14. Comparing ANN and Seasonal Average valve configurations with the recorded; generally Seasonal Average valve settings give more accurate results however for some of the days forecasted results are better.

15. Especially in autumn 2008 and some 2009 values, there was a peak at 22:00 hours which is an unusual situation which can be explained as probable pumping from a governmental organization.

CHAPTER 6

CONSEQUENCES AND RECOMMENDATIONS

The data set of Ankara N8-3 network has problems resulting from the device malfunctions and misreading of measured records which is a major bottleneck of the analysis of the daily demand curve forecasting. During the preprocessing, processing and analysis, training data for N8-3 network were adjusted according to the criteria given in Chapter 3.3.2 due to inappropriate values. The reason of inappropriate values the water authority (ASKI) severely operates the water distribution system out of necessity. On the other hand, no adjustment was applied for Antalya data set since the forecasting is applied to a closed sub-zone of a pressure zone. Selecting and collecting available data is one of the important steps in order to build proper training domain. Consequences of this study shows that ANN model gave relatively successful results, however it is sometimes unable to forecast the peak values.

Water consumption depends not only on temperature, relative humidity but also shining period, rainfall period, population, storeys of the buildings, human behavior and other factors (extraordinary situations like fire-fighting). However, there are problems to obtain available data from the institutions and directorates and hence only two variable, temperature and relative humidity, from meteorological data were used. The other variables were selected as human behavior and season which are obtained easily from related calendars.

Considering the literature survey this study may be one of the pioneering studies that forecast daily demand curves in hourly basis. In civil engineering, daily, weekly or monthly forecasting methods were generally used. Recent studies show that hourly and even minutely forecasting are becoming real.

24 hour forecasting gives practical advances to the water utility for the management of operation and field staff management. Considering the forecasted values, a new approach for calculating the performance analysis, in other words customer conformity, of a water distribution network with a short term forecasted daily demand curve rather than a past recorded value. This will lead a water utility to estimate necessary precautions about the system before any incident occurs.

Using the forecasted total volume and peak values, water consumption trend of a particular pressure zone can be calculated for planning needs. The improvement can be realized by increasing the size of the concerning pipes and/or better valving of the related pipes, operation of the valves and pumps, necessary strengthening of pipes, valves and other equipment’s. Besides, forecasted daily demand curves will lead the utility to calculate the future water consumption. This will increase the efficiency of the staff and system if and only if the utility takes the necessary measures.

Optimum valve operation can be achieved for the forecasted day or period of time for leakage minimization. Leakage reduction can be increased by not only determining the optimum valve settings but also fixing the optimum locations of control valves and increasing the number of them. Detailed field survey should be carried out in N8-3 pressure zone for determining the critical control valve locations and their configuration.

SCADA records enrichment, proper training data selection and improvement of ANN model such as introducing more variables may give better forecast results. This may be held by installing new monitoring equipments and improvement of SCADA system.

Principal component analysis (PCA) may be conducted for selecting the independent parameter selection for the implementation of ANN model. Using the analysis, more relevant independent variables may probably give better results.

In this study, pumping periods were not taken in to consideration. It is obvious that the nodal pressure may be different whether it was fed from the storage of pump. During the ANN data domain building, this may be an important input variable for training the domain and hence obtaining the forecast.

As stated, Matlab and Neural Network Toolbox module was used in this study. An automated model, a software package program (NeuroSolutions, Easy NN) may be used rather than Matlab for better and practical results. This software packages may help for checking the Matlab calculations. Besides, model implementation and automated trial and error procedure will be a great advance for quick results.

Root mean square error (RMSE) and mean absolute percentage error (MAPE) may be used for the comparison of forecasted values. A comparison of R^2 with RMSE and MAPE may probably give better understanding of the forecast.

Future studies may include a Decision Support System (DSS) for dynamically and on demand calculation of the valve optimization, performance analysis considering the forecasted diurnal curve. Also, self-organized and smart valves, set openings according to the changes in water consumption and pressure, can be inserted to the critical nodes. DSS will guide water utilities for future modeling of pressure zone and hence distribution network with the optimum operation considering the water budget of the utility.

This study may be practically implemented for any water authority using the related modules and codes.

REFERENCES

Adeli H., Neural Networks in Civil Engineering: 1989-2000, Computer Aided Civil and Infrastructure Engineering, (2001), 126-142.

Anderson J. A., “Brain Modeling and Memory”, First International Conference on Mathematical Modeling, 1977.

Bektas, O., "Developing a Methodology for Finding Network Water Losses Using Information Technologies: A Case Study”, M. Sc. Thesis, METU, Department of Civil Engineering, 2010.

Bhave, P. R., "Analysis of Flow in Water Distribution Networks", Technomic Publishing Company, Inc., Pennsylvania, 1991.

Cesario, L., "Modeling, Analysis, and Design of Water Distribution Systems", American Water Works Association, 1995.

Germanopoulos, G., “A Technical Note on the Inclusion of Pressure Dependent Demand and Leakage Terms in Water Supply Network Models”, Civil Engineering Systems, Vol. 2, September, 1985.

Gill, P. R.; Murray, W.; and Wright, M. H. "The Levenberg-Marquardt Method." §4.7.3 in *Practical Optimization.* London: Academic Press, pp. 136-137, 1981.

Gupta, R., Bhave, P.R., "Reliability Analysis of Water Distribution Systems," Journal of the Environmental Engineering, ASCE, 120(2), pp.447-460,1994.

Güngör, İ., Kayacan M. C., Korkmaz M.,"Endüstriyel Odun Hammaddesi Talebinin Tahmininde Yapay Sinir Ağlarının Kullanımı ve Bazı TahminYöntemleri ile Karşılaştırılması", Yöneylem Araştırması ve Endüstri Mühendisliği XXIV. Ulusal Kongresi, Çukurova Üniversitesi ve Gaziantep Üniversitesi, Endüstri Mühendisliği Bölümleri, Adana, (2004).

Hopfield, J., "Neuralnetworksandphysical systems with emergent collective computational abilities." *Proceedings of the National Academy of Sciences of the USA*, vol. 79, no. 8, 1982.

Kame'enui A.E., "Water Demand Forecasting in Puget Sound Region: Short and Long Term Models", M. Sc. Thesis, University of Washington, Department of Civil and Enviromental Engineering, 2003.

Kohonen T., "Associative Memory: A system-theoretical approach", Springer-Verlag, 1977.

Lawrence, J., *Introduction to Neural Networks. Design, Theory, and Applications*, California Scientific Software Press, Nevada City, 1994.

Lingireddy, S and Brion, G. M., Artifician Neural Networks in Water Supply Engineering, 2005.

Loh R.H., "Time Series Forecast with Neural Network and Wavelet Techniques", B. Sc. Pass Degree, University of Quensland, Department of Electrical and Computer Engineering, 2003.

Mansoor M. A. M. and Viravamoorthy K., "Application of Neural Networks for Estimating Nodal Outflows as a Function of Pressures in Water Distribution Systems", Conference Paper, 2005.

Matlab (2008a) User Guide

Mays, L. W., "Water Resources Handbook", New York, McGraw-Hill, 1996.

Mays, L. W., Tung Y. "Hydrosystems Engineering and Management", New York, McGraw-Hill, 1992.

McCulloch, W.W. and Pitts, W., A Logical Calculus of Ideas Imminent in Nervous Activity. Bull. Math. Biophys., 5, 115−133, 1943.

Merzi, N., Şendil, U., Yağız, E., Eker, İ., Poyraz, S., "Hydraulic Modeling Process of N8 Pressure Zone of Ankara Water Distribution Network" (in Turkish), ASKI/METU Joint Education and Training Program, 1st Progress Report, Middle East Technical University, Ankara, May 1998a.

Okkan U. Dalkılıç H.Y, "Demirköprü Barajı Aylık Buharlaşma Yüksekliklerinin Yapay Sinir Ağları ile Tahmin Edilmesi", DSİ Teknik Bülten Sayı:108, 30-37, 2010.

Nohutcu, M., Analysis of Water Distribution Networks with Pressure Dependent Demand, M. Sc. Thesis, METU, Dept. of Civ. Eng., 2002.

Özkan O., Kınacı C., Sağıroğlu Ş., "Determining Dissolved Oxygen change using Artificial Neural Networks: An Example of Kızılırmak River, İTÜ Dergisi, Cilt 5 Sayı 3 Kısım 1, 30-38, 2006

Ozkan, T., "Determination of Leakages in Water Distribution Network using SCADA Data", M. Sc. Thesis Study, METU, Department of Civil Engineering, 2001

Özkan, T., "Leakage Control by Optimal Valve Operation", Ph. D. Thesis Study, METU, Department of Civil Engineering, 2008.

Raman, H, Sunilkumar, N, "Multivariate Modelling of Water Resources Time Series Using Artificial Neural Networks", Hydrological Sciences Journal 40, April 1995.

Rossini, P. A., Artificial Neural Networks versus Multiple Regression in the Valuation of Residential Property, Australian Land Economics Review, 1997

Saraç T., Yapay Sinir Ağları, Gazi Üniversitesi Endüstri Mühendisliği Bölümü, Seminer Projesi., 2004

Stark, H. L, “The Application of Artificial Neural Networks to Water Demand Modelling”, M. Sc. Thesis, University of of Alberta, Department of Civil and Enviromental Engineering, 2002

Soyupak, S., Karaer, F., Gürbüz, H., Kıvrak, E., Şentürk, E., Yazıcı, A., Neural Computations and Applications, 2003, pages 166-172.

Terzi, Ö., “Yapay Sinir Ağları Metodu ile Eğirdir Gölü Su Sıcaklığı Tahmini”, Süleyman Demirel Üniversitesi, Fen Bilimleri Enstitüsü Dergisi, 2006

Walski, T. M., "Water Distribution Valve Topology for Reliability Analysis", Reliability Engineering and System Safety, 1993.

YILDIZ, E., "Reliability of Water Distribution Systems", M. Sc. Thesis, METU, Department of Civil Engineering, 2002

Web 1, A Brief Summary of Neural Network Types, April 2009,

http://www.heatonresearch.com/content/brief-summary-neural-network-types

10.06.2011

Web 2, Learn Artificial Neural Networks,

http://www.learnartificialneuralnetworks.com/#topologies

10.06.2011

Web 3, Introduction to Neural Networks

http://home.agh.edu.pl/~vlsi/AI/intro/

10.06.2011

Web 4, Why use activation functions?

http://www.faqs.org/faqs/ai-faq/neural-nets/part2/section-10.html

11.06.2011

Web 5, Coefficient of Determination

http://en.wikipedia.org/wiki/Coefficient_of_determination

11.06.2011

Web 6, Linden, M. ,"The Discovery of Brain", 2008

http://www.kennislink.nl/publicaties/de-ontdekking-van-het-brein

20.07.2011

Web 7, Supervised Learning

http://en.wikipedia.org/wiki/Supervised_learning

22.07.2011

Web 8, Levenberg–Marquardt algorithm

http://en.wikipedia.org/wiki/Levenberg%E2%80%93Marquardt_algorithm

21.07.2011

Web 9, Neural Network Learning by the Levenberg–Marquardt algorithm with Bayesian Regularization

http://crsouza.blogspot.com/2009/11/neural-network-learning-by-levenberg_18.html

21.07.2011

APPENDIX A

FORECASTED AND RECORDED DDCS FOR N8-3 PRESSURE ZONE

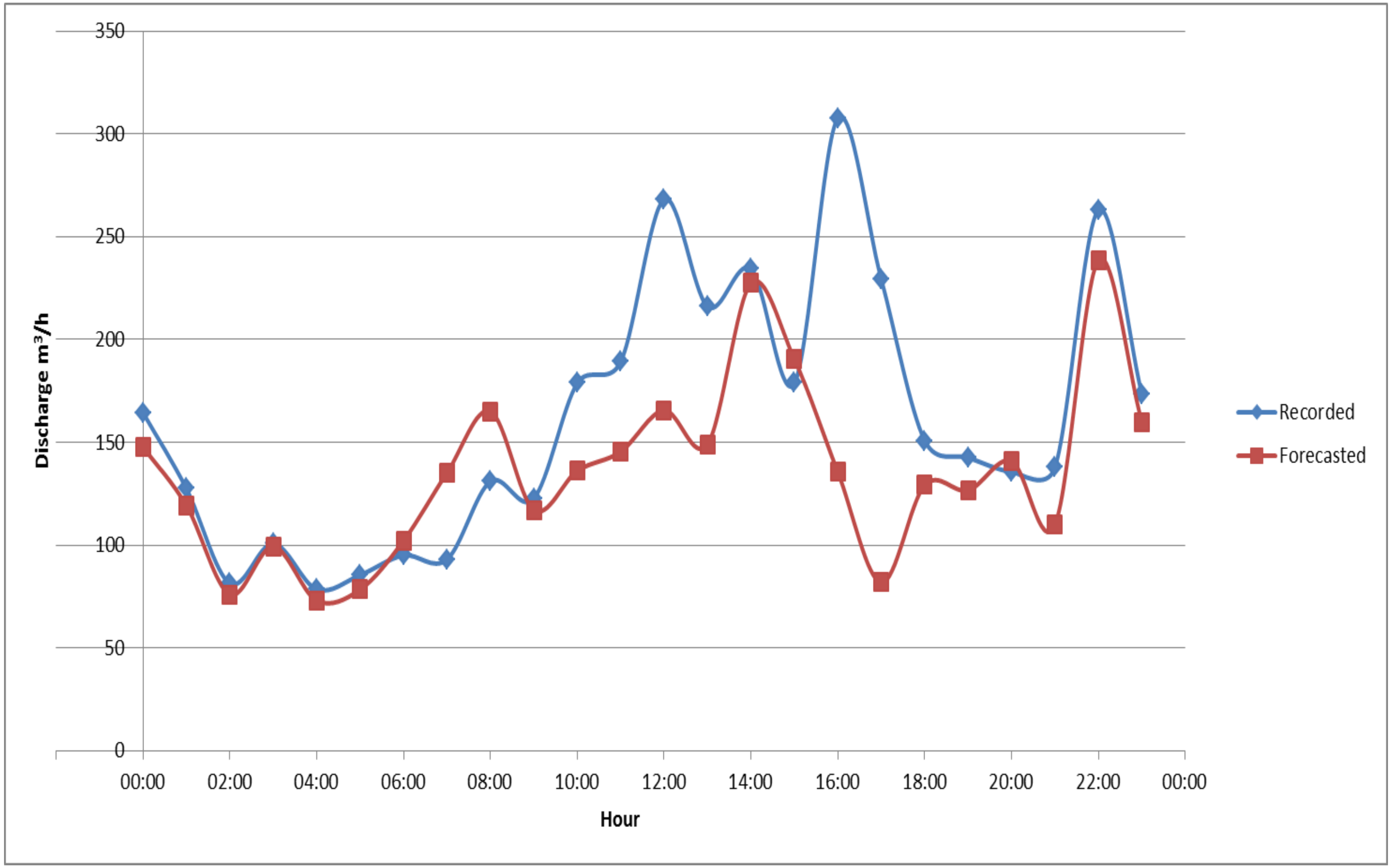


Figure A-1 Recorded and Forecasted DDC for 16.11.2008

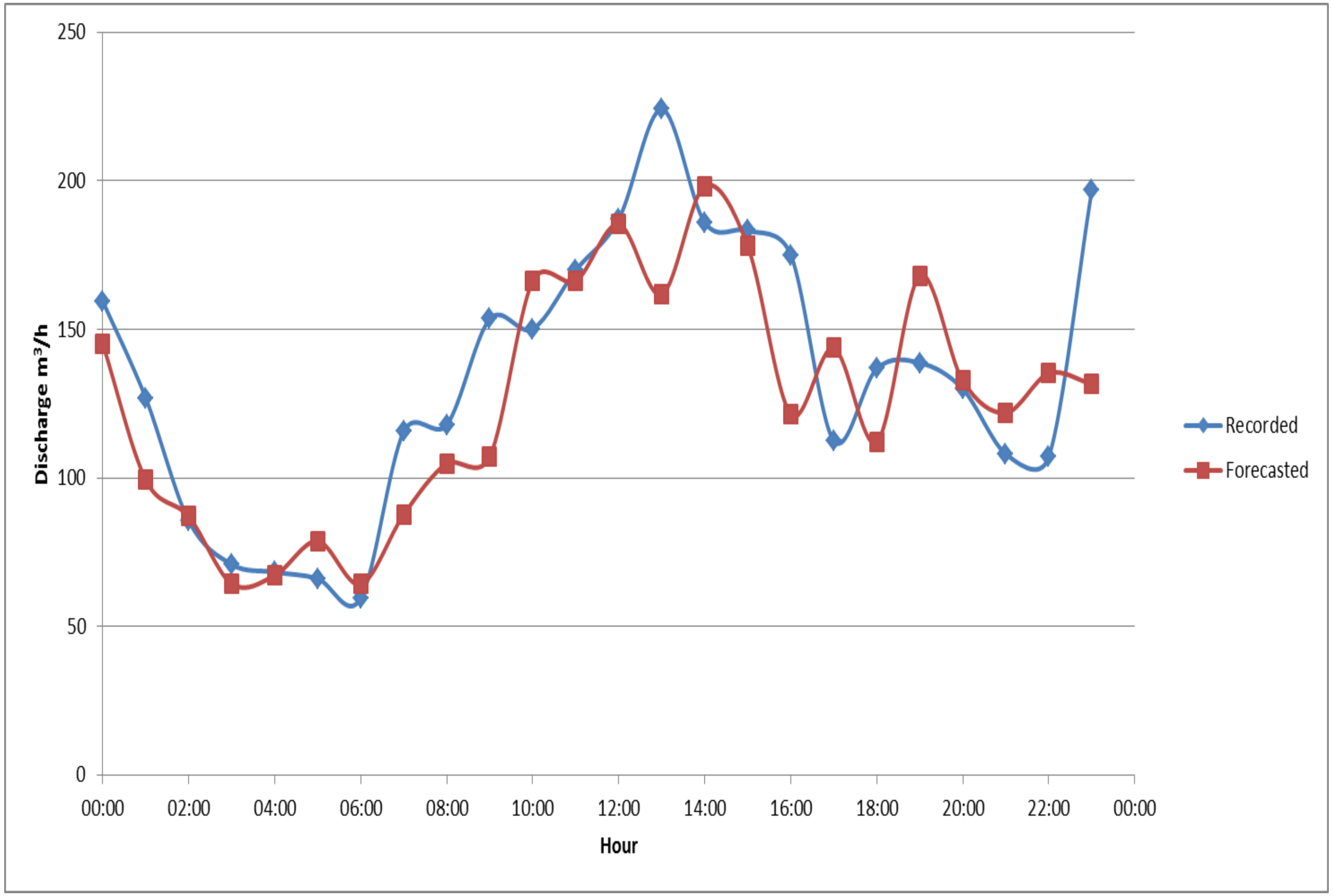


Figure A-2 Recorded and Forecasted DDC for 11.10.2008

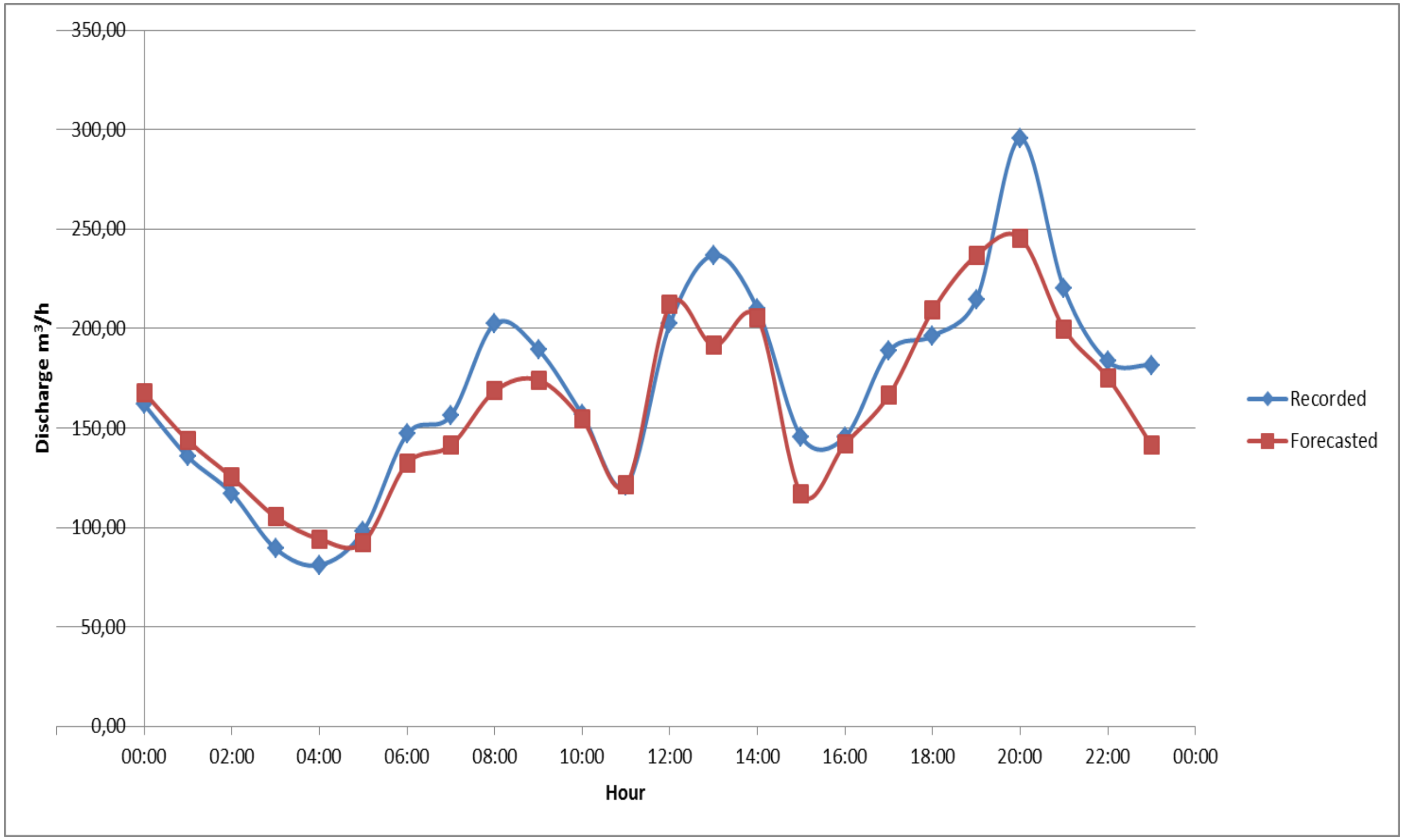


Figure A-3 Recorded and Forecasted DDC for 25.10.2007

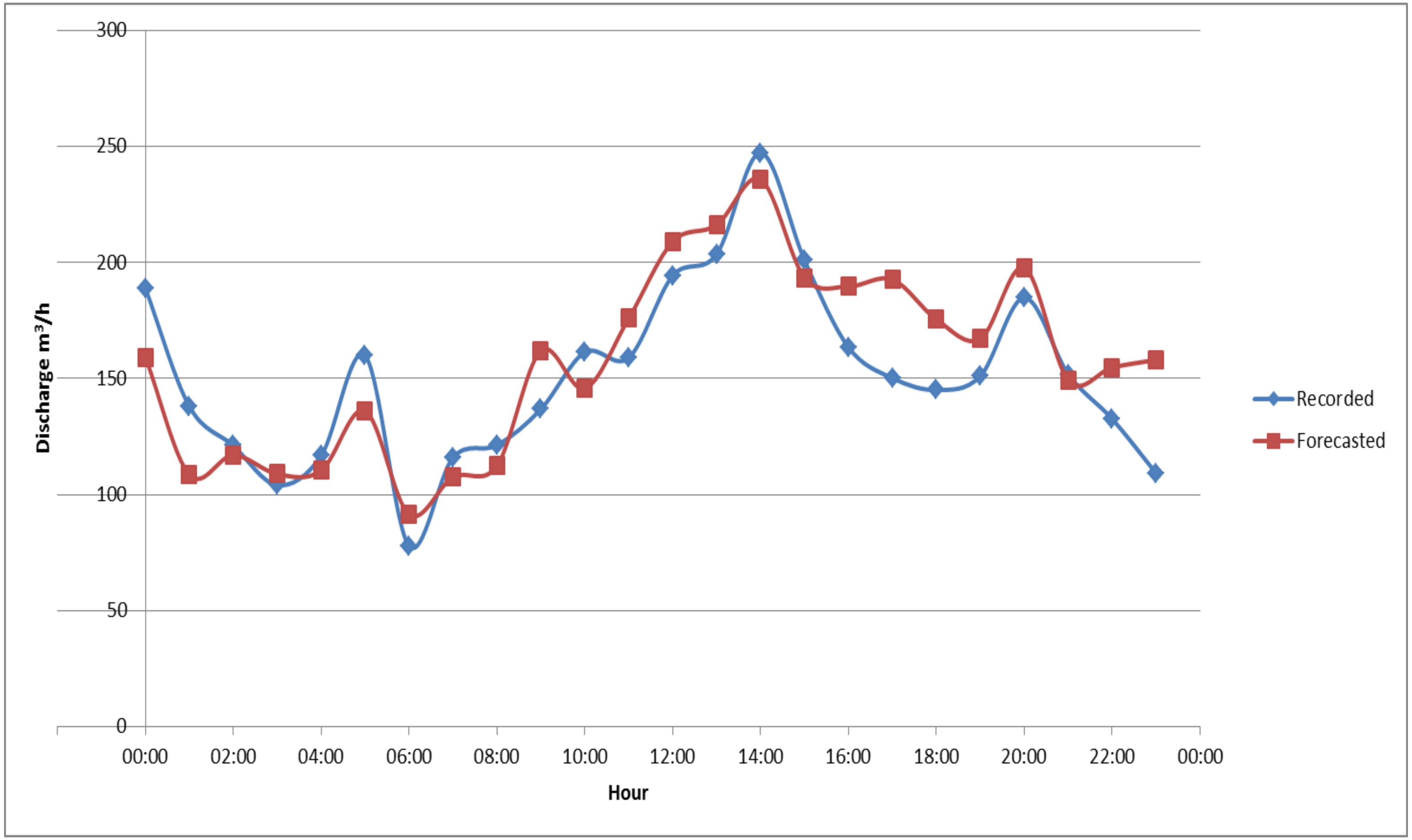


Figure A-4 Recorded and Forecasted DDC for 06.09.2008

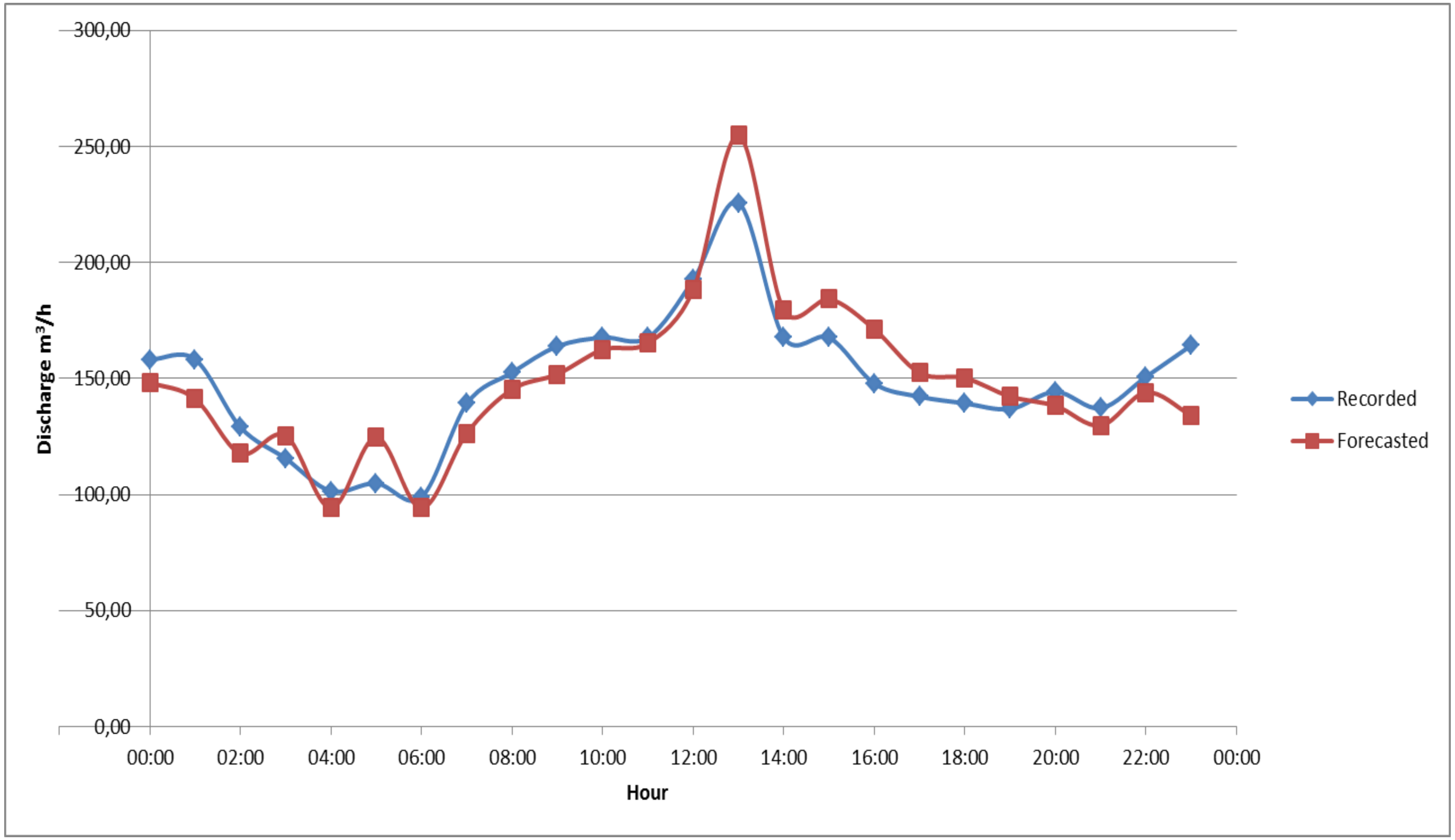


Figure A-5 Recorded and Forecasted DDC for 15.01.2009

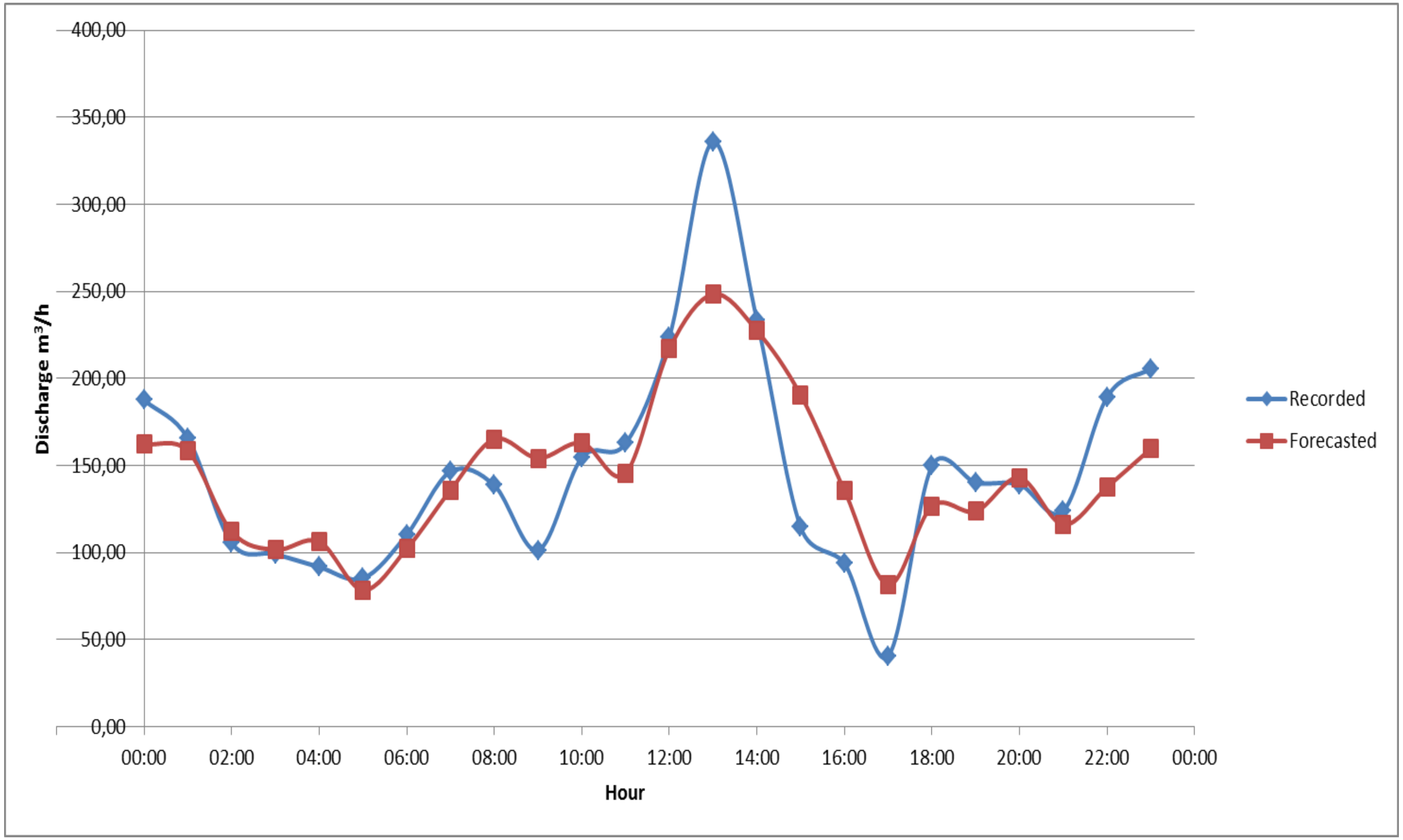


Figure A-6 Recorded and Forecasted DDC for 23.02.2009

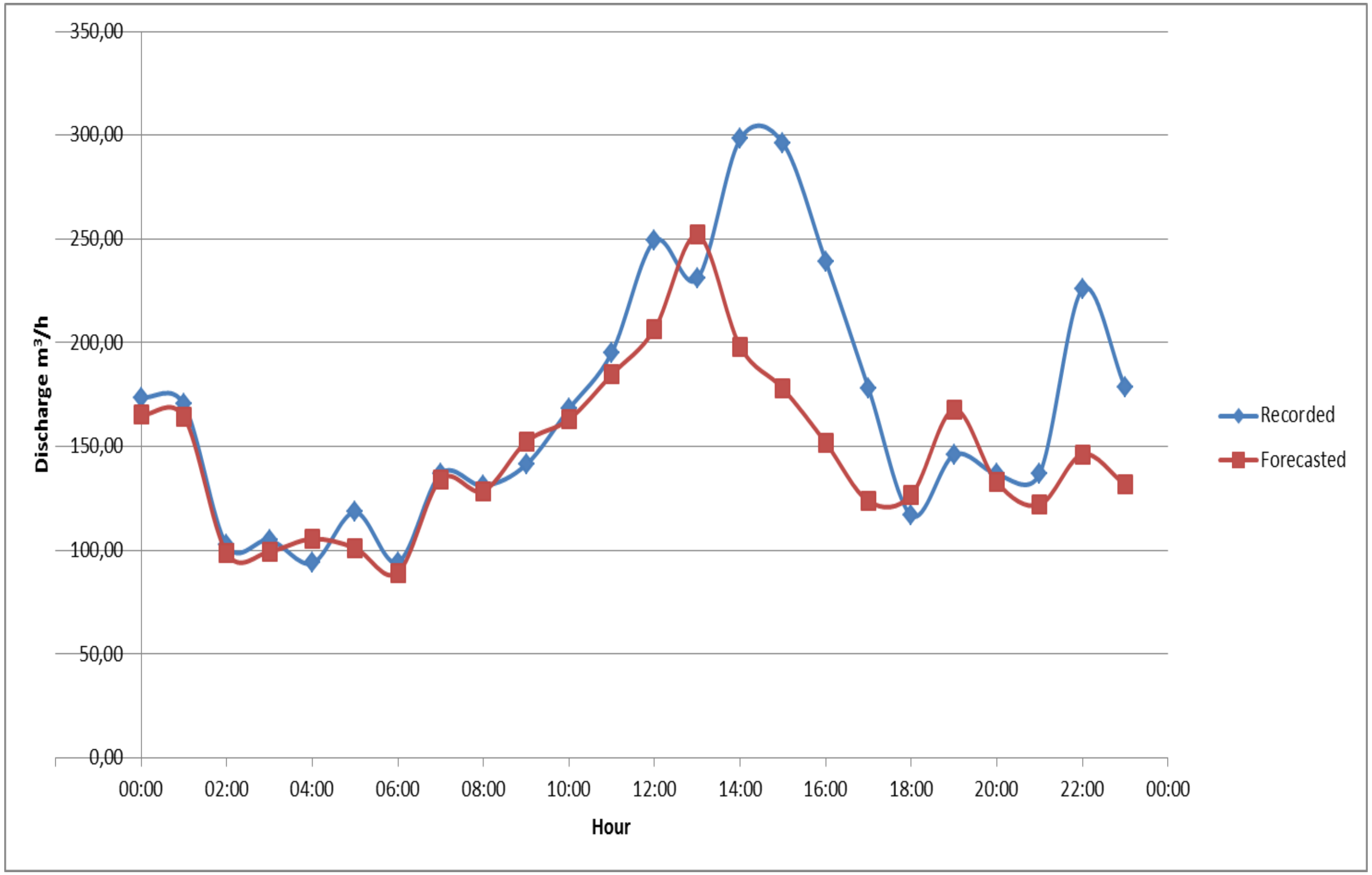


Figure A-7 Recorded and Forecasted DDC for 10.01.2009

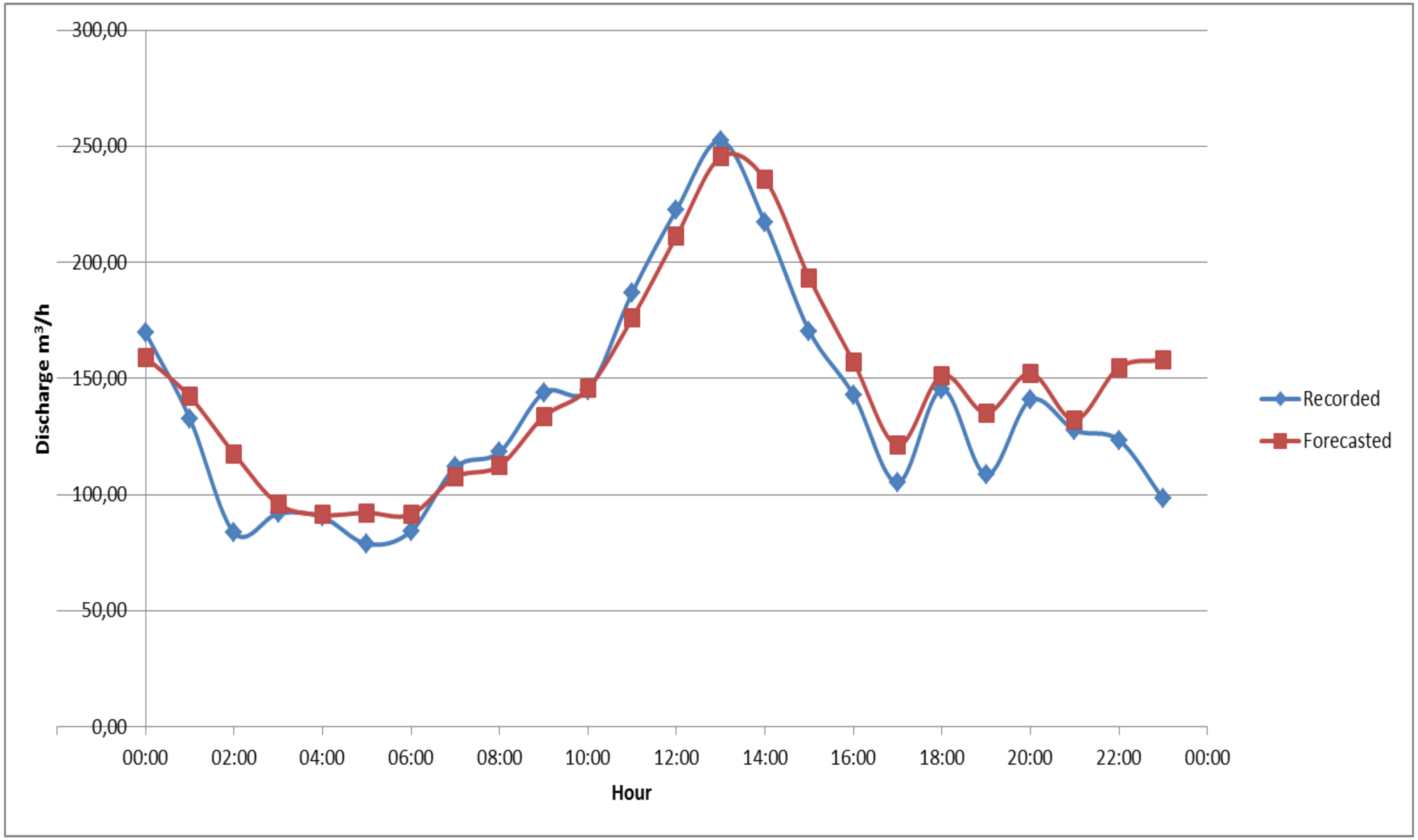


Figure A-8 Recorded and Forecasted DDC for 13.12.2008

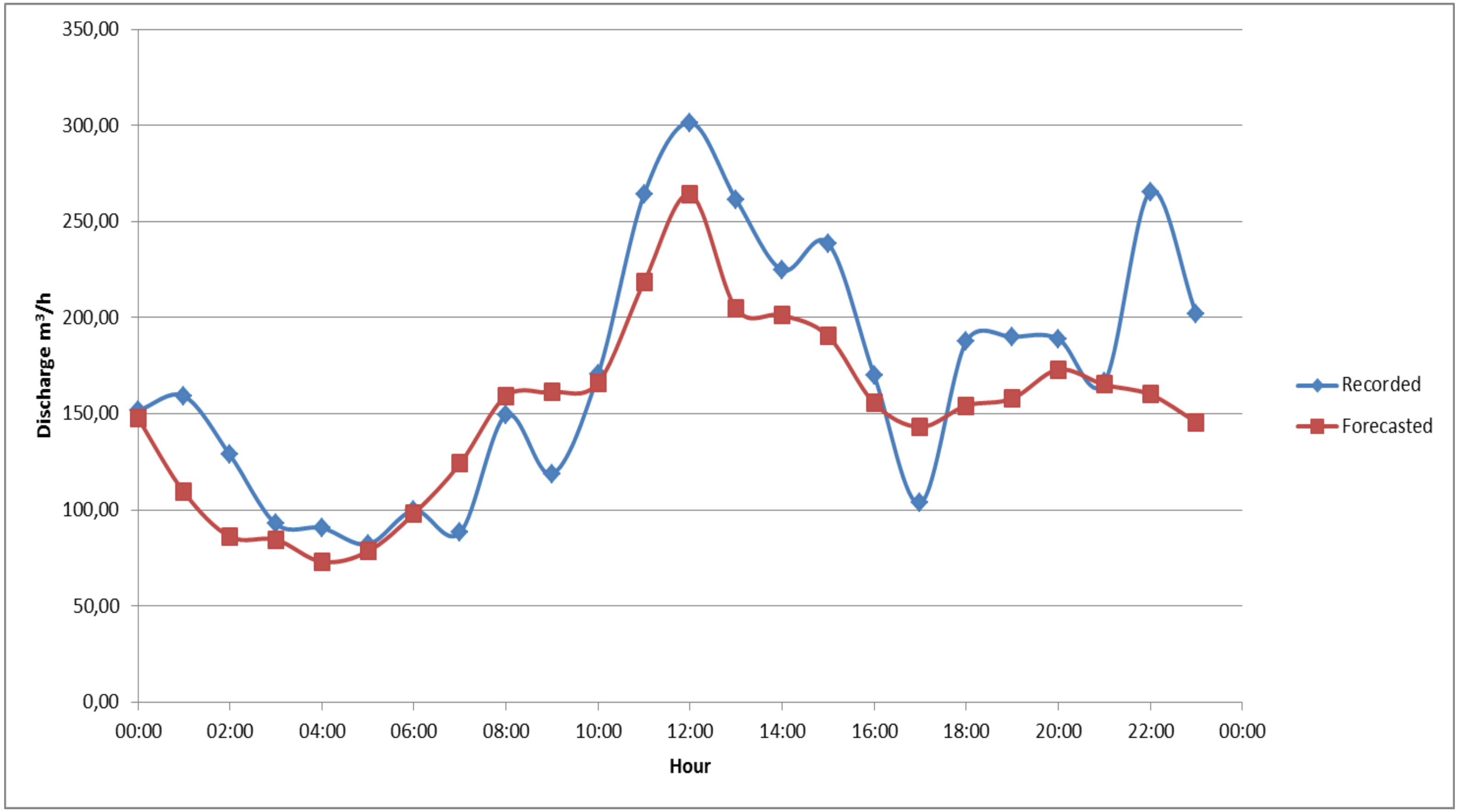


Figure A-9 Recorded and Forecasted DDC for 08.03.2009

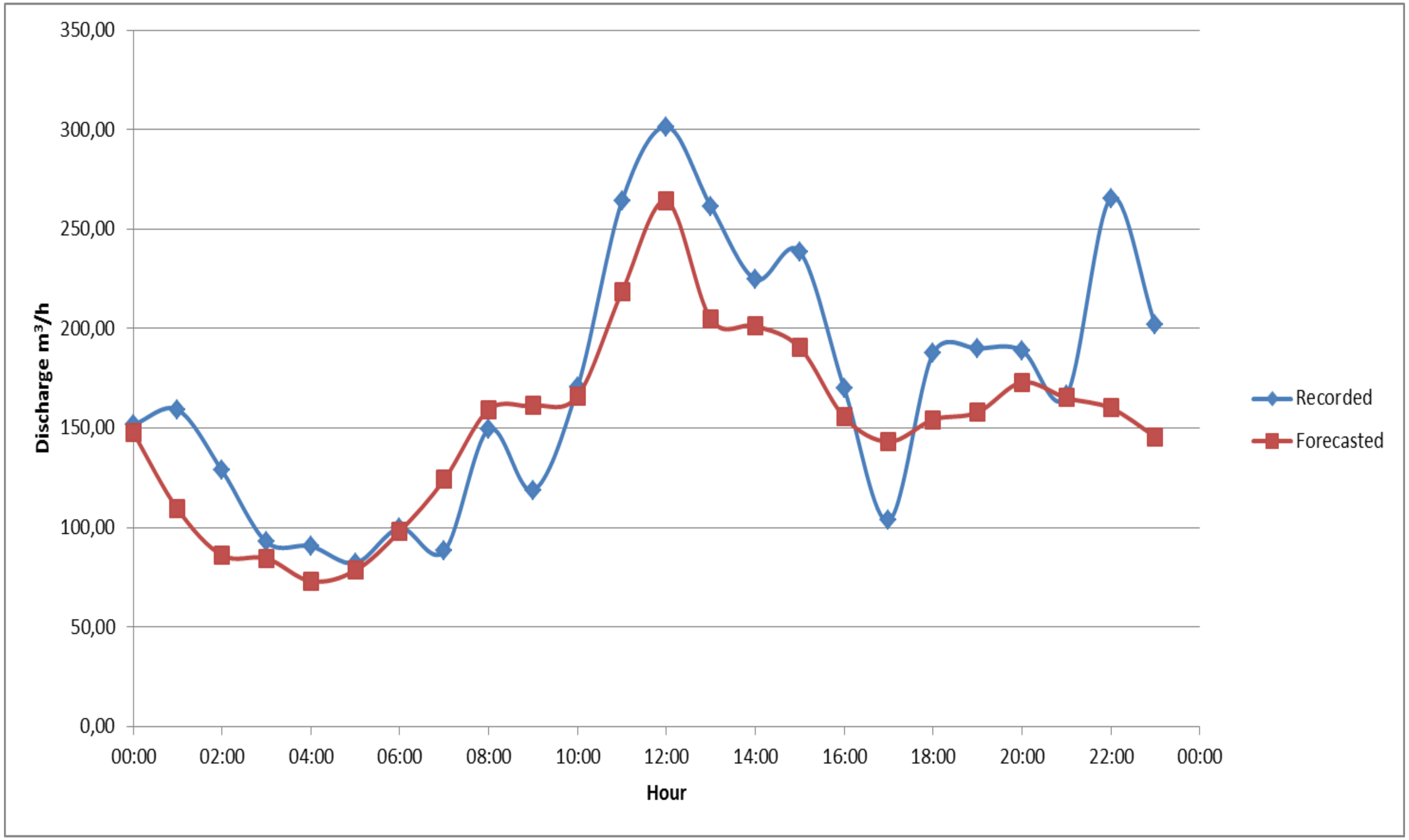


Figure A-10 Recorded and Forecasted DDC for 11.05.2009

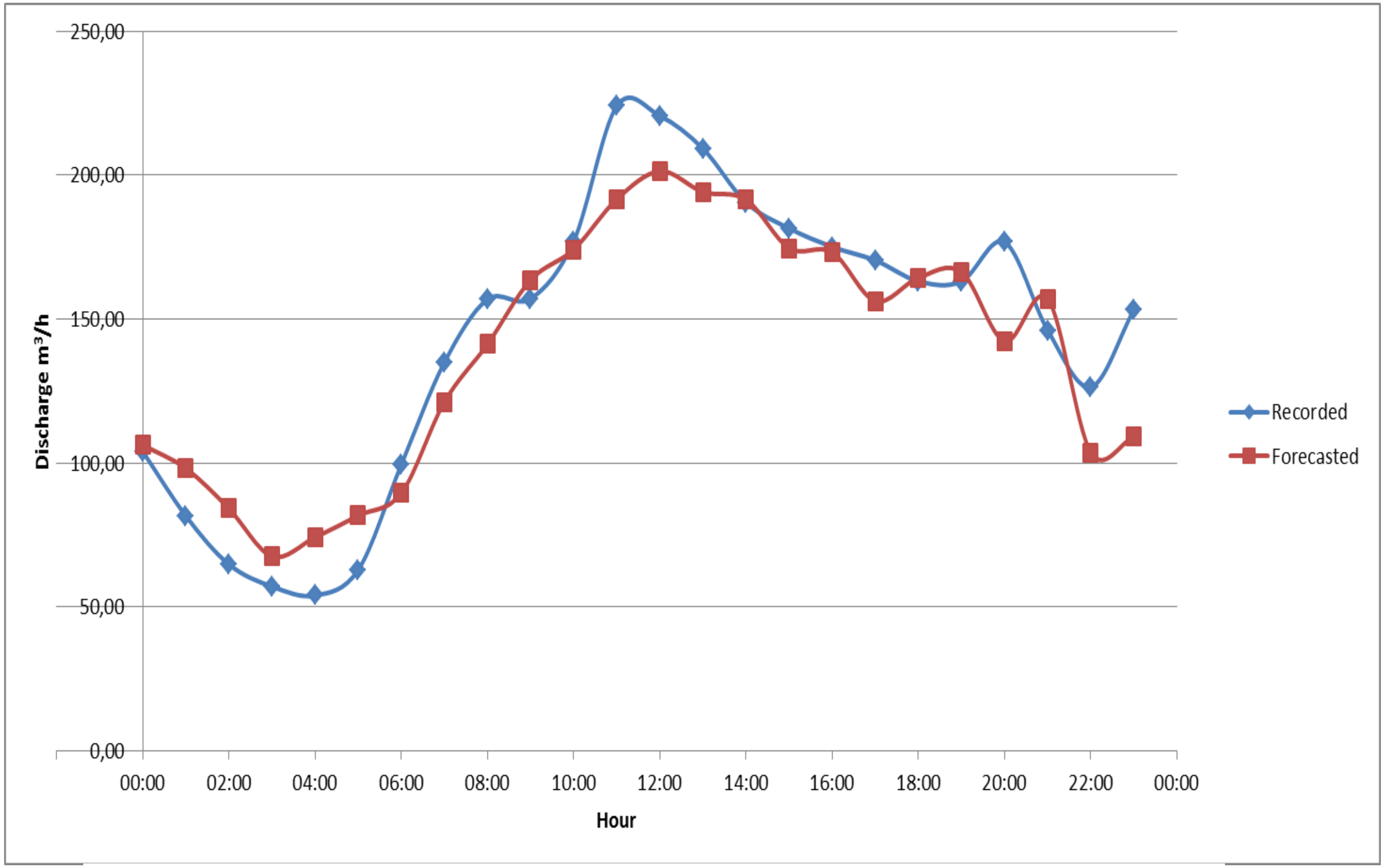


Figure A-11 Recorded and Forecasted DDC for 14.05.2008

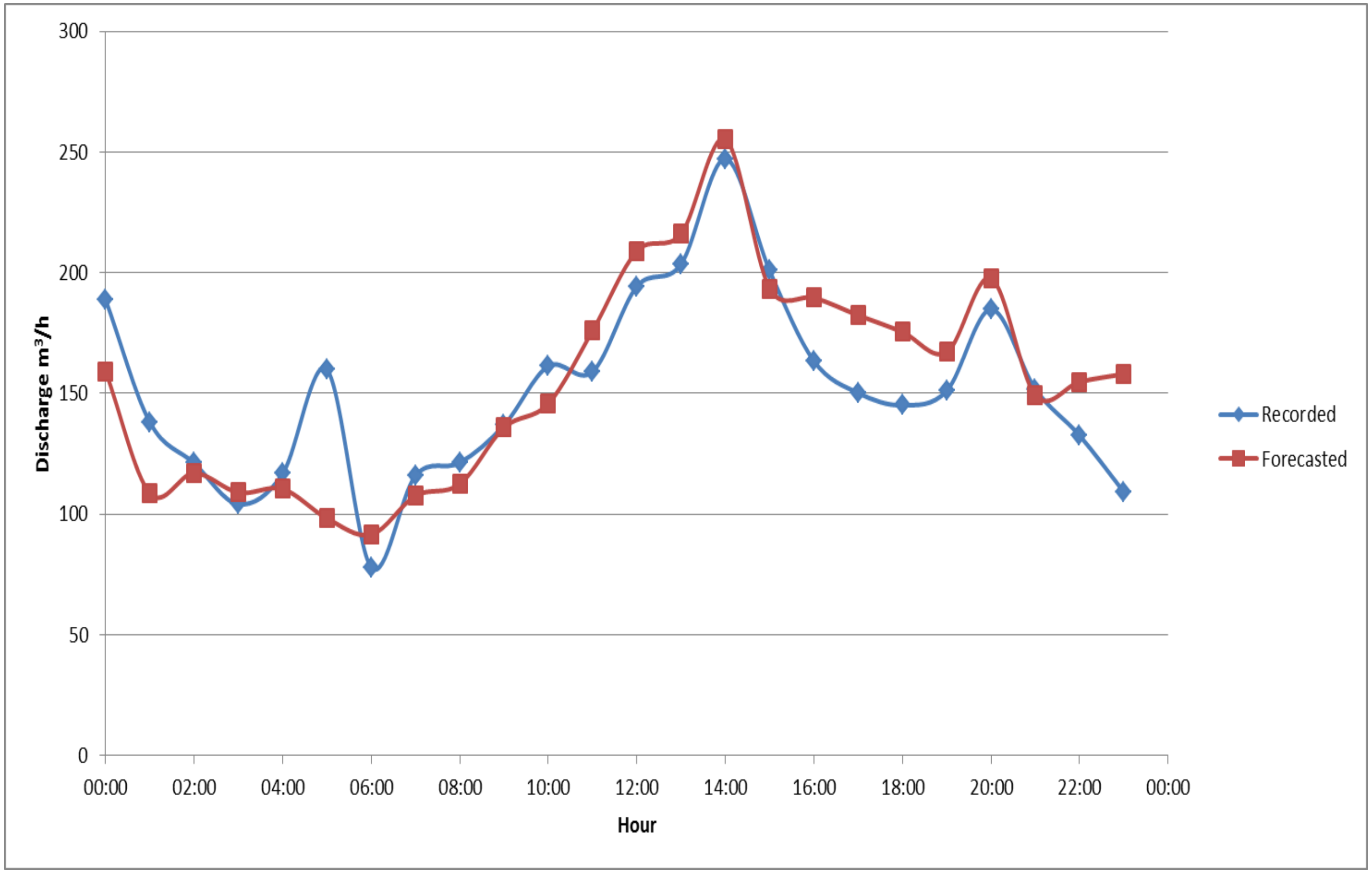


Figure A-12 Recorded and Forecasted DDC for 23.04.2008

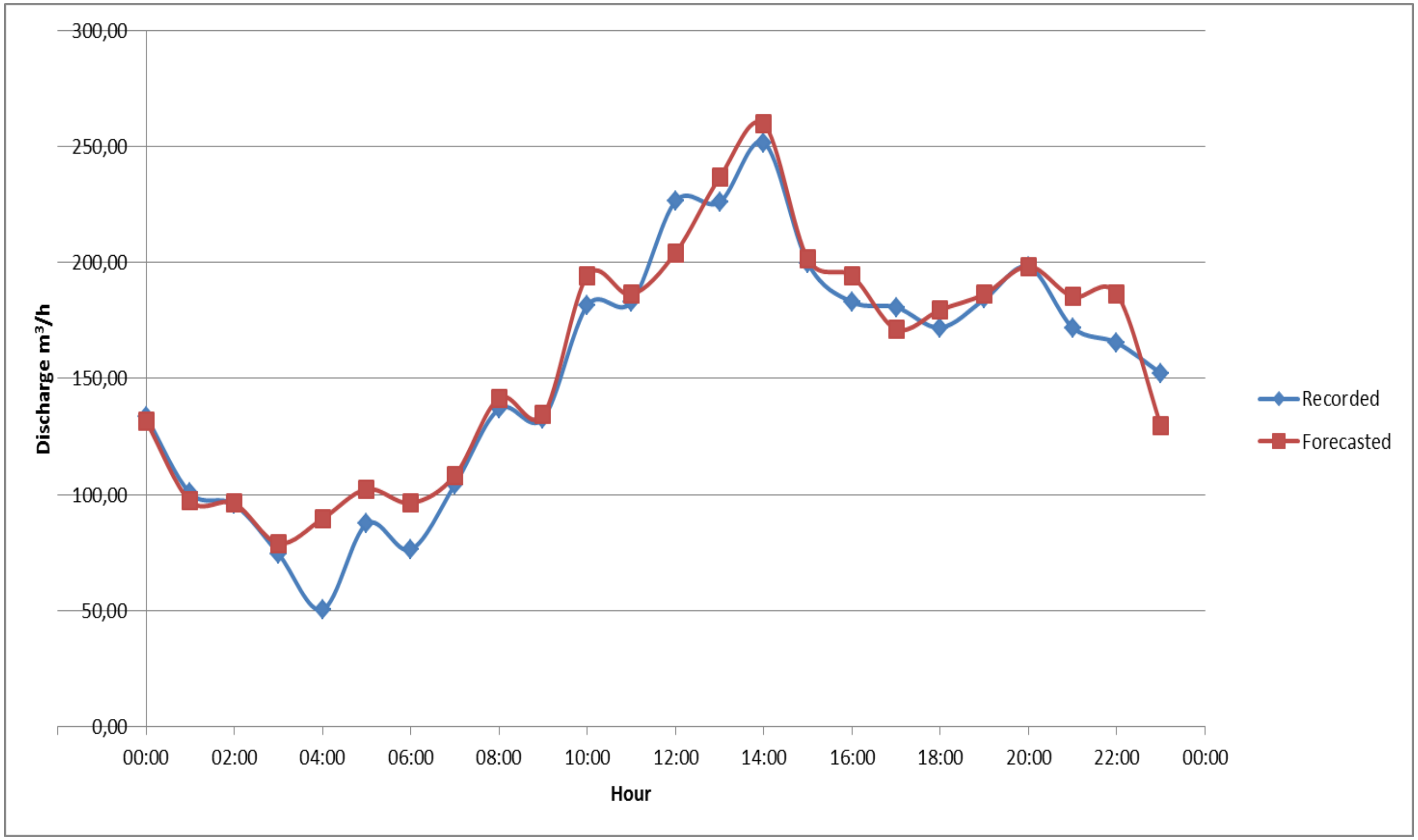


Figure A-13 Recorded and Forecasted DDC for 03.08.2008

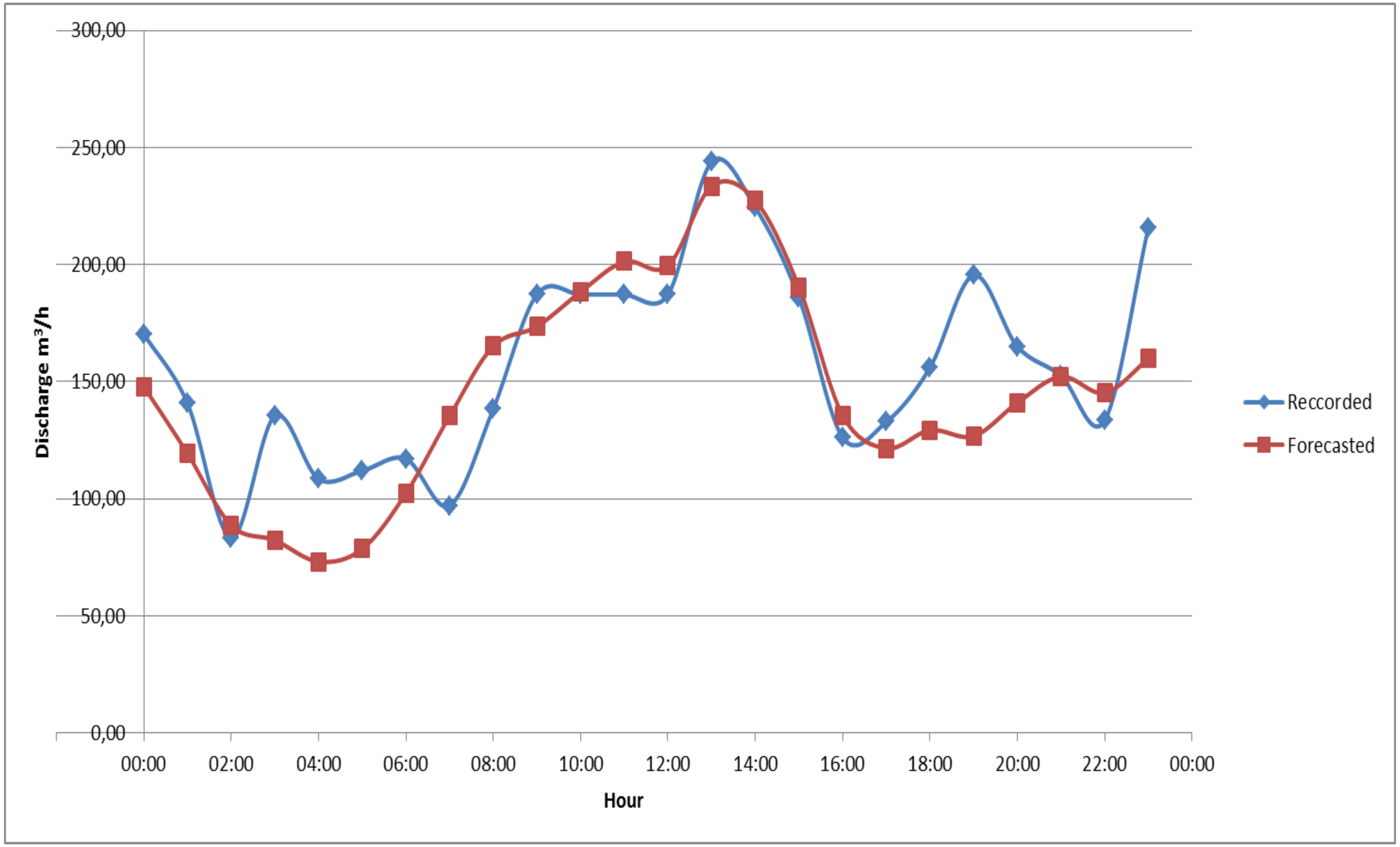


Figure A-14 Recorded and Forecasted DDC for 21.08.200

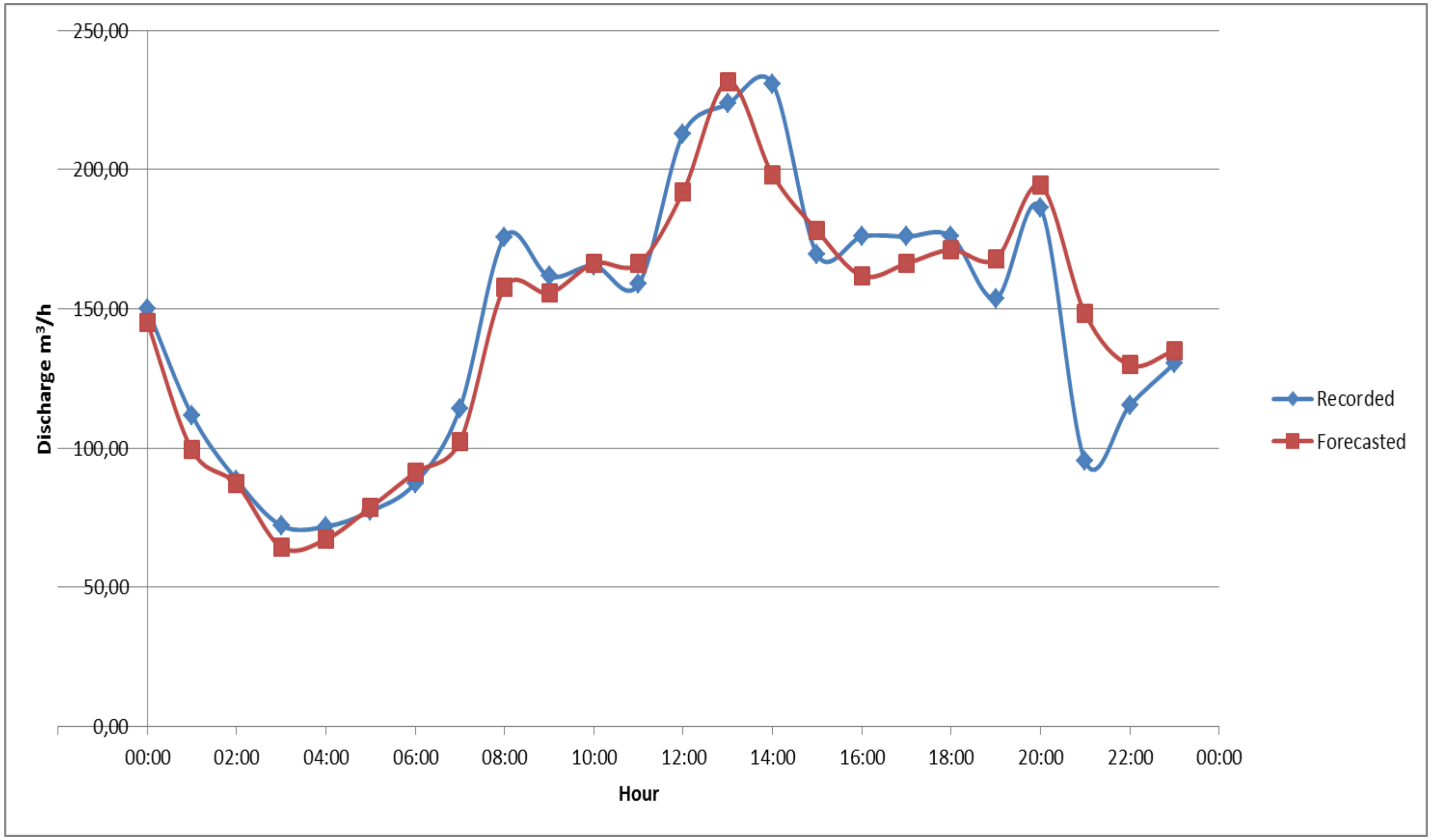


Figure A-15 Recorded and Foreasted DDC for 18.07.2008

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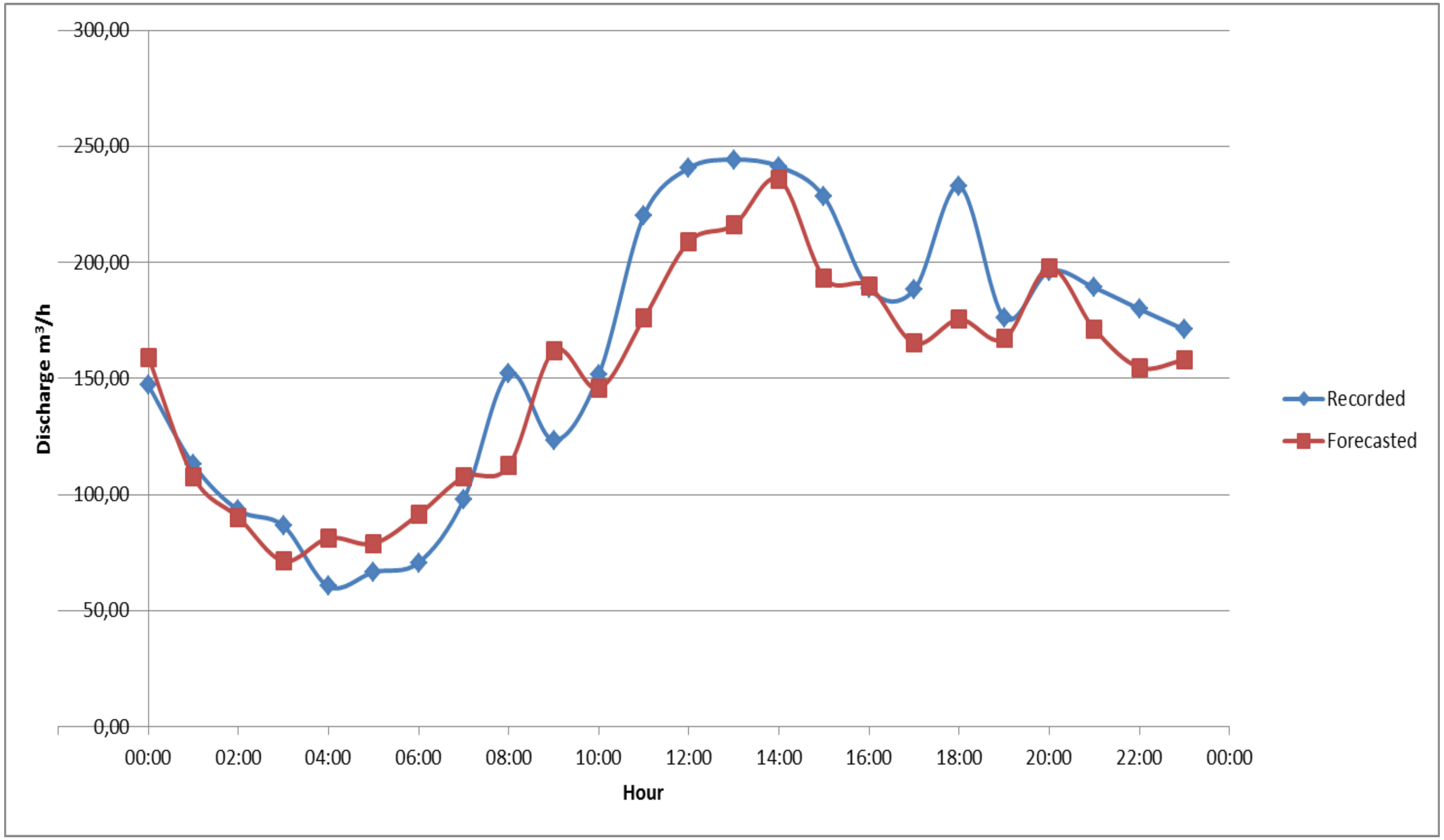

Figure A-16 Recorded and Forecasted DDC for 29.06.2008

APPENDIX B

FORECASTED, RECORDED AND SEASONAL AVERAGE DDCS FOR ANTALYA WATER DISTRIBUTION NETWORK

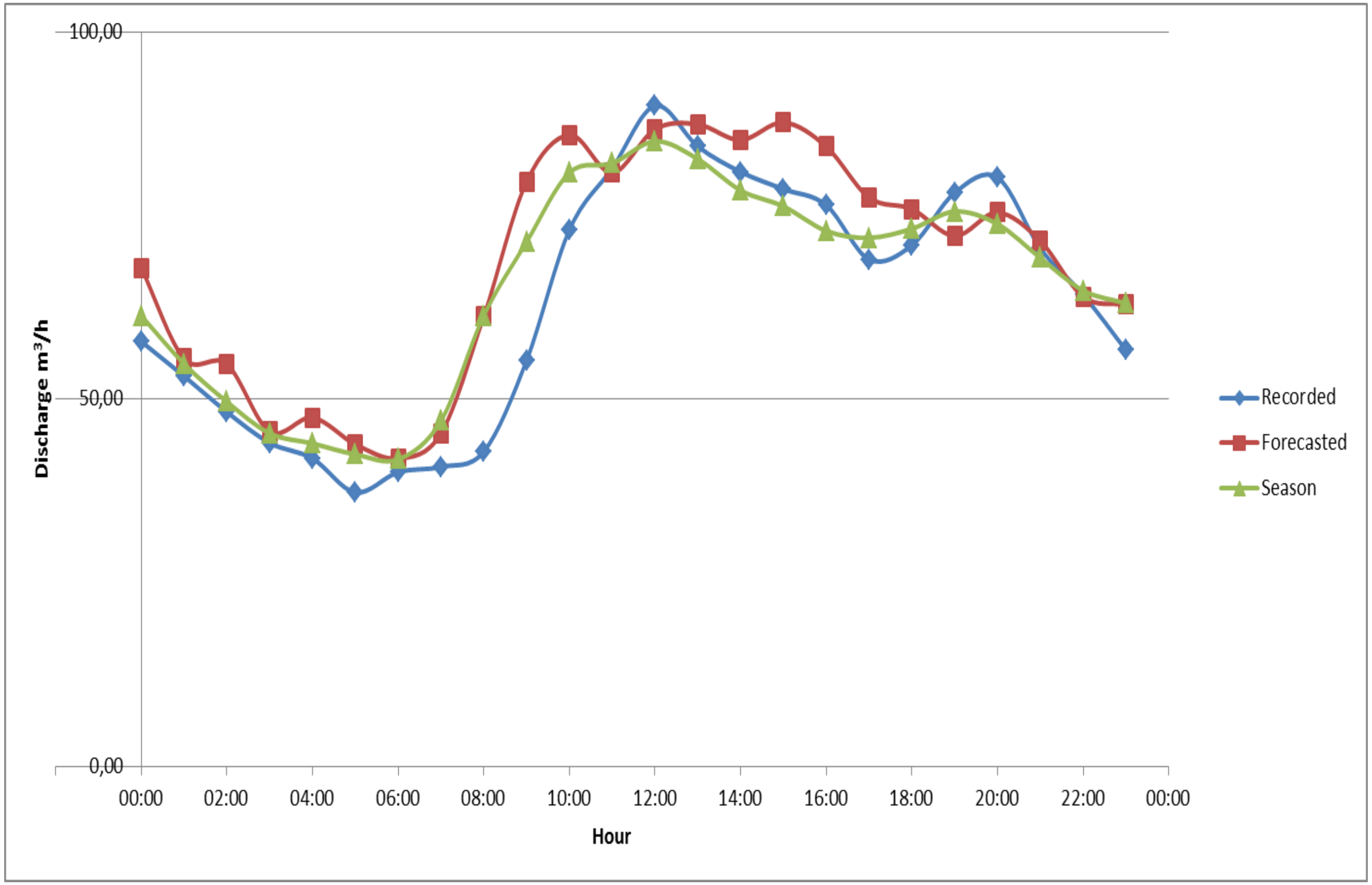

Figure B-1 Recorded and Forecasted DDC for 25.10.2009 with corresponding seasonal average

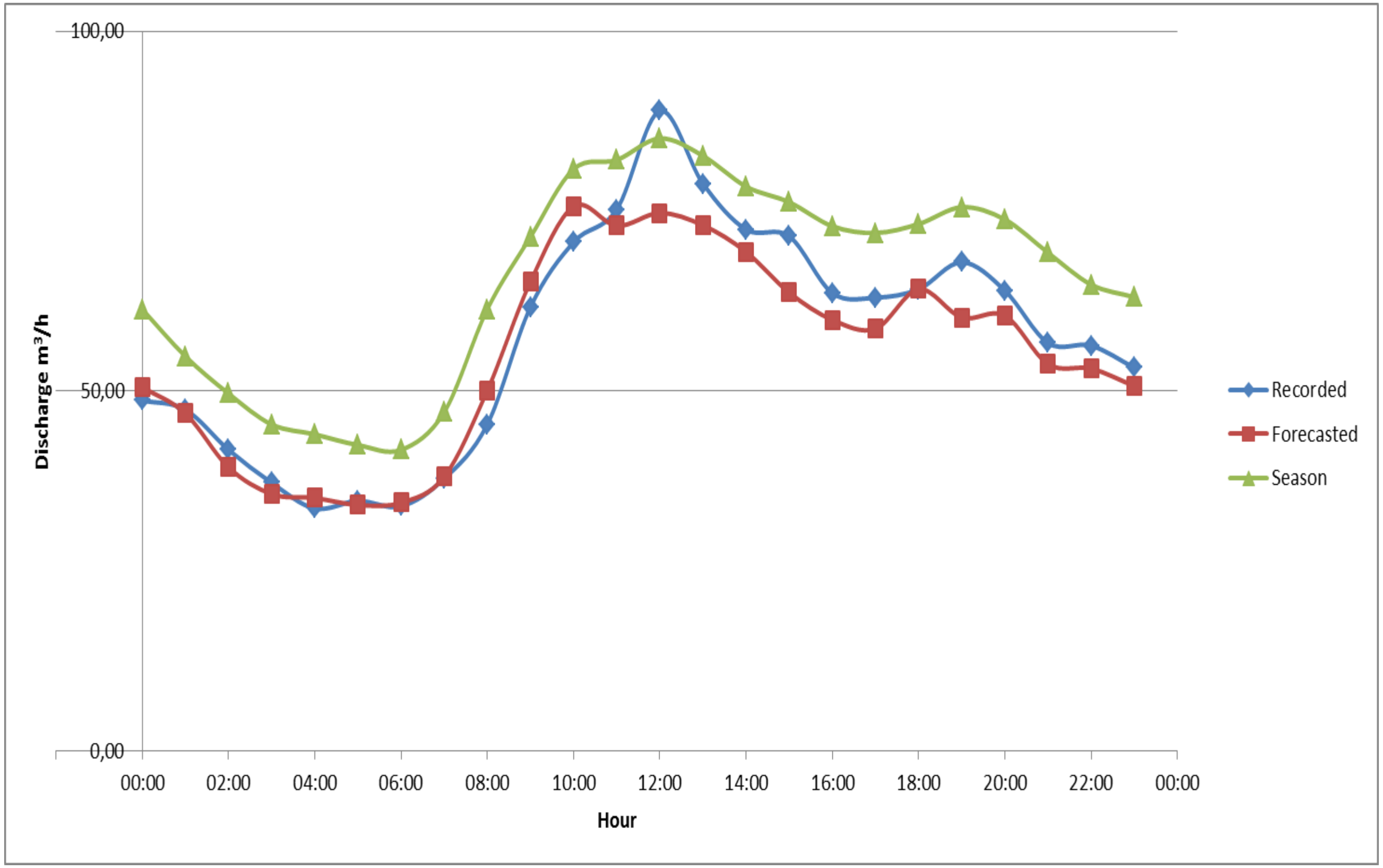

Figure B-2 Recorded and Forecasted DDC for 30.11.2009 with corresponding seasonal average

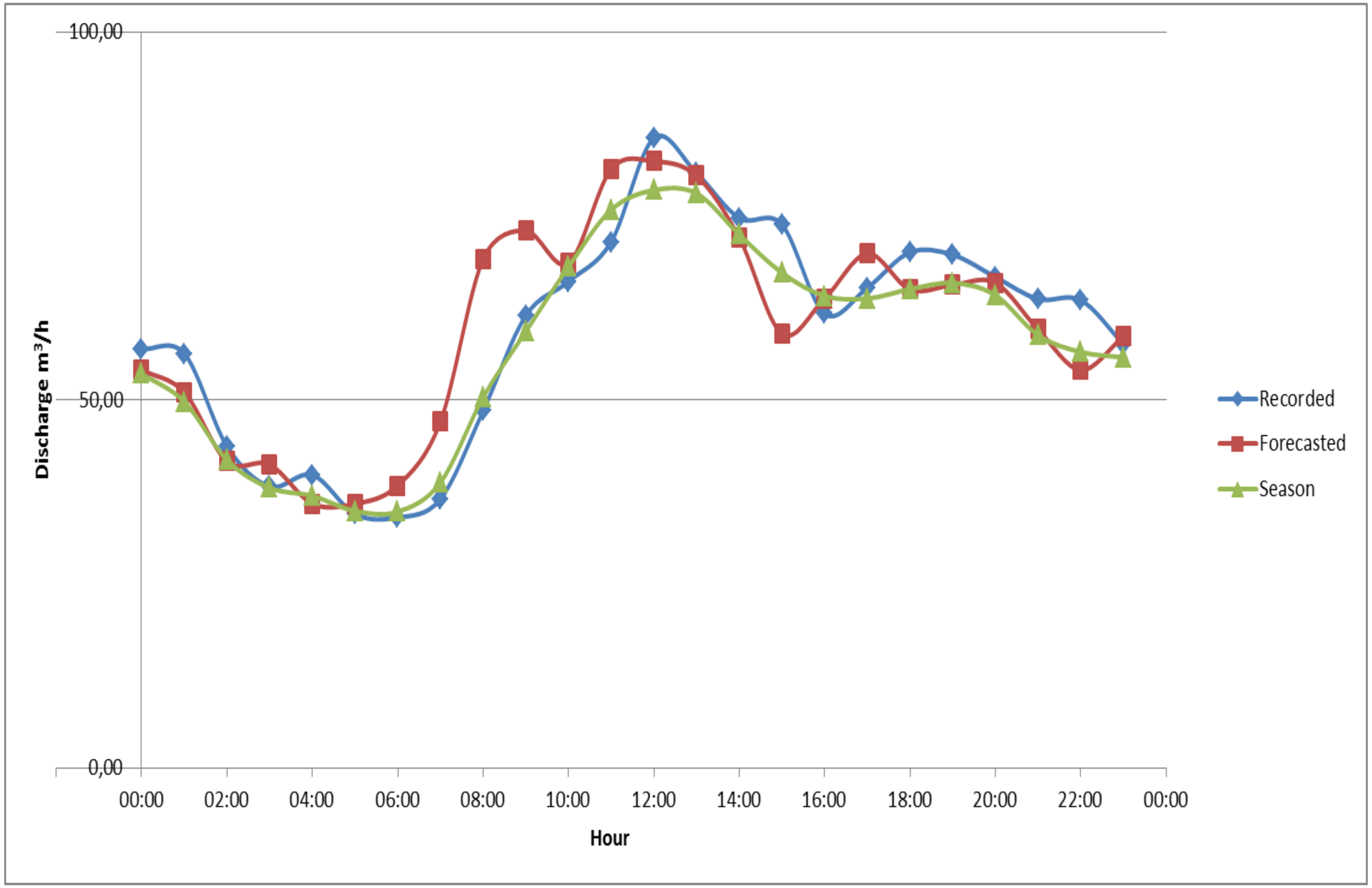

Figure B-3 Recorded and Forecasted DDC for 06.12.2009 with corresponding seasonal average

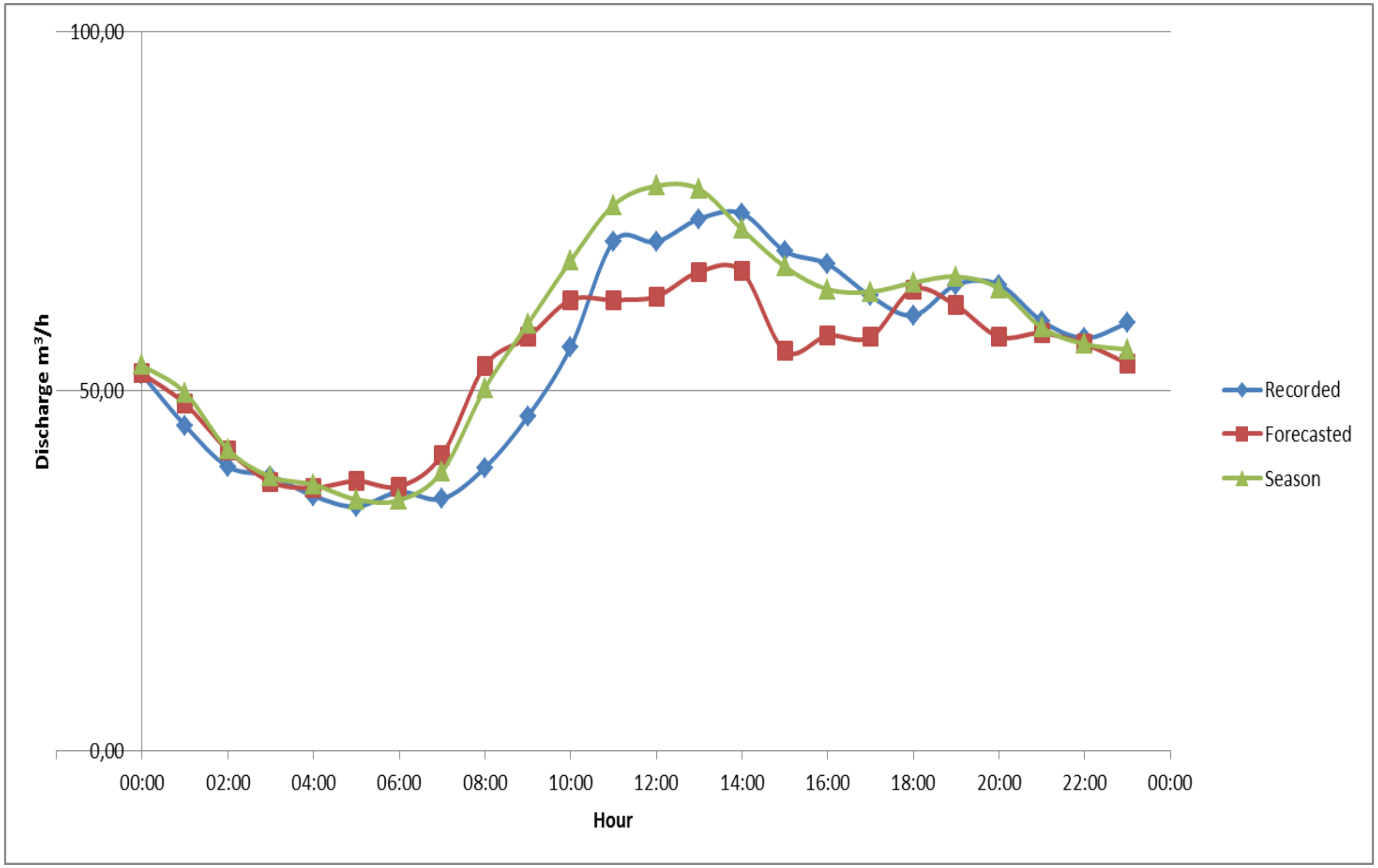

Figure B-4 Recorded and Forecasted DDC for 31.01.2010 with corresponding seasonal average

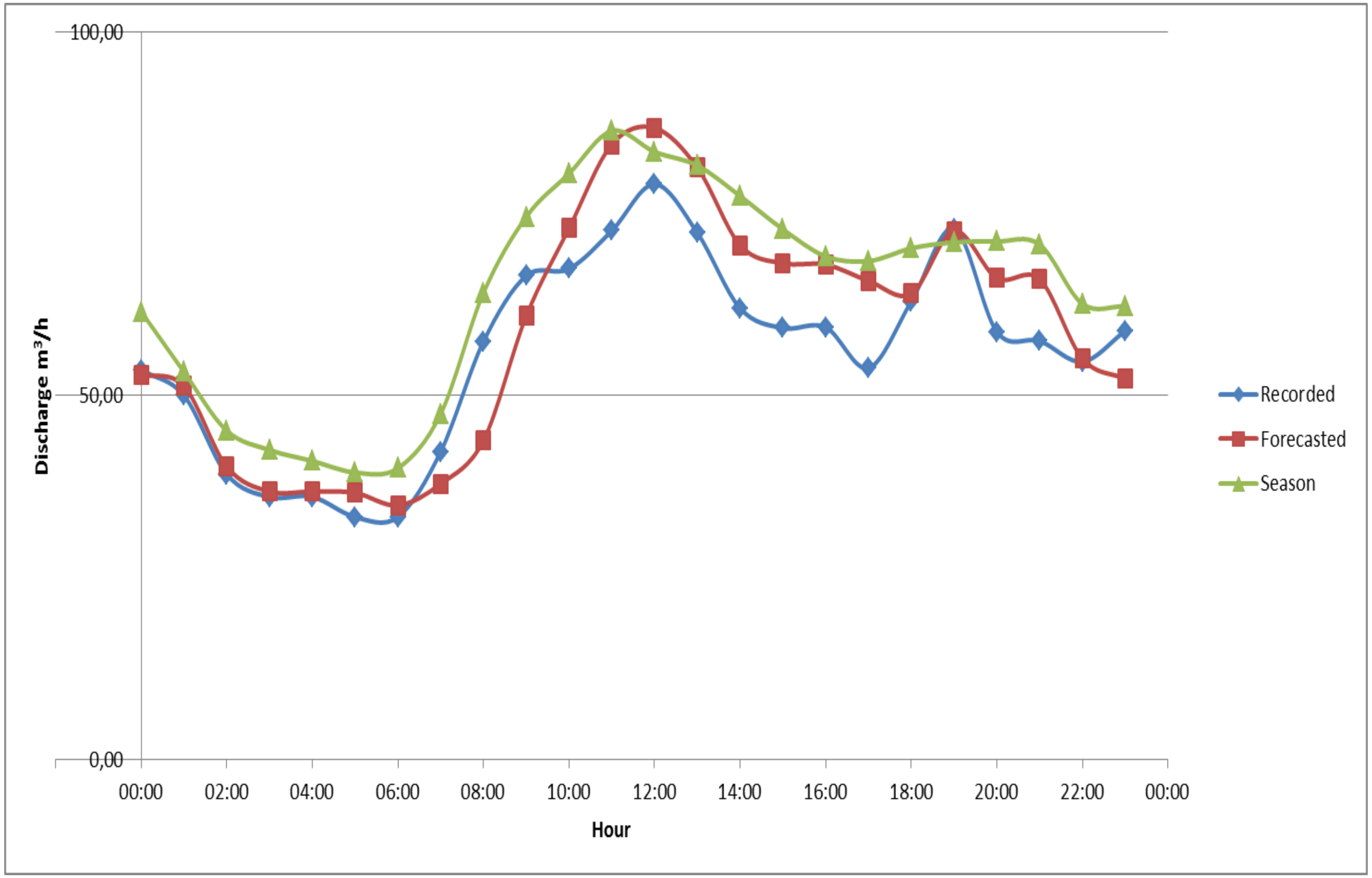

Figure B-5 Recorded and Forecasted DDC for 08.03.2010 with corresponding seasonal average

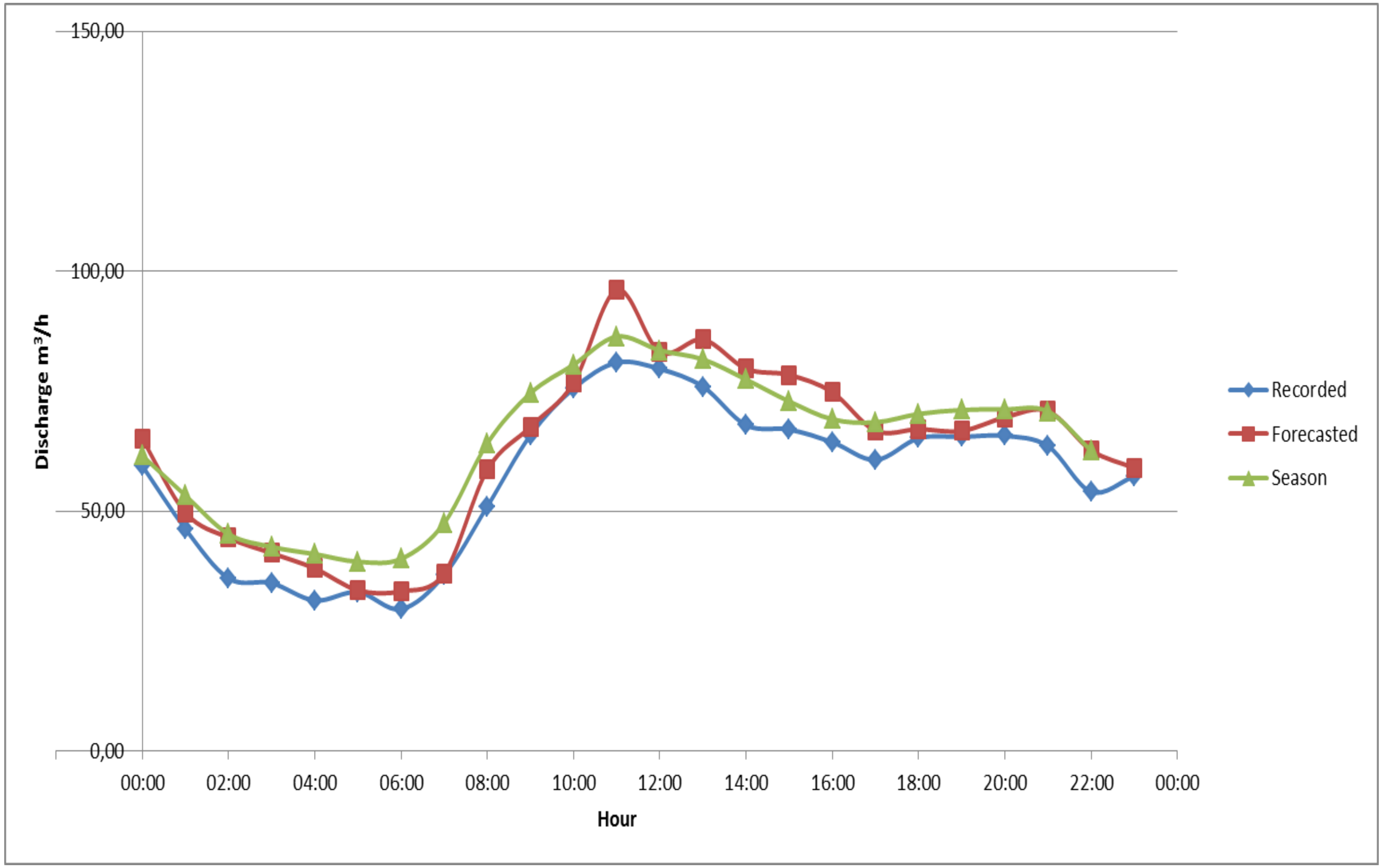

Figure B-6 Recorded and Forecasted DDC for 22.05.2010 with corresponding seasonal average

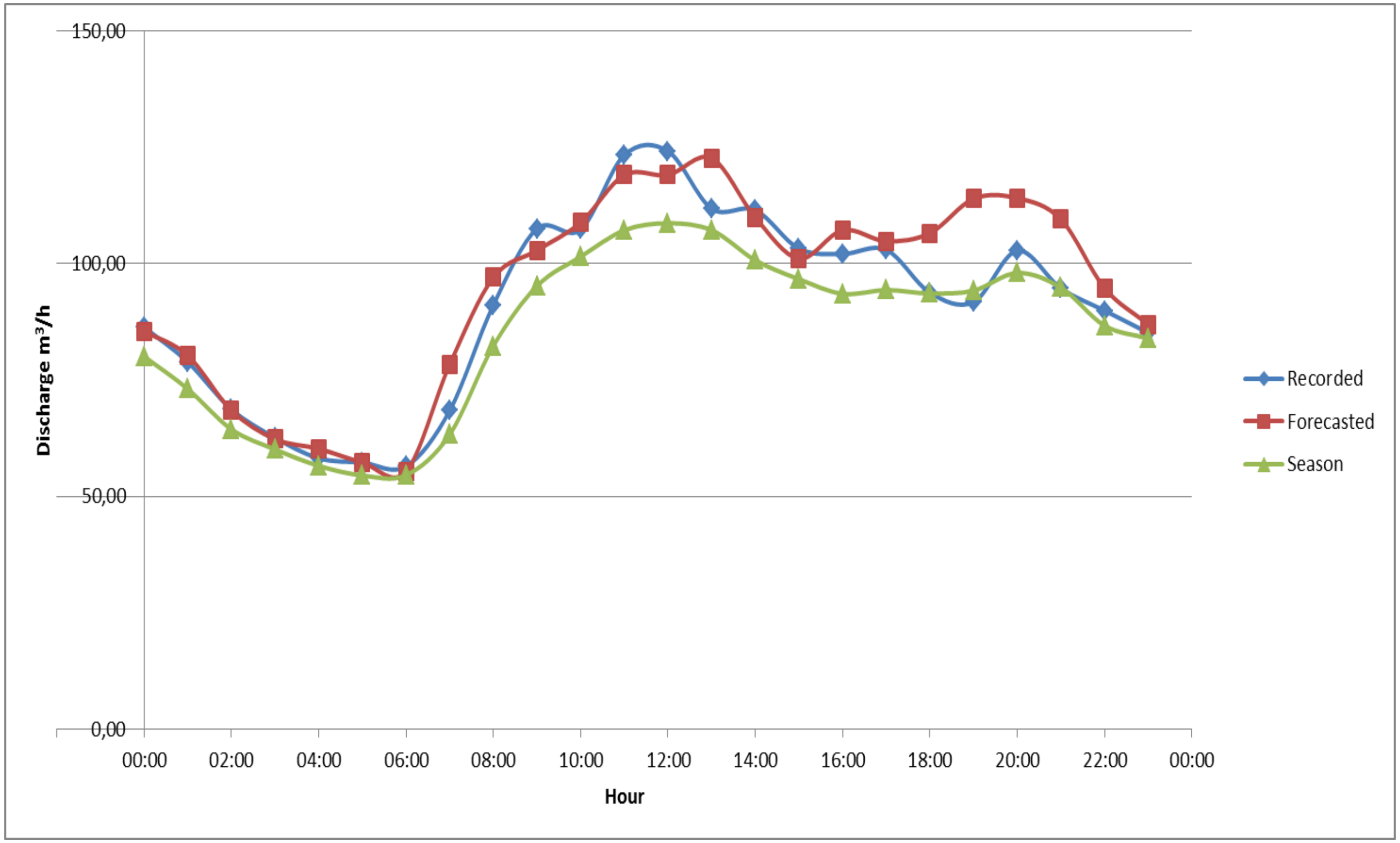

Figure B-7 Recorded and Forecasted DDC for 15.07.2009 with corresponding seasonal average

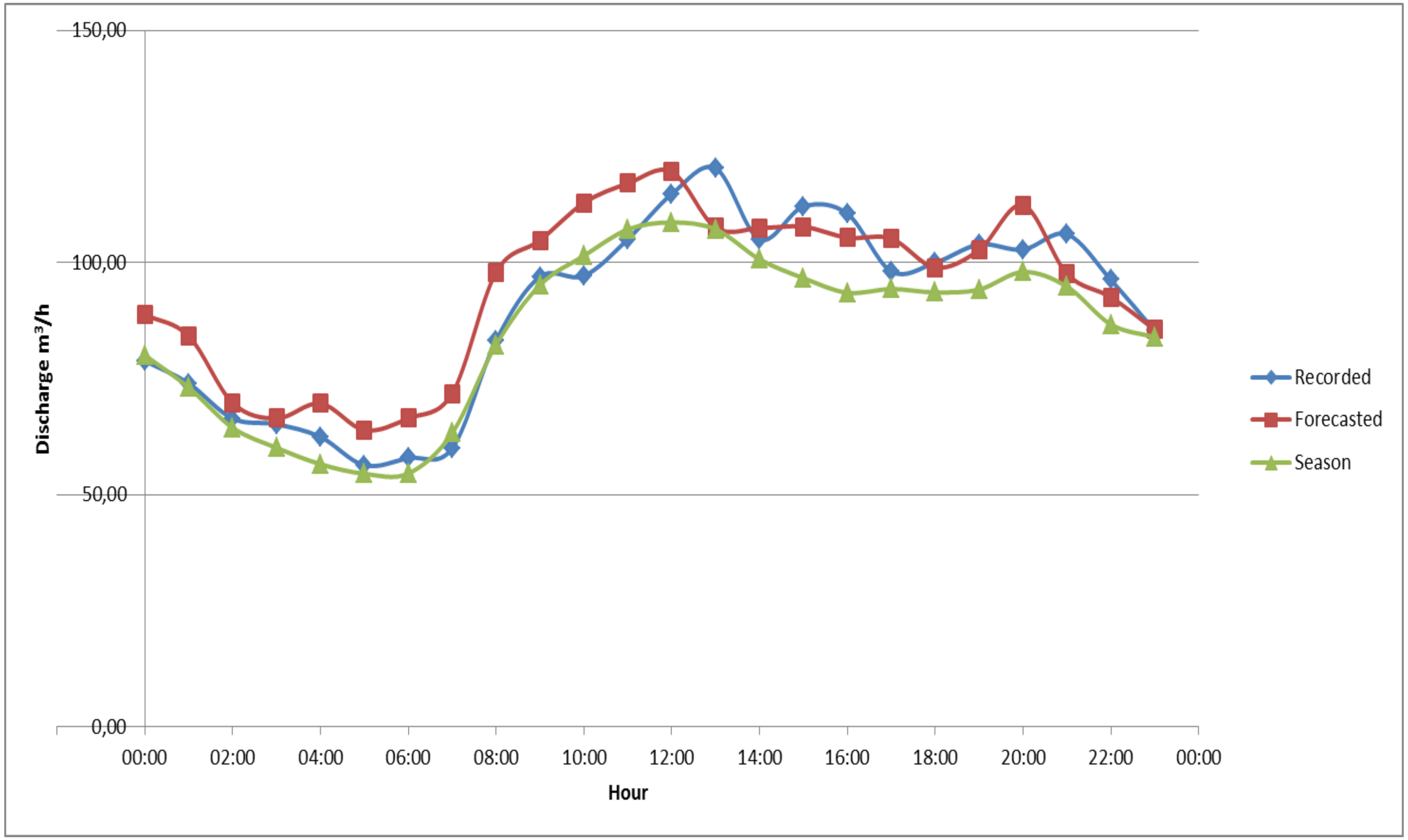

Figure B-8 Recorded and Forecasted DDC for 09.08.2009 with corresponding seasonal average

APPENDIX C

OPTIMUM VALVE SETTING FOR PRESSURE MANAGEMENT

Table C-1 DDC values for 06.09.2008 and corresponding values

Hours	Recorded	Forecasted	The Day Before 05.09.2008	Seasonal Average
	(m^3/hr)	(m^3/hr)	(m^3/hr)	(m^3/hr)
00:00	188.83	159.15	199.27	142.00
01:00	137.98	108.54	159.74	117.13
02:00	121.04	116.94	105.85	94.18
03:00	104.04	108.85	116.72	85.59
04:00	116.72	110.32	144.83	77.58
05:00	159.79	136.09	158.36	90.27
06:00	77.86	91.42	101.15	95.52
07:00	115.92	107.55	104.21	104.42
08:00	121.23	112.36	206.66	140.24
09:00	136.75	161.95	198.31	146.78
10:00	161.29	145.66	184.94	144.07
11:00	158.97	175.95	207.36	176.89
12:00	194.28	208.93	184.50	206.36
13:00	203.56	216.15	230.38	247.75
14:00	247.20	235.77	210.73	240.38
15:00	200.84	193.37	153.93	186.52
16:00	163.36	189.65	211.07	176.44
17:00	150.12	192.58	183.90	159.10
18:00	145.02	175.43	156.74	163.69
19:00	151.06	167.03	139.79	159.07
20:00	184.81	197.72	182.96	162.43
21:00	151.81	149.16	143.30	147.33
22:00	132.53	154.75	204.18	159.55
23:00	109.12	157.98	178.38	156.61

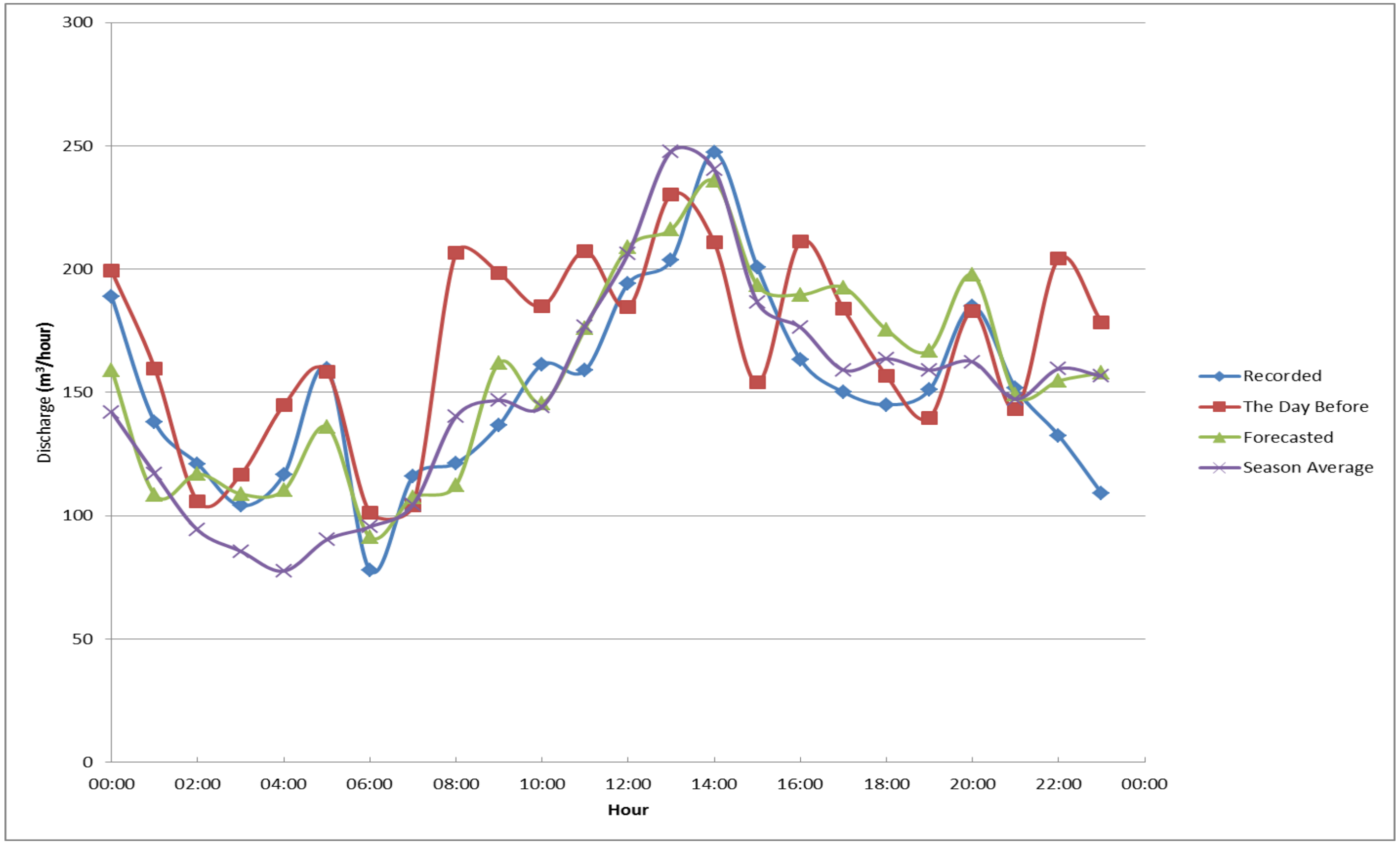

Figure C-1 Graphical demonstration of related DDCs (06.09.2008)

Table C-2 CODE I and II Results of Recorded DDC (06.09.2008)

Hours	Demand (m^3/hr)	Valve Openings V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	188.83	0.09	1	0.00	0	0.00	0	0.00	0	0.11	1
01:00	137.98	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	121.04	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	104.04	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
04:00	116.72	0.00	0	0.00	0	0.00	0	0.00	0	0.14	1
05:00	159.79	0.00	1	0.00	0	0.00	0	0.00	0	0.12	1
06:00	77.86	0.45	1	0.00	0	0.00	0	0.00	0	0.62	1
07:00	115.92	0.00	0	0.22	1	0.00	0	0.00	0	0.00	0
08:00	121.23	0.17	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	136.75	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	161.29	0.26	1	0.00	0	0.00	0	0.32	1	0.00	0
11:00	158.97	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	194.28	0.00	0	0.00	0	0.00	0	0.47	1	0.00	0
13:00	203.56	0.28	1	0.00	0	0.00	0	0.54	1	0.00	0
14:00	247.20	0.23	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	200.84	0.82	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	163.36	0.78	1	0.00	0	0.00	0	0.00	0	0.53	1
17:00	150.12	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	145.02	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	151.06	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	184.81	0.48	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	151.81	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	132.53	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	109.12	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-3 CODE I and II Results of The Day Before Recorded Day DDC (05.09.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	199.27	0.12	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	159.74	0.14	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	105.85	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	116.72	0.00	0	0.00	0	0.00	0	0.00	0	0.16	1
04:00	144.83	0.00	0	0.00	0	0.00	0	0.00	0	0.13	1
05:00	158.36	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	101.15	0.00	0	0.21	1	0.00	0	0.00	0	0.00	0
07:00	104.21	0.00	0	0.27	1	0.00	0	0.00	0	0.00	0
08:00	206.66	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	198.31	0.19	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	184.94	0.29	1	0.00	0	0.00	0	0.47	1	0.00	0
11:00	207.36	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	184.50	0.00	0	0.00	0	0.00	0	0.39	1	0.00	0
13:00	230.38	0.00	0	0.00	0	0.00	0	0.31	1	0.00	0
14:00	210.73	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	153.93	0.78	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	211.07	0.74	1	0.00	0	0.00	0	0.00	0	0.00	1
17:00	183.90	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	156.74	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	139.79	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	182.96	0.47	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	143.30	0.53	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	204.18	0.65	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	178.38	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-4 CODE I and II Results of Forecasted DDC (06.09.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	159.15	0.10	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	108.54	0.05	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	116.94	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	108.85	0.00	0	0.00	0	0.00	0	0.00	0	0.11	1
04:00	110.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	136.09	0.00	0	0.00	0	0.00	0	0.00	0	0.08	1
06:00	91.42	0.21	1	0.18	1	0.00	0	0.00	0	0.19	1
07:00	107.55	0.00	0	0.18	1	0.00	0	0.00	0	0.00	0
08:00	112.36	0.17	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	161.95	0.14	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	145.66	0.36	1	0.00	0	0.00	0	0.52	1	0.00	0
11:00	175.95	0.31	1	0.00	0	0.00	0	0.02	0	0.00	0
12:00	208.93	0.00	0	0.00	0	0.00	0	0.48	1	0.00	0
13:00	216.15	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0
14:00	235.77	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	193.37	0.74	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	189.65	0.67	1	0.00	0	0.00	0	0.00	0	0.07	1
17:00	192.58	0.55	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	175.43	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	167.03	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	197.72	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	149.16	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	154.75	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	157.98	0.26	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-5 CODE I and II Results of Seasonal Average DDC (Autumn)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	142.00	0.10	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	117.13	0.23	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	94.18	0.00	0	0.00	0	0.00	0	0.00	0	0.38	1
03:00	85.59	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1
04:00	77.58	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	90.27	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	95.52	0.00	0	0.12	1	0.00	0	0.00	0	0.00	0
07:00	104.42	0.00	0	0.20	1	0.00	0	0.00	0	0.00	0
08:00	140.24	0.22	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	146.78	0.22	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	144.07	0.22	1	0.00	0	0.00	0	0.48	1	0.00	0
11:00	176.89	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	206.36	0.00	0	0.00	0	0.00	0	0.51	0	0.00	0
13:00	247.75	0.27	0	0.00	0	0.00	0	0.56	1	0.00	0
14:00	240.38	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	186.52	0.84	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	176.44	0.82	1	0.00	0	0.00	0	0.00	0	0.52	1
17:00	159.10	0.59	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	163.69	0.65	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	159.07	0.58	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	162.43	0.61	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	147.33	0.49	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	159.55	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	156.61	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-6 DDC values for 11.10.2008 and corresponding values

Hours	Recorded (m^3/hr)	Forecasted (m^3/hr)	The Day Before 10.10.2008 (m^3/hr)	Seasonal Average (m^3/hr)
00:00	159.44	145.17	130.64	142.00
01:00	126.92	99.36	95.46	117.13
02:00	85.61	87.06	100.05	94.18
03:00	70.90	64.39	61.60	85.59
04:00	68.32	67.19	74.85	77.58
05:00	66.12	78.72	74.83	90.27
06:00	59.47	64.30	114.45	95.52
07:00	115.64	87.71	123.97	104.42
08:00	117.85	104.85	170.37	140.24
09:00	153.45	107.16	118.34	146.78
10:00	150.16	166.34	186.08	144.07
11:00	169.90	166.23	49.06	176.89
12:00	187.10	185.34	129.76	206.36
13:00	224.04	161.75	153.86	247.75
14:00	185.99	198.18	220.86	240.38
15:00	183.23	177.98	183.46	186.52
16:00	175.05	121.46	155.11	176.44
17:00	112.56	143.67	39.79	159.10
18:00	136.78	112.16	116.43	163.69
19:00	138.74	167.95	147.27	159.07
20:00	129.94	132.72	120.69	162.43
21:00	108.10	121.95	159.10	147.33
22:00	107.10	135.20	202.99	159.55
23:00	196.75	131.63	157.05	156.61

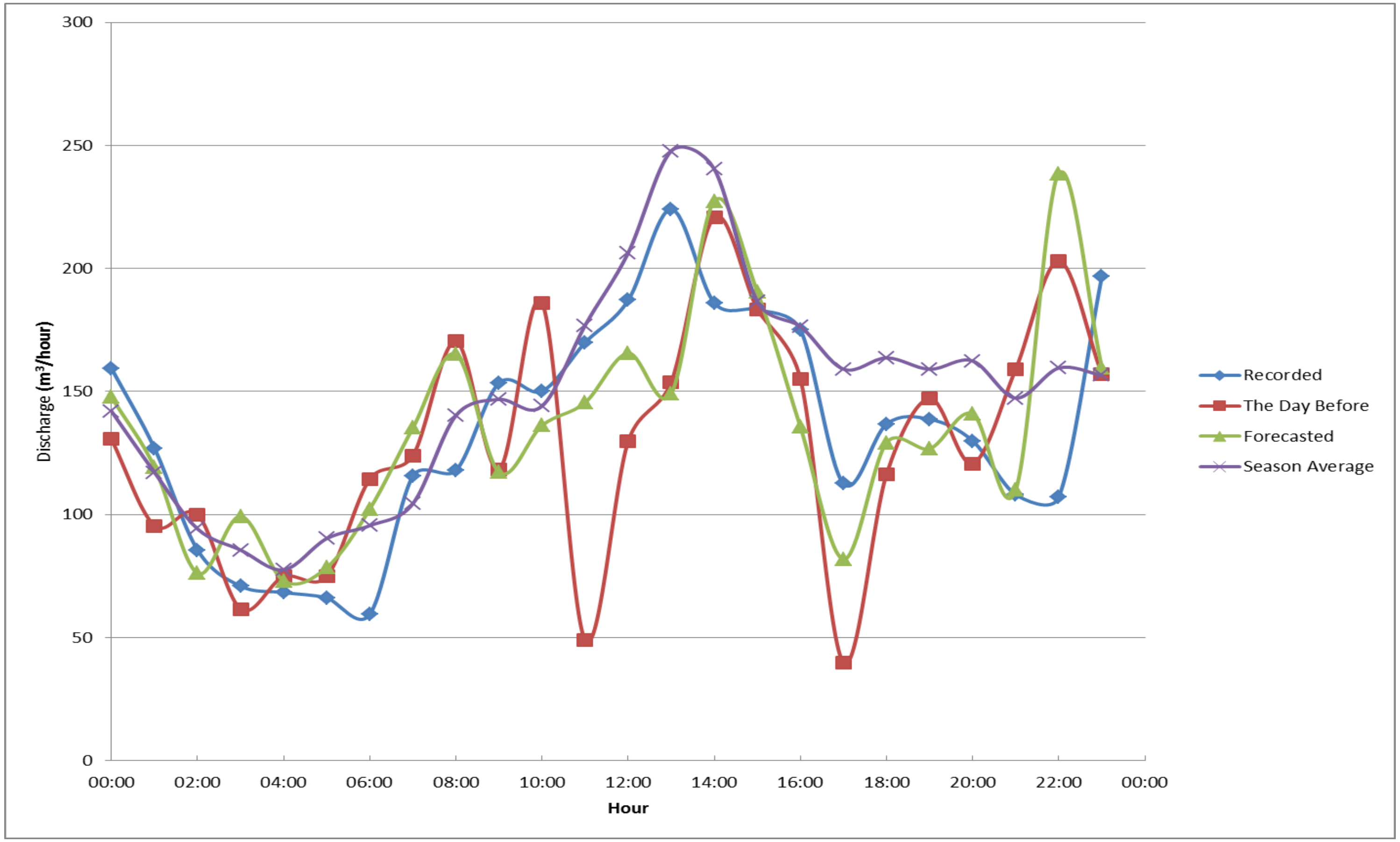

Figure C-2 Graphical demonstration of related DDCs (11.10.2008)

Table C-7 CODE I and II Results of Recorded DDC (11.10.2008)

Hours	Demand (m³/hr)	Valve Openings V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	159.44	0.09	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	126.92	0.02	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	85.61	0.32	1	0.00	0	0.00	0	0.00	0	0.46	1
03:00	70.90	0.51	1	0.00	0	0.00	0	0.31	1	0.58	1
04:00	68.32	0.45	1	0.00	0	0.00	0	0.00	0	0.56	1
05:00	66.12	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	59.47	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
07:00	115.64	0.00	0	0.22	1	0.00	0	0.00	0	0.00	0
08:00	117.85	0.17	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	153.45	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	150.16	0.26	1	0.00	0	0.00	0	0.32	1	0.00	0
11:00	169.90	0.33	1	0.00	0	0.00	0	0.00	1	0.00	0
12:00	187.10	0.00	0	0.00	0	0.00	0	0.47	1	0.00	0
13:00	224.04	0.00	0	0.00	0	0.00	0	0.12	1	0.00	0
14:00	185.99	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
15:00	183.23	0.03	0	0.00	0	0.00	0	0.00	0	0.00	0
16:00	175.05	0.11	1	0.00	0	0.00	0	0.00	0	0.07	0
17:00	112.56	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	136.78	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	138.74	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	129.94	0.48	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	108.10	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	107.10	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	196.75	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-8 CODE I and II Results of The Day Before Recorded Day DDC (10.10.2008)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	130.64	0.12	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	95.46	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	100.05	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	61.60	0.49	1	0.00	0	0.00	0	0.00	0	0.21	1
04:00	74.85	0.41	1	0.00	0	0.00	0	0.00	0	0.12	1
05:00	74.83	0.29	1	0.00	0	0.00	0	0.00	0	0.00	0
06:00	114.45	0.00	0	0.21	1	0.00	0	0.00	0	0.00	0
07:00	123.97	0.00	0	0.17	1	0.00	0	0.00	0	0.00	0
08:00	170.37	0.14	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	118.34	0.19	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	186.08	0.29	1	0.00	0	0.00	0	0.47	1	0.00	0
11:00	49.06	0.86	1	0.00	0	0.00	0	0.00	0	0.69	1
12:00	129.76	0.00	0	0.00	0	0.00	0	0.39	1	0.00	0
13:00	153.86	0.00	0	0.00	0	0.00	0	0.31	0	0.00	0
14:00	220.86	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	183.46	0.78	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	155.11	0.74	1	0.00	0	0.00	0	0.00	0	0.00	0
17:00	39.79	0.89	1	0.00	0	0.00	0	0.40	1	0.66	1
18:00	116.43	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	147.27	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	120.69	0.47	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	159.10	0.32	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	202.99	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	157.05	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-9 CODE I and II Results of Forecasted DDC (11.10.2008)

Hours	Demand (m^3/hr)	Valve Openings V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	145.17	0.10	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	99.36	0.15	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	87.06	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	64.39	0.00	0	0.18	1	0.00	0	0.00	0	0.36	1
04:00	67.19	0.25	1	0.00	0	0.00	0	0.00	0	0.28	1
05:00	78.72	0.00	0	0.00	0	0.00	0	0.00	0	0.39	1
06:00	64.30	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0
07:00	87.71	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0
08:00	104.85	0.17	1	0.00	0	0.00	0	0.00	0	0.00	1
09:00	107.16	0.14	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	166.34	0.36	1	0.00	0	0.00	0	0.52	1	0.00	0
11:00	166.23	0.31	0	0.00	0	0.00	0	0.02	0	0.00	0
12:00	185.34	0.00	0	0.00	0	0.00	0	0.48	0	0.00	0
13:00	161.75	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
14:00	198.18	0.28	1	0.00	0	0.00	0	0.00	0	0.00	1
15:00	177.98	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	121.46	0.67	1	0.00	0	0.00	0	0.00	0	0.00	0
17:00	143.67	0.55	0	0.00	0	0.00	0	0.00	0	0.00	0
18:00	112.16	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	167.95	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	132.72	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	121.95	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	135.20	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	131.63	0.26	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-10 DDC values for 25.10.2007 and corresponding values

Hours	Recorded (m^3/hr)	Forecasted (m^3/hr)	The Day Before 24.10.2007 (m^3/hr)	Seasonal Average (m^3/hr)
00:00	161.85	167.83	162.67	142.00
01:00	135.53	143.71	147.15	117.13
02:00	117.18	125.36	147.15	94.18
03:00	89.36	105.34	147.15	85.59
04:00	81.22	94.27	147.15	77.58
05:00	98.33	92.57	146.65	90.27
06:00	146.93	132.27	69.90	95.52
07:00	156.33	141.27	132.35	104.42
08:00	202.36	168.64	94.78	140.24
09:00	189.36	174.18	118.19	146.78
10:00	156.78	154.34	87.51	144.07
11:00	121.05	121.46	72.25	176.89
12:00	202.39	211.98	77.21	206.36
13:00	236.98	191.47	102.04	247.75
14:00	210.02	205.36	126.45	240.38
15:00	145.66	116.94	131.83	186.52
16:00	145.58	141.98	184.17	176.44
17:00	188.72	166.47	217.22	159.10
18:00	196.36	209.14	204.54	163.69
19:00	214.71	236.88	165.71	159.07
20:00	295.49	245.64	140.63	162.43
21:00	220.11	199.94	140.63	147.33
22:00	183.52	175.36	175.36	159.55
23:00	181.70	141.32	153.67	156.61

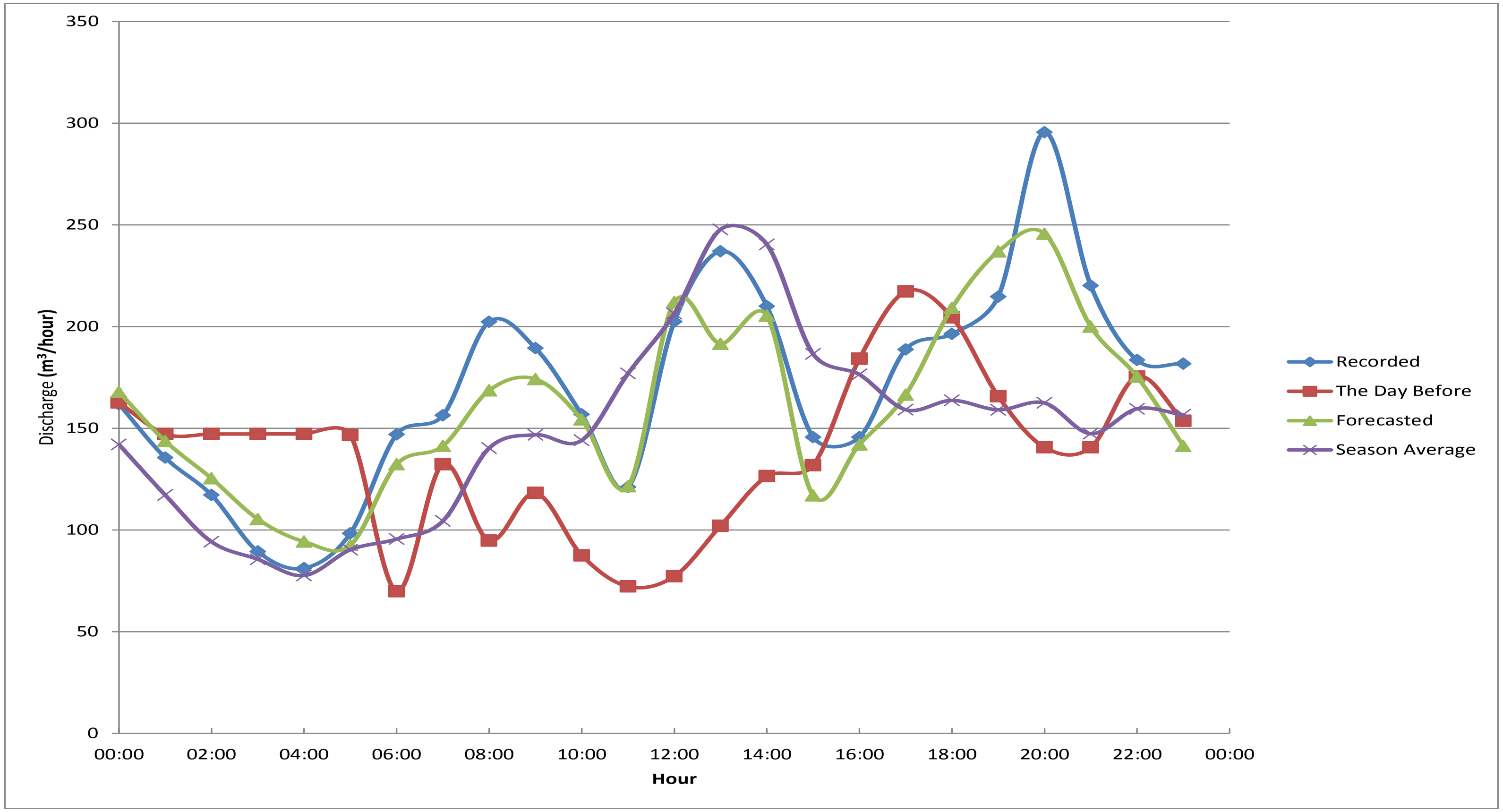

Figure C-3 Graphical demonstration of related DDCs (25.10.2007)

Table C-11 CODE I and II Results of Recorded DDC (25.10.2007)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	164.48	0.16	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	127.52	0.27	1	0.00	0	0.00	0	0.00	0	0.04	0
02:00	81.46	0.36	1	0.00	0	0.00	0	0.00	0	0.41	1
03:00	100.82	0.00	0	0.00	0	0.00	0	0.00	0	0.11	1
04:00	78.59	0.21	1	0.00	0	0.00	0	0.00	0	0.36	1
05:00	85.53	0.19	1	0.00	0	0.00	0	0.00	0	0.00	0
06:00	95.12	0.00	0	0.13	1	0.00	0	0.00	0	0.00	0
07:00	93.13	0.00	0	0.14	1	0.00	0	0.00	0	0.00	0
08:00	131.05	0.20	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	122.85	0.15	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	178.88	0.00	0	0.00	0	0.05	0	0.24	1	0.02	0
11:00	189.27	0.11	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	268.18	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
13:00	216.1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
14:00	234.27	0.00	0	0.00	0	0.00	0	0.00	0	0.11	1
15:00	178.88	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	307.68	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
17:00	229.27	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
18:00	150.87	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	142.69	0.22	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	135.78	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	137.92	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	263	0.00	0	0.00	0	0.00	0	0.00	0	0.03	0
23:00	181.7	0.22	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-12 CODE I and II Results of The Day Before Recorded Day DDC (24.10.2007)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	230.58	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
01:00	124.42	0.07	0	0.00	0	0.00	0	0.00	0	0.00	0
02:00	78.25	0.32	1	0.00	0	0.00	0	0.00	0	0.51	1
03:00	90.41	0.23	1	0.00	0	0.00	0	0.00	0	0.35	1
04:00	67.70	0.57	1	0.00	0	0.00	0	0.00	0	0.71	1
05:00	88.30	0.52	1	0.00	0	0.00	0	0.00	0	0.64	1
06:00	110.99	0.00	0	0.16	1	0.00	0	0.00	0	0.00	0
07:00	126.08	0.00	0	0.26	1	0.00	0	0.00	0	0.00	0
08:00	121.63	0.19	1	0.03	0	0.00	0	0.00	0	0.00	0
09:00	164.69	0.26	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	88.85	0.02	0	0.00	0	0.01	0	0.00	0	0.09	0
11:00	343.90	0.58	1	0.00	0	0.00	0	0.00	0	0.67	1
12:00	238.12	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
13:00	237.07	0.00	0	0.00	0	0.00	0	0.48	1	0.00	0
14:00	271.42	0.48	1	0.00	0	0.00	0	0.00	0	0.02	0
15:00	222.39	0.80	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	182.53	1.00	1	0.00	0	0.00	0	0.00	0	1.00	1
17:00	7.43	0.86	1	0.00	0	0.00	0	0.68	1	0.92	1
18:00	117.50	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	150.88	0.14	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	123.81	0.22	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	106.19	0.29	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	241.82	0.08	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	179.76	0.47	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-13 CODE I and II Results of Forecasted DDC (25.10.2007)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	147.78	0.12	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	119.28	0.06	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	76.15	0.00	0	0.00	0	0.00	0	0.00	0	0.27	1
03:00	99.34	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1
04:00	73.09	0.32	1	0.00	0	0.00	0	0.00	0	0.39	1
05:00	78.49	0.35	1	0.00	0	0.00	0	0.00	0	0.35	1
06:00	102.25	0.00	0	0.14	1	0.00	0	0.00	0	0.00	0
07:00	135.25	0.00	0	0.26	1	0.00	0	0.00	0	0.00	0
08:00	165.14	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	117.20	0.18	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	136.20	0.24	1	0.00	0	0.00	0	0.35	1	0.00	0
11:00	145.51	0.34	1	0.00	0	0.00	0	0.00	0	0.02	0
12:00	165.61	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
13:00	149.18	0.00	0	0.00	0	0.00	0	0.35	0	0.00	0
14:00	227.43	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	190.41	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	135.55	0.21	1	0.00	0	0.00	0	0.00	0	0.16	1
17:00	81.89	0.45	1	0.00	0	0.00	0	0.00	0	0.51	1
18:00	129.25	0.49	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	126.72	0.48	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	140.95	0.18	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	110.07	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	238.58	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0
23:00	159.77	0.16	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-14 DDC values for 13.12.2008 and corresponding values

Hours	Recorded	Forecasted	The Day Before 12.12.2008	Seasonal Average
	(m^3/hr)	(m^3/hr)	(m^3/hr)	(m^3/hr)
00:00	169.65	159.15	155.76	158.52
01:00	132.71	142.14	148.05	145.84
02:00	83.56	117.61	143.25	123.46
03:00	91.81	95.88	130.20	94.50
04:00	90.26	91.2	81.50	85.82
05:00	78.70	92.15	90.50	85.77
06:00	84.24	91.42	72.34	96.39
07:00	111.77	107.55	103.31	123.38
08:00	118.24	112.36	103.65	134.55
09:00	143.89	133.57	98.57	148.12
10:00	144.95	145.66	124.26	162.09
11:00	187.07	175.95	158.60	178.59
12:00	222.68	211.32	225.77	216.25
13:00	252.38	245.37	249.56	233.84
14:00	217.07	235.77	234.16	208.44
15:00	170.41	193.37	206.52	188.02
16:00	142.92	157.14	164.70	166.20
17:00	105.08	121.22	111.94	132.16
18:00	145.30	151.31	137.85	146.85
19:00	108.48	135.21	114.11	155.54
20:00	140.70	152.18	128.55	158.21
21:00	127.67	132.14	118.68	146.10
22:00	123.44	154.75	108.39	173.98
23:00	98.12	157.98	176.76	157.41

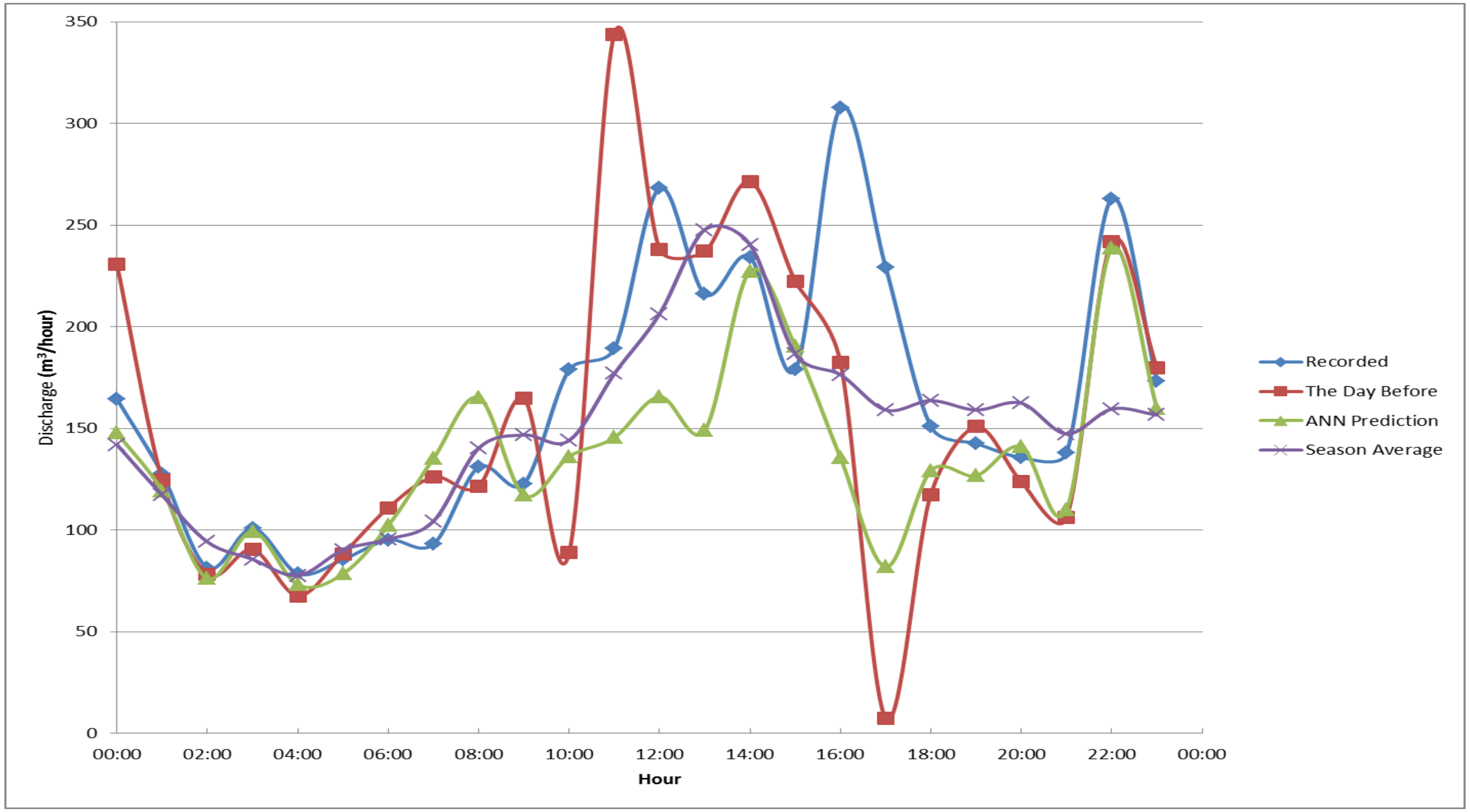

Figure C-4 Graphical demonstration of related DDCs (13.12.2008)

Table C-15 CODE I and II Results of Recorded DDC (13.12.2008)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	187.54	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	165.60	0.11	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	105.36	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	99.16	0.00	0	0.00	0	0.00	0	0.00	0	0.42	1
04:00	91.64	0.15	1	0.00	0	0.00	0	0.00	0	0.00	0
05:00	85.23	0.16	1	0.00	0	0.00	0	0.00	0	0.00	0
06:00	110.32	0.00	0	0.13	1	0.00	0	0.00	0	0.00	0
07:00	146.50	0.00	0	0.18	1	0.00	0	0.00	0	0.00	0
08:00	138.58	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	101.32	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	154.58	0.42	1	0.00	0	0.00	0	0.37	1	0.00	0
11:00	162.70	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	223.76	0.00	0	0.00	0	0.00	0	0.45	1	0.00	0
13:00	335.84	0.00	0	0.00	0	0.00	0	0.11	1	0.00	0
14:00	233.34	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	114.44	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	93.85	0.19	1	0.00	0	0.00	0	0.00	0	0.46	1
17:00	40.60	0.62	1	0.00	0	0.00	0	0.00	0	0.51	1
18:00	149.84	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	140.10	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	139.07	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	123.96	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	189.29	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	205.70	0.49	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-16 CODE I and II Results of The Day Before Recorded Day DDC (12.12.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	155.76	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	148.05	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	143.25	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	130.20	0.00	0	0.00	0	0.00	0	0.00	0	0.46	1
04:00	81.50	0.36	1	0.00	0	0.00	0	0.00	0	0.41	1
05:00	90.50	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	72.34	0.00	0	0.14	1	0.00	0	0.00	0	0.00	0
07:00	103.31	0.00	0	0.18	1	0.00	0	0.00	0	0.00	0
08:00	103.65	0.19	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	98.57	0.26	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	124.26	0.28	1	0.00	0	0.00	0	0.27	1	0.00	0
11:00	158.60	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	225.77	0.00	0	0.00	0	0.00	0	0.40	1	0.00	0
13:00	249.56	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
14:00	234.16	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
15:00	206.52	0.19	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	164.70	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
17:00	111.94	0.25	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	137.85	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	114.11	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	128.55	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	118.68	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	108.39	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	176.76	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-17 CODE I and II Results of Forecasted DDC (13.12.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	159.15	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	142.14	0.26	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	117.61	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	95.88	0.00	0	0.00	0	0.00	0	0.00	0	0.32	1
04:00	91.2	0.00	0	0.00	0	0.00	0	0.00	0	0.17	1
05:00	92.15	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
06:00	91.42	0.36	1	0.23	1	0.00	0	0.00	0	0.00	0
07:00	107.55	0.00	0	0.26	1	0.00	0	0.00	0	0.00	0
08:00	112.36	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	133.57	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	145.66	0.40	1	0.00	0	0.00	0	0.34	1	0.00	0
11:00	175.95	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	211.32	0.00	0	0.00	0	0.00	0	0.38	1	0.00	0
13:00	245.37	0.00	0	0.00	0	0.00	0	0.16	1	0.00	0
14:00	235.77	0.52	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	193.37	0.47	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	157.14	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
17:00	121.22	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	151.31	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	135.21	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	152.18	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	132.14	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	154.75	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	157.98	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-18 CODE I and II Results of Seasonal Average DDC (Winter)

Hours	Demand (m³/hr)	Valve Openings V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	158.52	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	145.84	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	123.46	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	94.50	0.00	0	0.00	0	0.00	0	0.00	0	0.31	1
04:00	85.82	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	85.77	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	96.39	0.00	0	0.21	1	0.00	0	0.00	0	0.00	0
07:00	123.38	0.00	0	0.30	1	0.00	0	0.00	0	0.00	0
08:00	134.55	0.29	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	148.12	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	162.09	0.43	1	0.00	0	0.00	0	0.39	1	0.00	0
11:00	178.59	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	216.25	0.00	0	0.00	0	0.00	0	0.40	1	0.00	0
13:00	233.84	0.00	0	0.00	0	0.00	0	0.42	1	0.00	0
14:00	208.44	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	188.02	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	166.20	0.42	1	0.00	0	0.00	0	0.00	0	0.45	1
17:00	132.16	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	146.85	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	155.54	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	158.21	0.48	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	146.10	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	173.98	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	157.41	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-19 DDC values for 10.01.2009 and corresponding values

Hours	Recorded	Forecasted	The Day Before 09.01.2009	Seasonal Average
	(m^3/hr)	(m^3/hr)	(m^3/hr)	(m^3/hr)
00:00	173.70	158.18	165.21	158.52
01:00	170.32	158.18	164.22	145.84
02:00	102.50	129.03	98.64	123.46
03:00	105.03	115.50	99.45	94.50
04:00	93.85	101.46	105.54	85.82
05:00	118.45	104.84	101.1	85.77
06:00	94.27	98.88	89.18	96.39
07:00	136.93	139.15	134.21	123.38
08:00	131.17	152.55	128.64	134.55
09:00	141.32	163.84	152.37	148.12
10:00	168.21	167.63	163.11	162.09
11:00	195.36	167.63	184.77	178.59
12:00	249.17	192.49	206.71	216.25
13:00	230.91	225.69	251.97	233.84
14:00	298.22	167.63	198.18	208.44
15:00	296.16	167.63	177.98	188.02
16:00	239.27	147.81	151.84	166.20
17:00	178.06	99.77	123.66	132.16
18:00	116.85	139.30	126.79	146.85
19:00	146.05	136.85	167.95	155.54
20:00	136.75	144.26	132.72	158.21
21:00	137.00	137.18	121.95	146.10
22:00	225.82	150.73	146.32	173.98
23:00	178.43	164.29	131.63	157.41

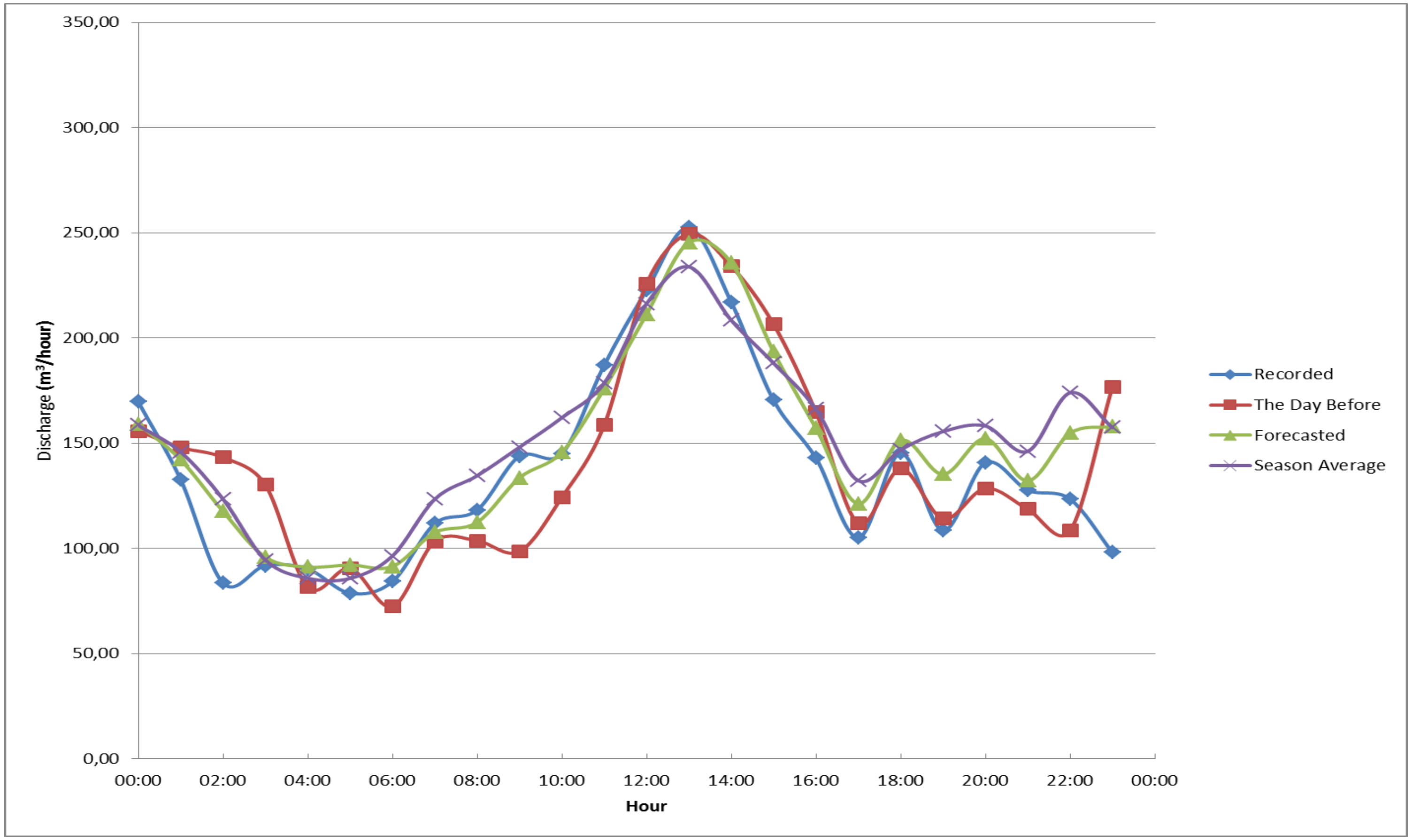

Figure C-5 Graphical demonstration of related DDCs (10.01.2009)

Table C-20 CODE I and II Results of Recorded DDC (10.01.2009)

Hours	Demand (m^3/hr)	Valve Openings V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	173.70	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	170.32	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	102.50	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	105.03	0.00	0	0.00	0	0.00	0	0.00	0	0.27	0
04:00	93.85	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1
05:00	118.45	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	94.27	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
07:00	136.93	0.00	0	0.32	1	0.00	0	0.00	0	0.00	0
08:00	131.17	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	141.32	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	168.21	0.45	1	0.00	0	0.00	0	0.42	1	0.00	0
11:00	195.36	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	249.17	0.00	0	0.00	0	0.00	0	0.51	1	0.00	0
13:00	230.91	0.00	0	0.00	0	0.00	0	0.42	1	0.00	0
14:00	298.22	0.51	1	0.00	0	0.00	0	0.32	1	0.00	0
15:00	296.16	0.55	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	239.27	0.57	1	0.00	0	0.00	0	0.00	0	0.49	1
17:00	178.06	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	116.85	0.32	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	146.05	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	136.75	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	137.00	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	225.82	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	178.43	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-21 CODE I and II Results of The Day Before Recorded Day DDC (09.01.2009)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	158.18	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	158.18	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	129.03	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	115.50	0.00	0	0.00	0	0.00	0	0.00	0	0.39	0
04:00	101.46	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1
05:00	104.84	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	98.88	0.00	0	1.00	1	0.00	0	0.00	0	0.00	0
07:00	139.15	0.00	0	0.33	1	0.00	0	0.00	0	0.00	0
08:00	152.55	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	163.84	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	167.63	0.45	1	0.00	0	0.00	0	0.42	1	0.00	0
11:00	167.63	0.40	0	0.00	0	0.00	0	0.00	0	0.00	0
12:00	192.49	0.00	0	0.00	0	0.00	0	0.37	1	0.00	0
13:00	225.69	0.00	0	0.00	0	0.00	0	0.41	1	0.00	0
14:00	167.63	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	167.63	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	147.81	0.48	1	0.00	0	0.00	0	0.00	0	0.00	0
17:00	99.77	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
18:00	139.30	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	136.85	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	144.26	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	137.18	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	150.73	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	164.29	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-22 CODE I and II Results of Forecasted DDC (10.01.2009)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	165.21	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	164.22	0.25	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	98.64	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	99.45	0.00	0	0.00	0	0.00	0	0.00	0	0.05	0
04:00	105.54	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1
05:00	101.1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	89.18	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
07:00	134.21	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
08:00	128.64	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	152.37	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	163.11	0.43	1	0.00	0	0.00	0	0.39	1	0.00	0
11:00	184.77	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	206.71	0.00	0	0.00	0	0.00	0	0.38	1	0.00	0
13:00	251.97	0.00	0	0.00	0	0.00	0	0.45	1	0.00	0
14:00	198.18	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	177.98	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	151.84	0.49	1	0.00	0	0.00	0	0.00	0	0.00	0
17:00	123.66	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	126.79	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	167.95	0.48	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	132.72	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	121.95	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	146.32	0.32	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	131.63	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-23 DDC values for 23.02.2009 and corresponding values

Hours	Recorded	Forecasted	The Day Before 22.02.2009	Seasonal Average
	(m^3/hr)	(m^3/hr)	(m^3/hr)	(m^3/hr)
00:00	187.54	162.34	187.43	158.52
01:00	165.60	158.19	179.92	145.84
02:00	105.36	111.94	137.48	123.46
03:00	99.16	101.56	113.56	94.50
04:00	91.64	106.31	187.99	85.82
05:00	85.23	78.49	130.92	85.77
06:00	110.32	102.25	149.44	96.39
07:00	146.50	135.87	74.53	123.38
08:00	138.58	165.13	106.87	134.55
09:00	101.32	154.18	122.52	148.12
10:00	154.58	162.98	140.03	162.09
11:00	162.70	145.51	173.25	178.59
12:00	223.76	216.97	203.09	216.25
13:00	335.84	248.33	276.74	233.84
14:00	233.34	227.43	264.64	208.44
15:00	114.44	190.41	234.21	188.02
16:00	93.85	135.55	209.77	166.20
17:00	40.60	81.54	213.31	132.16
18:00	149.84	126.63	73.92	146.85
19:00	140.10	123.71	178.86	155.54
20:00	139.07	142.95	176.73	158.21
21:00	123.96	116.08	154.25	146.10
22:00	189.29	137.59	158.79	173.98
23:00	205.70	159.66	249.78	157.41

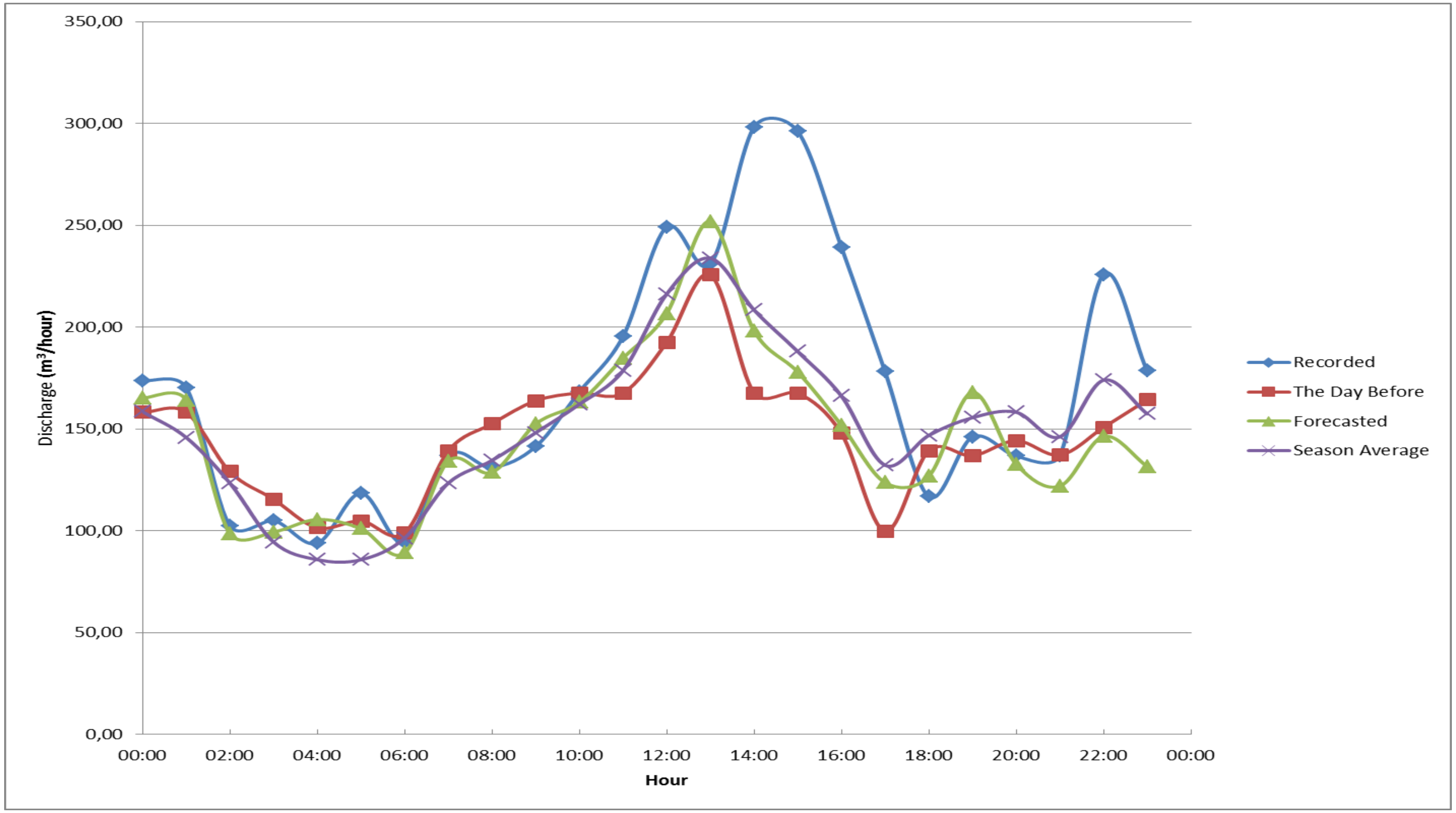

Figure C-6 Graphical demonstration of related DDCs (23.02.2009)

Table C-24 CODE I and II Results of Recorded DDC (23.02.2009)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	187.54	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	165.60	0.11	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	105.36	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	99.16	0.00	0	0.00	0	0.00	0	0.00	0	0.32	1
04:00	91.64	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
05:00	85.23	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
06:00	110.32	0.00	0	0.23	1	0.00	0	0.00	0	0.00	0
07:00	146.50	0.00	0	0.28	1	0.00	0	0.00	0	0.00	0
08:00	138.58	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	101.32	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	154.58	0.42	1	0.00	0	0.00	0	0.37	1	0.00	0
11:00	162.70	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	223.76	0.00	0	0.00	0	0.00	0	0.45	1	0.00	0
13:00	335.84	0.68	1	0.00	0	0.00	0	0.64	1	0.00	0
14:00	233.34	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	114.44	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	93.85	0.69	1	0.00	0	0.00	0	0.00	0	0.00	0
17:00	40.60	0.78	1	0.00	0	0.00	0	0.46	1	0.65	1
18:00	149.84	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	140.10	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	139.07	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	123.96	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	189.29	0.22	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	205.70	0.19	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-25 CODE I and II Results of The Day Before Recorded Day DDC (22.02.2009)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	187.43	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	179.92	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	137.48	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	113.56	0.00	0	0.00	0	0.00	0	0.00	0	0.36	1
04:00	187.99	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
05:00	130.92	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
06:00	149.44	0.00	0	0.34	1	0.00	0	0.00	0	0.00	0
07:00	74.53	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
08:00	106.87	0.23	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	122.52	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	140.03	0.40	1	0.00	0	0.00	0	0.33	1	0.00	0
11:00	173.25	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	203.09	0.00	0	0.00	0	0.00	0	0.37	1	0.00	0
13:00	276.74	0.15	1	0.00	0	0.00	0	0.47	1	0.00	0
14:00	264.64	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	234.21	0.22	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	209.77	0.17	1	0.00	0	0.00	0	0.00	0	0.17	1
17:00	213.31	0.15	1	0.00	0	0.00	0	0.00	0	0.12	1
18:00	73.92	0.55	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	178.86	0.49	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	176.73	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	154.25	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	158.79	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	249.78	0.18	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-26 CODE I and II Results of Forecasted DDC (23.02.2009)

Hours	Demand (m³/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	162.34	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	158.19	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	111.94	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	101.56	0.00	0	0.00	0	0.00	0	0.00	0	0.32	1
04:00	106.31	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	78.49	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	102.25	0.00	0	0.22	1	0.00	0	0.00	0	0.00	0
07:00	135.87	0.00	0	0.26	1	0.00	0	0.00	0	0.00	0
08:00	165.13	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	154.18	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	162.98	0.43	1	0.00	0	0.00	0	0.39	1	0.00	0
11:00	145.51	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	216.97	0.00	0	0.00	0	0.00	0	0.40	1	0.00	0
13:00	248.33	0.00	0	0.00	0	0.00	0	0.47	1	0.00	0
14:00	227.43	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	190.41	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	135.55	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
17:00	81.54	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
18:00	126.63	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	123.71	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	142.95	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	116.08	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	137.59	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	159.66	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-27 DDC values for 08.03.2009 and corresponding values

Hours	Recorded	Forecasted	The Day Before 07.03.2008	Seasonal Average
	(m^3/hr)	(m^3/hr)	(m^3/hr)	(m^3/hr)
00:00	151.63	147.78	185.19	123.56
01:00	159.20	109.32	174.38	93.31
02:00	128.68	86.15	127.83	67.74
03:00	92.81	84.59	77.02	61.81
04:00	90.69	73.09	116.39	56.45
05:00	82.23	78.49	85.09	71.45
06:00	99.73	98.17	95.93	96.59
07:00	88.25	124.17	171.50	136.33
08:00	149.39	159.27	167.04	157.41
09:00	118.75	161.29	182.52	170.06
10:00	170.56	166.24	190.22	194.65
11:00	264.35	218.67	227.50	227.48
12:00	301.50	264.14	252.99	233.01
13:00	261.48	204.68	133.05	225.57
14:00	224.82	201.32	185.74	207.73
15:00	238.62	190.41	219.30	187.47
16:00	169.97	155.54	174.63	169.92
17:00	103.61	143.22	134.05	169.78
18:00	187.62	154.31	129.96	175.65
19:00	189.99	157.94	161.01	178.75
20:00	189.03	173.05	169.64	186.64
21:00	166.35	165.21	138.83	160.92
22:00	265.53	160.08	136.69	154.59
23:00	201.77	145.67	261.01	148.01

Figure C-7 Graphical demonstration of related DDCs (08.03.2009)

Table C-28 CODE I and II Results of Recorded DDC (08.03.2009)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	151.63	0.34	1	0.00	0	0	0	0.00	0	0.00	0
01:00	159.20	0.41	1	0.00	0	0	0	0.00	0	0.00	0
02:00	128.68	0.26	1	0.00	0	0	0	0.00	0	0.00	0
03:00	92.81	0.00	0	0.00	0	0	0	0.00	0	0.17	1
04:00	90.69	0.58	1	0.00	0	0	0	0.00	0	0.00	0
05:00	82.23	0.46	1	0.00	0	0	0	0.00	0	0.33	1
06:00	99.73	0.00	0	0.12	1	1	0	0.00	0	0.00	0
07:00	88.25	0.00	0	0.00	0	0	0	0.00	0	0.00	0
08:00	149.39	0.31	1	0.00	0	0	0	0.00	0	0.00	0
09:00	118.75	0.23	1	0.00	0	0	0	0.00	0	0.00	0
10:00	170.56	0.36	1	0.00	0	0	0	0.27	1	0.00	0
11:00	264.35	0.22	1	0.00	0	0	0	0.00	0	0.11	1
12:00	301.50	0.12	1	0.00	0	0	0	0.00	0	0.00	0
13:00	261.48	0.39	1	0.00	0	0	0	0.45	1	0.00	0
14:00	224.82	0.23	1	0.00	0	0	0	0.00	0	0.00	0
15:00	238.62	0.22	1	0.00	0	0	0	0.00	0	0.00	0
16:00	169.97	0.41	1	0.00	0	0	0	0.00	0	0.37	1
17:00	103.61	0.21	1	0.00	0	0	0	0.00	0	0.00	0
18:00	187.62	0.43	1	0.00	0	0	0	0.00	0	0.00	0
19:00	189.99	0.37	1	0.00	0	0	0	0.00	0	0.00	0
20:00	189.03	0.47	1	0.00	0	0	0	0.00	0	0.00	0
21:00	166.35	0.41	1	0.00	0	0	0	0.00	0	0.00	0
22:00	265.53	0.25	1	0.00	0	0	0	0.00	0	0.00	0
23:00	201.77	0.24	1	0.00	0	0	0	0.02	0	0.00	0

Table C-29 CODE I and II Results of The Day Before Recorded Day DDC (07.03.2009)

Hours	Demand (m^3/hr)	Valve Openings V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	185.19	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	174.38	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	127.83	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
03:00	77.02	0.00	0	0.00	0	0.00	0	0.00	0	0.18	1
04:00	116.39	0.24	1	0.00	0	0.00	0	0.00	0	0.12	0
05:00	85.09	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	95.93	0.00	0	0.13	1	0.00	0	0.00	0	0.00	0
07:00	171.50	0.00	0	0.43	1	0.00	0	0.00	0	0.00	0
08:00	167.04	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	182.52	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	190.22	0.45	1	0.00	0	0.00	0	0.37	1	0.00	0
11:00	227.50	0.45	1	0.00	0	0.00	0	0.00	0	0.38	1
12:00	252.99	0.41	0	0.00	0	0.00	0	0.50	1	0.00	0
13:00	133.05	0.27	1	0.00	0	0.00	0	0.31	1	0.00	0
14:00	185.74	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	219.30	0.23	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	174.63	0.42	1	0.00	0	0.00	0	0.00	0	0.39	1
17:00	134.05	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	129.96	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	161.01	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	169.64	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	138.83	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	136.69	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	261.01	0.65	1	0.00	0	0.00	0	0.04	0	0.00	0

Table C-30 CODE I and II Results of Forecasted DDC (08.03.2009)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	147.78	0.32	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	109.32	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	86.15	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	84.59	0.00	0	0.00	0	0.00	0	0.00	0	0.36	1
04:00	73.09	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	78.49	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	98.17	0.00	0	0.15	1	0.00	0	0.00	0	0.00	0
07:00	124.17	0.05	0	0.39	1	0.00	0	0.00	0	0.00	0
08:00	159.27	0.29	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	161.29	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	166.24	0.36	1	0.00	0	0.00	0	0.32	1	0.00	0
11:00	218.67	0.41	1	0.00	0	0.00	0	0.00	0	0.29	1
12:00	264.14	0.43	0	0.00	0	0.00	0	0.52	1	0.00	0
13:00	204.68	0.35	1	0.00	0	0.00	0	0.44	1	0.00	0
14:00	201.32	0.50	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	190.41	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	155.54	0.38	1	0.00	0	0.00	0	0.00	0	0.26	1
17:00	143.22	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	154.31	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	157.94	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	173.05	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	165.21	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	160.08	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	145.67	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-31 CODE I and II Results of Seasonal Average DDC (Spring)

Hours	Demand (m³/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	123.56	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	93.31	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	67.74	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	61.81	0.00	0	0.00	0	0.00	0	0.00	0	0.31	1
04:00	56.45	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	71.45	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	96.59	0.00	0	0.14	1	0.00	0	0.00	0	0.00	0
07:00	136.33	0.18	0	0.21	1	0.00	0	0.00	0	0.00	0
08:00	157.41	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	170.06	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	194.65	0.43	1	0.00	0	0.00	0	0.39	1	0.00	0
11:00	227.48	0.45	1	0.00	0	0.00	0	0.00	0	0.38	1
12:00	233.01	0.39	0	0.00	0	0.00	0	0.44	1	0.00	0
13:00	225.57	0.47	1	0.00	0	0.00	0	0.41	1	0.00	0
14:00	207.73	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	187.47	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	169.92	0.41	1	0.00	0	0.00	0	0.00	0	0.37	1
17:00	169.78	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	175.65	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	178.75	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	186.64	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	160.92	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	154.59	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	148.01	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-32 DDC values for 11.05.2009 and corresponding values

Hours	Recorded (m³/hr)	Forecasted (m³/hr)	The Day Before 10.05.2009 (m³/hr)	Seasonal Average (m³/hr)
00:00	117.62	132.21	123.42	123.56
01:00	28.73	84.39	67.76	93.31
02:00	12.64	59.11	56.03	67.74
03:00	104.26	64.37	56.03	61.81
04:00	96.21	71.61	56.03	56.45
05:00	80.95	78.67	56.19	71.45
06:00	80.62	82.17	67.28	96.59
07:00	119.63	87.71	143.97	136.33
08:00	132.16	124.31	158.62	157.41
09:00	200.13	184.94	176.68	170.06
10:00	222.32	209.04	242.23	194.65
11:00	282.08	236.58	256.47	227.48
12:00	273.35	241.17	257.38	233.01
13:00	256.07	209.38	240.05	225.57
14:00	228.75	198.18	210.60	207.73
15:00	199.14	177.98	187.75	187.47
16:00	196.54	174.04	167.34	169.92
17:00	187.85	179.21	173.12	169.78
18:00	193.88	181.27	175.97	175.65
19:00	189.69	167.95	167.91	178.75
20:00	199.15	181.27	174.08	186.64
21:00	181.43	161.38	145.29	160.92
22:00	178.28	135.2	138.25	154.59
23:00	164.37	131.63	147.83	148.01

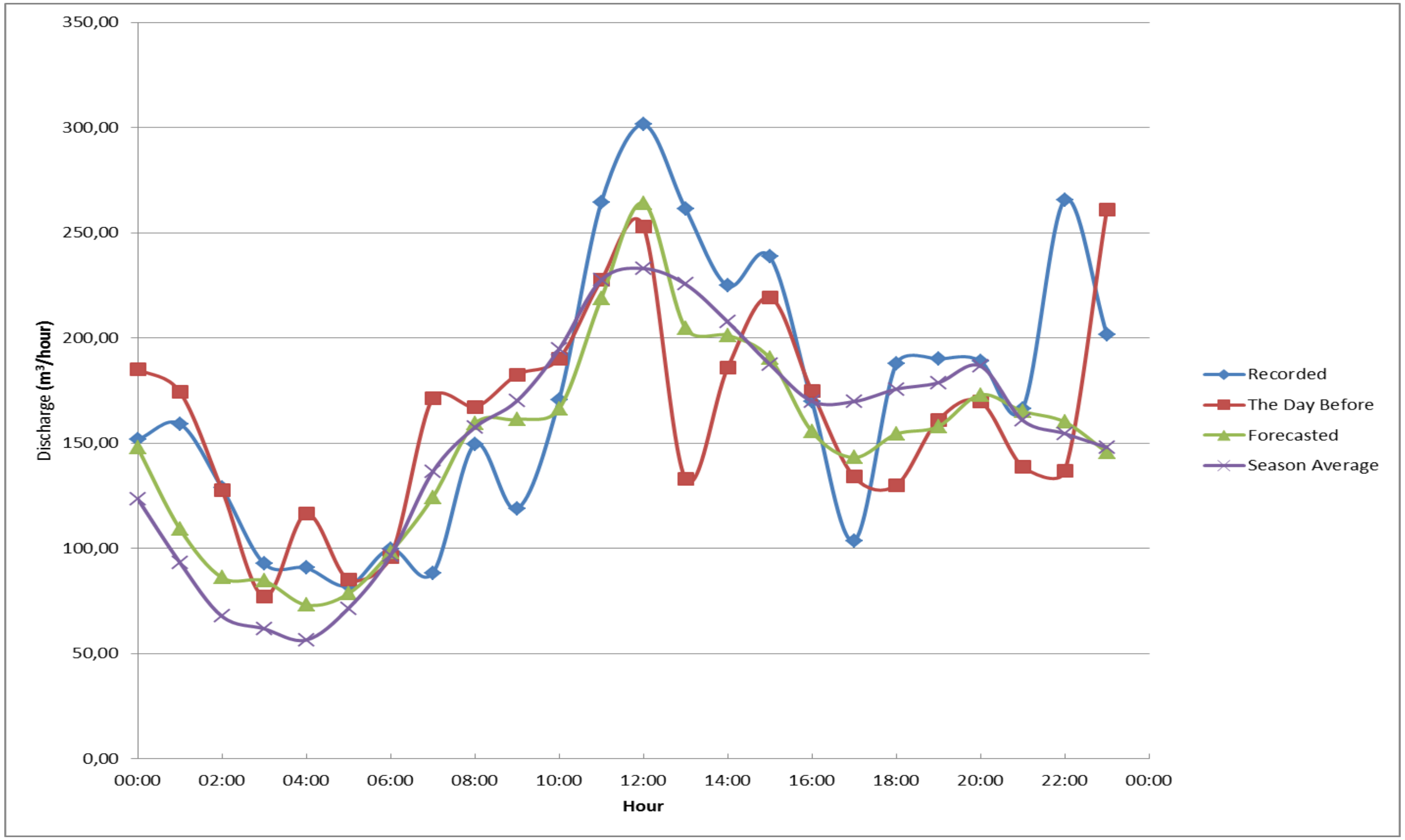

Figure C-8 Graphical demonstration of related DDCs (11.05.2009)

Table C-33 CODE I and II Results of Recorded DDC (11.05.2009)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	117.62	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	28.73	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
02:00	12.64	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	104.26	0.00	0	0.00	0	0.00	0	0.00	0	0.45	1
04:00	96.21	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	80.95	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	80.62	0.00	0	0.14	1	0.00	0	0.00	0	0.00	0
07:00	119.63	0.00	0	0.27	1	0.00	0	0.00	0	0.00	0
08:00	132.16	0.25	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	200.13	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	222.32	0.49	1	0.00	0	0.00	0	0.38	1	0.00	0
11:00	282.08	0.53	1	0.00	0	0.00	0	0.00	0	0.42	1
12:00	273.35	0.48	0	0.00	0	0.00	0	0.51	1	0.00	0
13:00	256.07	0.49	1	0.00	0	0.00	0	0.43	1	0.00	0
14:00	228.75	0.47	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	199.14	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	196.54	0.49	1	0.00	0	0.00	0	0.00	0	0.39	1
17:00	187.85	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	193.88	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	189.69	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	199.15	0.48	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	181.43	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	178.28	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	164.37	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-34 CODE I and II Results of The Day Before Recorded Day DDC (10.05.2009)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	123.42	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	67.76	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
02:00	56.03	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	56.03	0.00	0	0.00	0	0.00	0	0.00	0	0.27	1
04:00	56.03	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	56.19	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	67.28	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
07:00	143.97	0.00	0	0.35	1	0.00	0	0.00	0	0.00	0
08:00	158.62	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	176.68	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	242.23	0.51	1	0.00	0	0.00	0	0.42	1	0.00	0
11:00	256.47	0.49	1	0.00	0	0.00	0	0.00	0	0.41	1
12:00	257.38	0.34	0	0.00	0	0.00	0	0.48	1	0.00	0
13:00	240.05	0.48	1	0.00	0	0.00	0	0.41	1	0.00	0
14:00	210.60	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	187.75	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	167.34	0.47	1	0.00	0	0.00	0	0.00	0	0.36	1
17:00	173.12	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	175.97	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	167.91	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	174.08	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	145.29	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	138.25	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	147.83	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-35 CODE I and II Results of Forecasted DDC (10.05.2009)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	132.21	0.29	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	84.39	0.23	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	59.11	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	64.37	0.00	0	0.00	0	0.00	0	0.00	0	0.32	1
04:00	71.61	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	78.67	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	82.17	0.00	0	0.12	1	0.00	0	0.00	0	0.00	0
07:00	87.71	0.00	0	0.15	1	0.00	0	0.00	0	0.00	0
08:00	124.31	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	184.94	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	209.04	0.44	1	0.00	0	0.00	0	0.41	1	0.00	0
11:00	236.58	0.47	1	0.00	0	0.00	0	0.00	0	0.38	1
12:00	241.17	0.42	0	0.00	0	0.00	0	0.45	1	0.00	0
13:00	209.38	0.39	1	0.00	0	0.00	0	0.37	1	0.00	0
14:00	198.18	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	177.98	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	174.04	0.44	1	0.00	0	0.00	0	0.00	0	0.35	1
17:00	179.21	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	181.27	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	167.95	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	181.27	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	161.38	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	135.2	0.25	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	131.63	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-36 DDC values for 23.04.2008 and corresponding values

Hours	Recorded	Forecasted	The Day Before 22.04.2008	Seasonal Average
	(m^3/hr)	(m^3/hr)	(m^3/hr)	(m^3/hr)
00:00	188.83	159.15	199.27	123.56
01:00	137.98	108.54	159.74	93.31
02:00	121.04	116.94	105.85	67.74
03:00	104.04	108.85	116.72	61.81
04:00	116.72	110.32	144.83	56.45
05:00	159.79	98.17	158.36	71.45
06:00	77.86	91.42	101.15	96.59
07:00	115.92	107.55	104.21	136.33
08:00	121.23	112.36	206.66	157.41
09:00	136.75	135.81	198.31	170.06
10:00	161.29	145.66	184.94	194.65
11:00	158.97	175.95	207.36	227.48
12:00	194.28	208.93	184.5	233.01
13:00	203.56	216.15	230.38	225.57
14:00	247.2	255.28	210.73	207.73
15:00	200.84	193.37	153.93	187.47
16:00	163.36	189.65	211.07	169.92
17:00	150.12	182.33	183.9	169.78
18:00	145.02	175.43	156.74	175.65
19:00	151.06	167.03	139.79	178.75
20:00	184.81	197.72	182.96	186.64
21:00	151.81	149.16	143.3	160.92
22:00	132.53	154.75	204.18	154.59
23:00	109.12	157.98	178.38	148.01

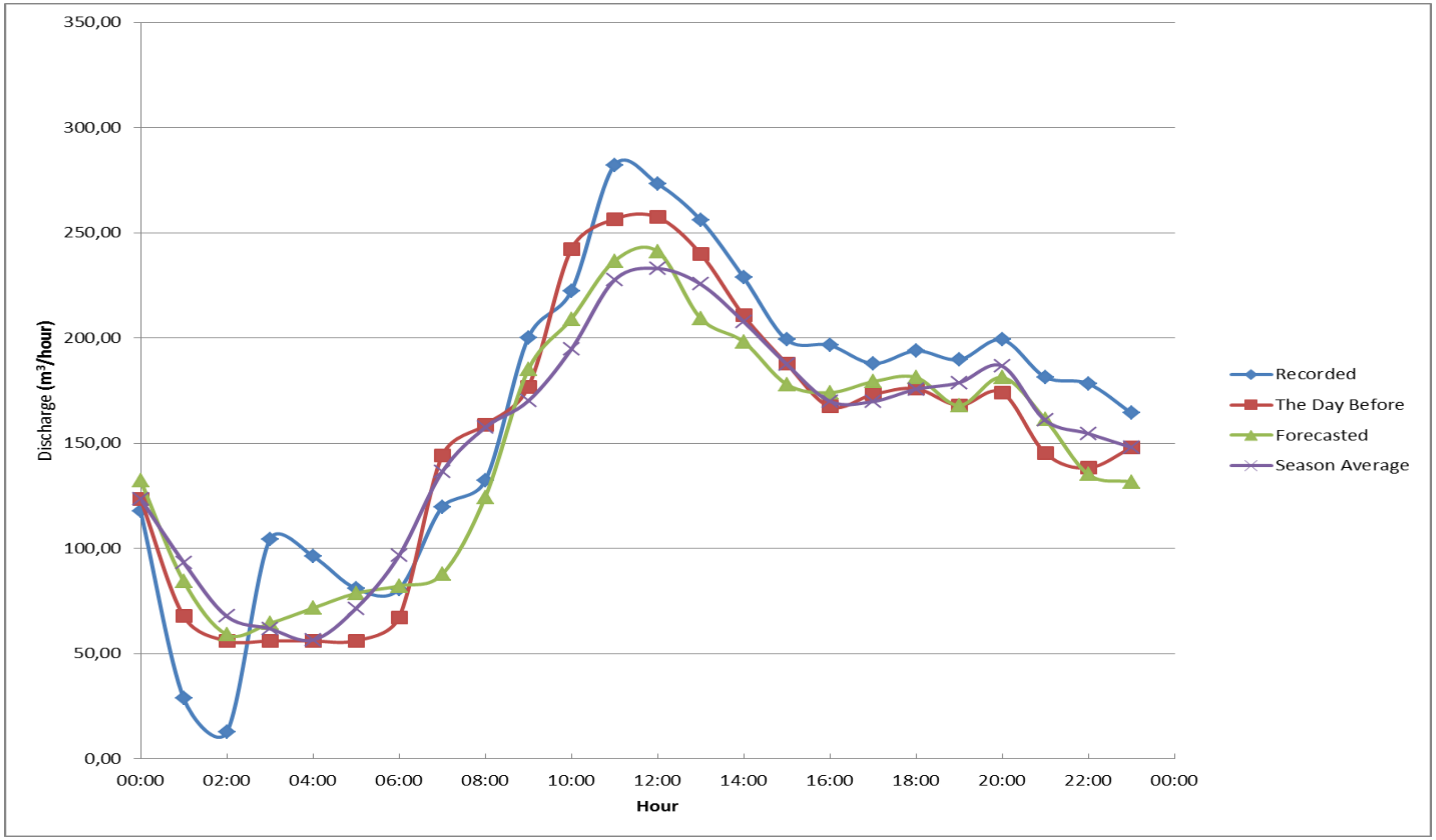

Figure C-9 Graphical demonstration of related DDCs (23.04.2008)

Table C-37 CODE I and II Results of Recorded DDC (23.04.2008)

Hours	Demand (m³/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	188.83	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	137.98	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	121.04	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	104.04	0.00	0	0.00	0	0.00	0	0.00	0	0.27	1
04:00	116.72	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	159.79	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	77.86	0.00	0	0.11	1	0.00	0	0.00	0	0.00	0
07:00	115.92	0.08	0	0.20	1	0.00	0	0.00	0	0.00	0
08:00	121.23	0.18	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	136.75	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	161.29	0.41	1	0.00	0	0.00	0	0.36	1	0.00	0
11:00	158.97	0.31	1	0.00	0	0.00	0	0.00	0	0.19	1
12:00	194.28	0.09	0	0.00	0	0.00	0	0.38	1	0.00	0
13:00	203.56	0.41	1	0.00	0	0.00	0	0.39	1	0.00	0
14:00	247.20	0.58	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	200.84	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	163.36	0.43	1	0.00	0	0.00	0	0.00	0	0.39	1
17:00	150.12	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	145.02	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	151.06	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	184.81	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	151.81	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	132.53	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	109.12	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-38 CODE I and II Results of The Day Before Recorded Day DDC (22.04.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	199.27	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	159.74	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	105.85	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	116.72	0.00	0	0.00	0	0.00	0	0.00	0	0.28	1
04:00	144.83	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	158.36	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	101.15	0.00	0	0.21	1	0.00	0	0.00	0	0.00	0
07:00	104.21	0.06	0	0.19	1	0.00	0	0.00	0	0.00	0
08:00	206.66	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	198.31	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	184.94	0.42	1	0.00	0	0.00	0	0.38	1	0.00	0
11:00	207.36	0.41	1	0.00	0	0.00	0	0.00	0	0.35	1
12:00	184.5	0.07	0	0.00	0	0.00	0	0.35	1	0.00	0
13:00	230.38	0.48	1	0.00	0	0.00	0	0.43	1	0.00	0
14:00	210.73	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	153.93	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	211.07	0.48	1	0.00	0	0.00	0	0.00	0	0.46	1
17:00	183.9	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	156.74	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	139.79	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	182.96	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	143.3	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	204.18	0.47	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	178.38	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-39 CODE I and II Results of Forecasted DDC (23.04.2008)

Hours	Demand (m³/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	159.15	0.29	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	108.54	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	116.94	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	108.85	0.00	0	0.00	0	0.00	0	0.00	0	0.26	1
04:00	110.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	136.09	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	91.42	0.00	0	0.18	1	0.00	0	0.00	0	0.00	0
07:00	107.55	0.05	0	0.18	1	0.00	0	0.00	0	0.00	0
08:00	112.36	0.16	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	161.95	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	145.66	0.37	1	0.00	0	0.00	0	0.34	1	0.00	0
11:00	175.95	0.35	1	0.00	0	0.00	0	0.00	0	0.22	1
12:00	208.93	0.10	0	0.00	0	0.00	0	0.45	1	0.00	0
13:00	216.15	0.45	1	0.00	0	0.00	0	0.38	1	0.00	0
14:00	235.77	0.58	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	193.37	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	189.65	0.43	1	0.00	0	0.00	0	0.00	0	0.39	1
17:00	192.58	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	175.43	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	167.03	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	197.72	0.49	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	149.16	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	154.75	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	157.98	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-40 DDC values for 21.08.2008 and corresponding values

Hours	Recorded (m³/hr)	Forecasted (m³/hr)	The Day Before 20.08.2008 (m³/hr)	Seasonal Average (m³/hr)
00:00	170.325	147.78	170.983	142.61
01:00	140.636	119.28	87.1412	112.92
02:00	83.1496	88.57	87.637	85.23
03:00	135.286	82.22	63.2536	70.44
04:00	108.461	73.09	77.6363	66.85
05:00	111.908	78.49	77.8117	80.43
06:00	117.025	102.25	89.4986	83.96
07:00	97.0303	135.25	134.31	110.64
08:00	138.301	165.14	126.413	141.46
09:00	187.2	173.54	160.247	158.77
10:00	187.2	188.36	159.756	180.93
11:00	187.2	201.28	190.68	208.71
12:00	187.2	199.46	194.325	241.32
13:00	243.836	233.51	242.656	243.43
14:00	224.314	227.43	195.373	220.42
15:00	185.689	190.41	207.762	191.80
16:00	126.127	135.55	178.853	184.94
17:00	132.797	121.47	100.756	170.01
18:00	155.981	129.25	124.128	177.39
19:00	195.443	126.72	168.384	186.72
20:00	165.019	140.95	154.048	199.84
21:00	152.513	152.17	146.845	176.09
22:00	133.4	145.14	223.41	156.76
23:00	215.814	159.77	170.88	144.50

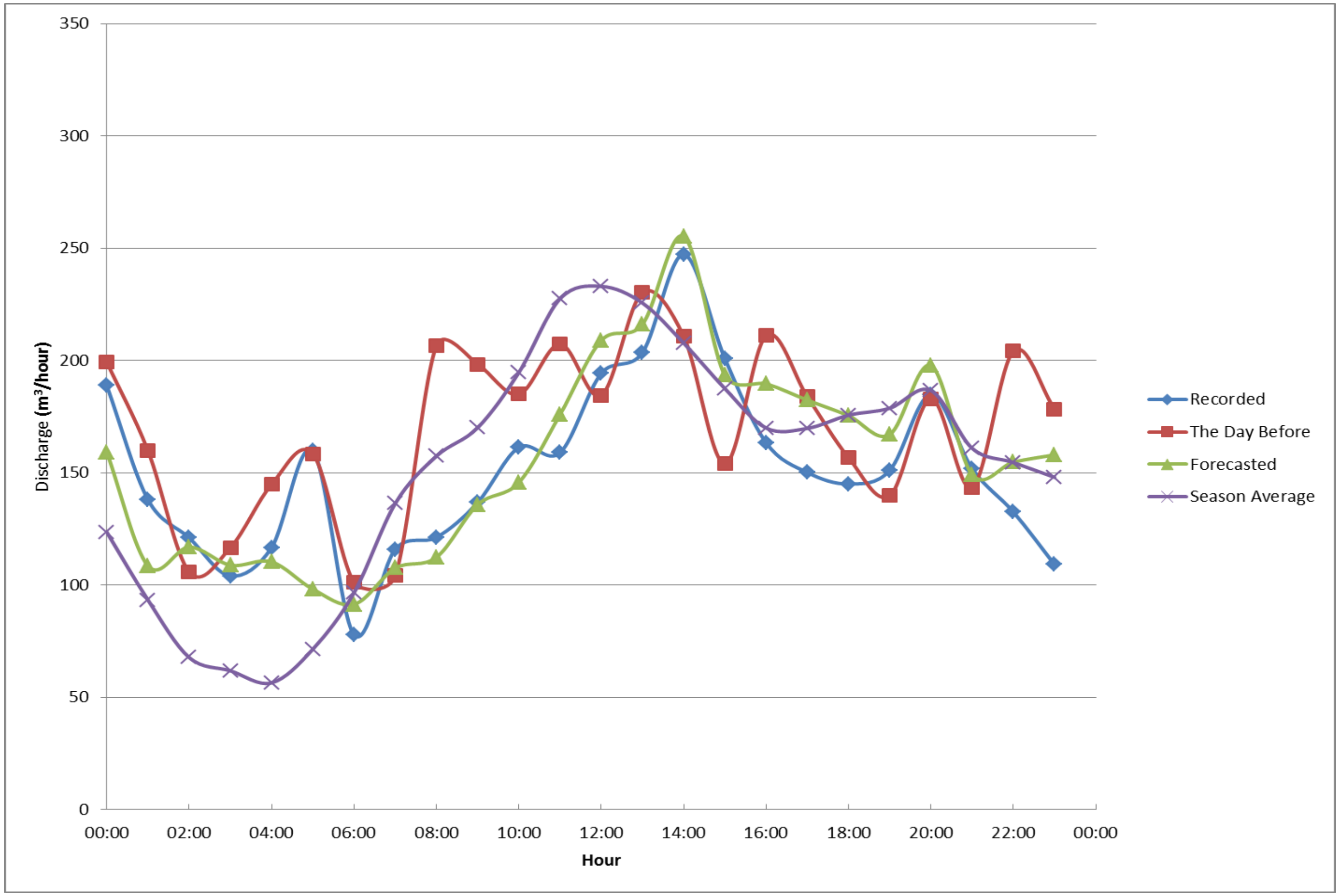

Figure C-10 Graphical demonstration of related DDCs (21.08.2008)

Table C-41 CODE I and II Results of Recorded DDC (21.08.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	170.33	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	140.64	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	83.15	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	135.29	0.51	1	0.00	0	0.00	0	0.00	0	0.49	1
04:00	108.46	0.00	0	0.00	0	0.00	0	0.31	1	0.00	0
05:00	111.91	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	117.02	0.00	0	0.31	1	0.00	0	0.00	0	0.00	0
07:00	97.03	0.00	0	0.22	1	0.00	0	0.00	0	0.00	0
08:00	138.30	0.26	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	187.20	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	187.20	0.46	1	0.00	0	0.00	0	0.38	1	0.00	0
11:00	187.20	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	187.20	0.00	0	0.00	0	0.00	0	0.34	1	0.00	0
13:00	243.84	0.45	1	0.00	0	0.00	0	0.43	1	0.00	0
14:00	224.31	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	185.69	0.47	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	126.13	0.32	1	0.00	0	0.00	0	0.00	0	0.30	1
17:00	132.80	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	155.98	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	195.44	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	165.02	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	152.51	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	133.40	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	215.81	0.49	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-42 CODE I and II Results of The Day Before Recorded Day DDC (20.08.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	170.983	0.40	1	0.00	0	0.00	0	0.00	0	0.19	1
01:00	87.1412	0.12	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	87.637	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	63.2536	0.00	0	0.00	0	0.00	0	0.00	0	0.29	1
04:00	77.6363	0.00	0	0.00	0	0.00	0	0.00	0	0.05	0
05:00	77.8117	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	89.4986	0.00	0	0.21	1	0.00	0	0.00	0	0.00	0
07:00	134.31	0.00	0	0.32	1	0.00	0	0.00	0	0.00	0
08:00	126.413	0.23	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	160.247	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	159.756	0.43	0	0.00	0	0.00	0	0.00	0	0.00	0
11:00	190.68	0.44	1	0.00	0	0.00	0	0.00	0	0.35	1
12:00	194.325	0.00	0	0.00	0	0.00	0	0.38	1	0.00	0
13:00	242.656	0.44	1	0.00	0	0.00	0	0.42	1	0.00	0
14:00	195.373	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	207.762	0.52	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	178.853	0.42	1	0.00	0	0.00	0	0.00	0	0.45	1
17:00	100.756	0.27	0	0.00	0	0.00	0	0.00	0	0.00	0
18:00	124.128	0.26	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	168.384	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	154.048	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	146.845	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	223.41	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	170.88	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-43 CODE I and II Results of Forecasted DDC (21.08.2008)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	147.78	0.03	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	119.28	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	88.57	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	82.22	0.00	0	0.00	0	0.00	0	0.00	0	0.38	1
04:00	73.09	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	78.49	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	102.25	0.00	0	0.24	1	0.00	0	0.00	0	0.00	0
07:00	135.25	0.00	0	0.33	1	0.00	0	0.00	0	0.00	0
08:00	165.14	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	173.54	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	188.36	0.46	1	0.00	0	0.00	0	0.39	1	0.00	0
11:00	201.28	0.56	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	199.46	0.00	0	0.00	0	0.00	0	0.39	1	0.00	0
13:00	233.51	0.39	1	0.00	0	0.00	0	0.35	1	0.00	0
14:00	227.43	0.52	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	190.41	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	135.55	0.34	1	0.00	0	0.00	0	0.00	0	0.33	1
17:00	121.47	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	129.25	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	126.72	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	140.95	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	152.17	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	145.14	0.35	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	159.77	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-44 CODE I and II Results of Seasonal Average DDC (Summer)

Hours	Demand (m³/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	142.61	0.32	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	112.92	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	85.23	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	70.44	0.00	0	0.00	0	0.00	0	0.00	0	0.35	1
04:00	66.85	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	80.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	83.96	0.00	0	0.16	1	0.00	0	0.00	0	0.00	0
07:00	110.64	0.00	0	0.25	1	0.00	0	0.00	0	0.00	0
08:00	141.46	0.28	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	158.77	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	180.93	0.44	1	0.00	0	0.00	0	0.37	1	0.00	0
11:00	208.71	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	241.32	0.00	0	0.00	0	0.00	0	0.41	1	0.00	0
13:00	243.43	0.45	1	0.00	0	0.00	0	0.43	1	0.00	0
14:00	220.42	0.49	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	191.80	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	184.94	0.45	1	0.00	0	0.00	0	0.00	0	0.49	1
17:00	170.01	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	177.39	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	186.72	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	199.84	0.52	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	176.09	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	156.76	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	144.50	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-45 DDC values for 18.07.2008 and corresponding values

Hours	Recorded	Forecasted	The Day Before 17.07.2008	Seasonal Average
	(m^3/hr)	(m^3/hr)	(m^3/hr)	(m^3/hr)
00:00	150.16	145.17	149.32	142.61
01:00	111.83	99.36	106.29	112.92
02:00	88.54	87.06	75.16	85.23
03:00	72.18	64.39	63.08	70.44
04:00	71.77	67.19	62.89	66.85
05:00	77.34	78.72	94.79	80.43
06:00	87.39	91.28	90.67	83.96
07:00	114.27	102.34	88.95	110.64
08:00	175.73	157.69	174.80	141.46
09:00	161.65	155.58	174.19	158.77
10:00	165.54	166.34	177.22	180.93
11:00	158.86	166.23	163.03	208.71
12:00	212.95	192.14	155.95	241.32
13:00	223.60	231.57	238.35	243.43
14:00	230.78	198.18	199.77	220.42
15:00	169.44	177.98	180.23	191.80
16:00	175.95	161.83	180.23	184.94
17:00	175.95	166.27	188.48	170.01
18:00	175.95	171.18	191.03	177.39
19:00	153.72	167.95	191.03	186.72
20:00	186.23	194.21	175.11	199.84
21:00	95.25	148.21	169.65	176.09
22:00	115.32	129.81	163.62	156.76
23:00	130.43	135.03	140.33	144.50

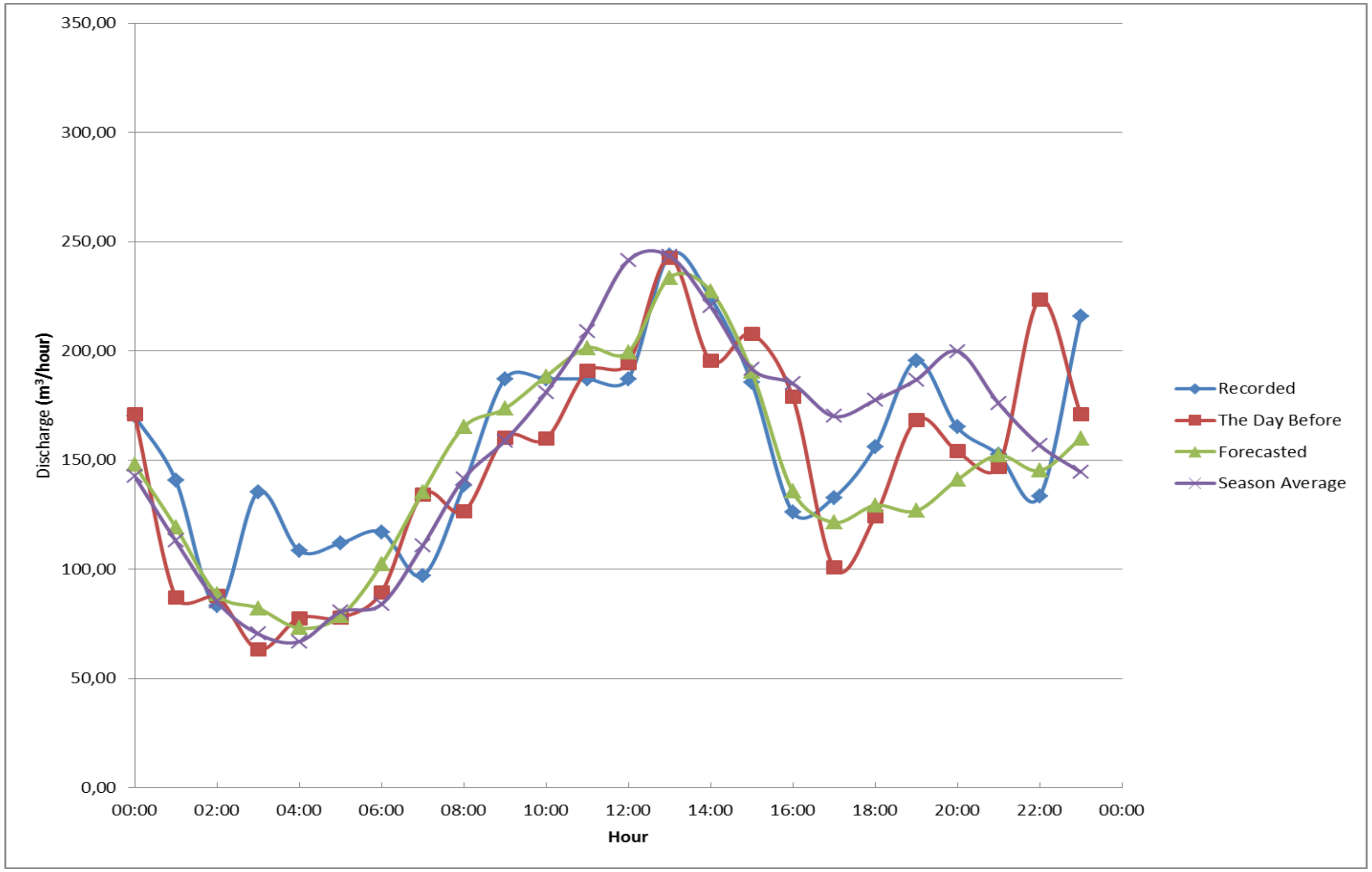

Figure C-11 Graphical demonstration of related DDCs (18.07.2008)

Table C-46 CODE I and II Results of Recorded DDC (18.07.2008)

Hours	Demand (m3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	188.83	0.09	1	0.00	0	0.00	0	0.00	0	0.11	1
01:00	137.98	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	121.04	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	104.04	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
04:00	116.72	0.00	0	0.00	0	0.00	0	0.00	0	0.14	1
05:00	159.79	0.00	1	0.00	0	0.00	0	0.00	0	0.12	1
06:00	77.86	0.45	1	0.00	0	0.00	0	0.00	0	0.62	1
07:00	115.92	0.00	0	0.22	1	0.00	0	0.00	0	0.00	0
08:00	121.23	0.17	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	136.75	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	161.29	0.26	1	0.00	0	0.00	0	0.32	1	0.00	0
11:00	158.97	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	194.28	0.00	0	0.00	0	0.00	0	0.47	1	0.00	0
13:00	203.56	0.28	1	0.00	0	0.00	0	0.54	1	0.00	0
14:00	247.20	0.23	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	200.84	0.82	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	163.36	0.78	1	0.00	0	0.00	0	0.00	0	0.53	1
17:00	150.12	0.43	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	145.02	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	151.06	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	184.81	0.48	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	151.81	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	132.53	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	109.12	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-47 CODE I and II Results of The Day Before Recorded Day DDC (17.07.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	150.16	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	111.83	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	88.54	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	72.18	0.00	0	0.00	0	0.00	0	0.00	0	0.29	1
04:00	71.77	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	77.34	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	87.39	0.00	0	0.17	1	0.00	0	0.00	0	0.00	0
07:00	114.27	0.00	0	0.26	1	0.00	0	0.00	0	0.00	0
08:00	175.73	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	161.65	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	165.54	0.41	1	0.00	0	0.00	0	0.35	1	0.00	0
11:00	158.86	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	212.95	0.00	0	0.00	0	0.00	0	0.37	1	0.00	0
13:00	223.60	0.43	1	0.00	0	0.00	0	0.39	1	0.00	0
14:00	230.78	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	169.44	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	175.95	0.41	1	0.00	0	0.00	0	0.00	0	0.42	1
17:00	175.95	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	175.95	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	153.72	0.34	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	186.23	0.48	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	95.25	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
22:00	115.32	0.21	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	130.43	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-48 CODE I and II Results of Forecasted DDC (18.07.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	145.17	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	99.36	0.23	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	87.06	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	64.39	0.00	0	0.00	0	0.00	0	0.00	0	0.27	1
04:00	67.19	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	78.72	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	91.28	0.00	0	0.18	1	0.00	0	0.00	0	0.00	0
07:00	102.34	0.00	0	0.18	1	0.00	0	0.00	0	0.00	0
08:00	157.69	0.29	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	155.58	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	166.34	0.41	1	0.00	0	0.00	0	0.36	1	0.00	0
11:00	166.23	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	192.14	0.00	0	0.00	0	0.00	0	0.38	1	0.00	0
13:00	231.57	0.42	1	0.00	0	0.00	0	0.41	1	0.00	0
14:00	198.18	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	177.98	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	161.83	0.39	1	0.00	0	0.00	0	0.00	0	0.37	1
17:00	166.27	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	171.18	0.38	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	167.95	0.37	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	194.21	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	148.21	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	129.81	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	135.03	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-49 DDC values for 29.06.2008 and corresponding values

Hours	Recorded	Forecasted	The Day Before 28.06.2008	Seasonal Average
	(m^3/hr)	(m^3/hr)	(m^3/hr)	(m^3/hr)
00:00	147.04	159.15	175.30	142.61
01:00	112.92	107.61	105.93	112.92
02:00	93.28	90.07	94.21	85.23
03:00	86.47	71.32	62.33	70.44
04:00	60.38	81.23	67.44	66.85
05:00	66.54	78.89	83.32	80.43
06:00	70.64	91.42	65.95	83.96
07:00	97.76	107.55	107.38	110.64
08:00	151.95	112.36	188.56	141.46
09:00	123.34	161.95	150.74	158.77
10:00	151.67	145.66	168.98	180.93
11:00	220.18	175.95	190.98	208.71
12:00	240.66	208.93	275.78	241.32
13:00	244.28	216.15	261.49	243.43
14:00	241.30	235.77	230.55	220.42
15:00	228.17	193.37	210.07	191.80
16:00	188.62	189.65	211.80	184.94
17:00	188.21	165.21	176.51	170.01
18:00	232.75	175.43	192.76	177.39
19:00	176.21	167.03	211.86	186.72
20:00	196.16	197.72	181.93	199.84
21:00	189.10	171.21	179.47	176.09
22:00	179.88	154.75	194.35	156.76
23:00	171.04	157.98	185.18	144.50

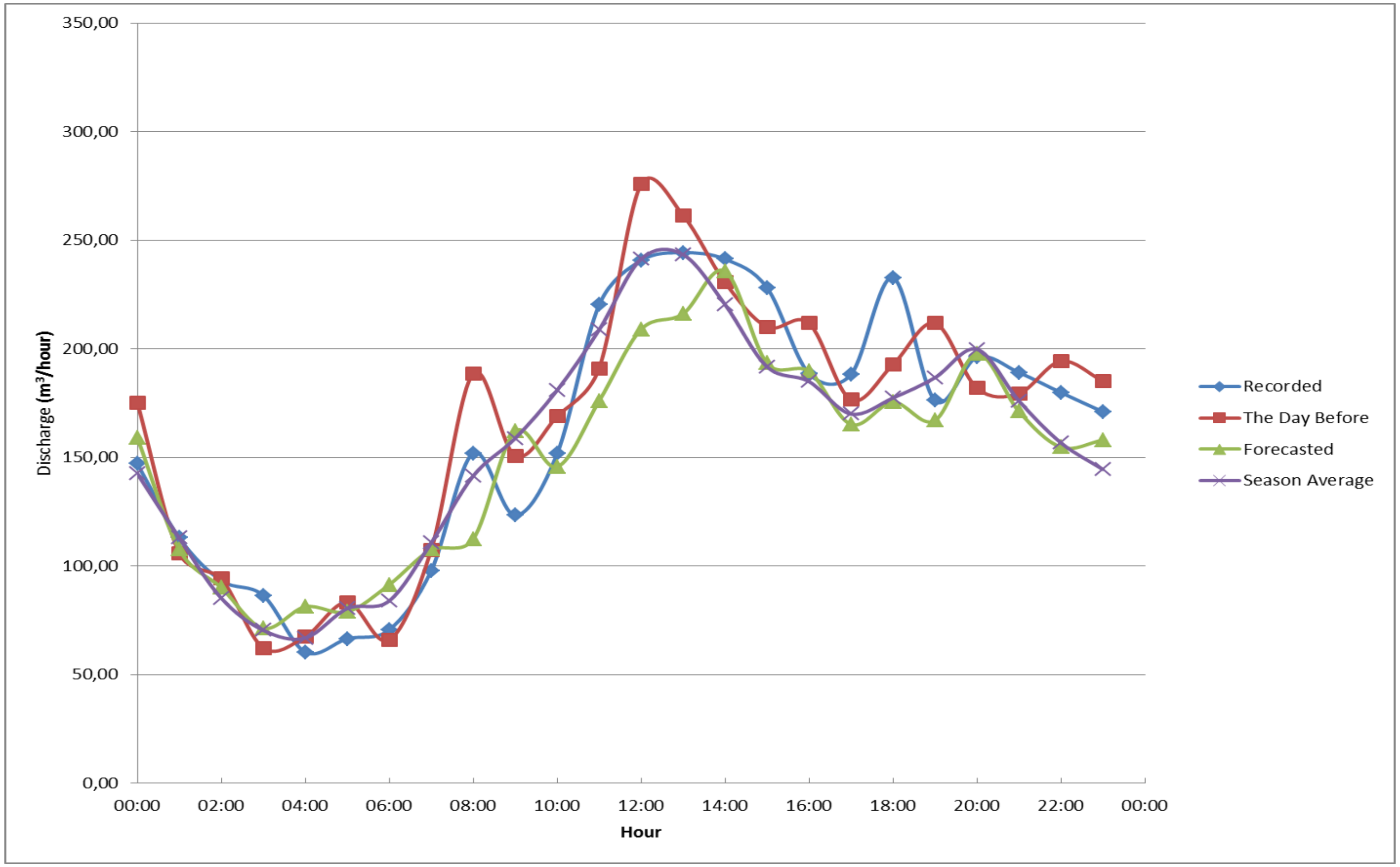

Figure C-12 Graphical demonstration of related DDCs (29.06.2008)

Table C-50 CODE I and II Results of Recorded DDC (29.06.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	147.04	0.33	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	112.92	0.27	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	93.28	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	86.47	0.00	0	0.00	0	0.00	0	0.00	0	0.36	1
04:00	60.38	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	66.54	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	70.64	0.00	0	0.14	1	0.00	0	0.00	0	0.00	0
07:00	97.76	0.00	0	0.21	1	0.00	0	0.00	0	0.00	0
08:00	151.95	0.30	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	123.34	0.31	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	151.67	0.34	1	0.00	0	0.00	0	0.29	1	0.00	0
11:00	220.18	0.50	1	0.00	0	0.00	0	0.21	1	0.00	0
12:00	240.66	0.00	0	0.00	0	0.00	0	0.41	1	0.00	0
13:00	244.28	0.45	1	0.00	0	0.00	0	0.43	1	0.00	0
14:00	241.30	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	228.17	0.53	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	188.62	0.46	1	0.00	0	0.00	0	0.00	0	0.52	1
17:00	188.21	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	232.75	0.60	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	176.21	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	196.16	0.51	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	189.10	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	179.88	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	171.04	0.42	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-51 CODE I and II Results of The Day Before Recorded Day DDC (28.06.2008)

Hours	Demand (m^3/hr)	Valve Openings									
		V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	175.30	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
01:00	105.93	0.24	1	0.00	0	0.00	0	0.00	0	0.00	0
02:00	94.21	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
03:00	62.33	0.00	0	0.00	0	0.00	0	0.00	0	0.27	1
04:00	67.44	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
05:00	83.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
06:00	65.95	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
07:00	107.38	0.00	0	0.25	1	0.00	0	0.00	0	0.00	0
08:00	188.56	0.45	1	0.00	0	0.00	0	0.00	0	0.00	0
09:00	150.74	0.36	1	0.00	0	0.00	0	0.00	0	0.00	0
10:00	168.98	0.37	1	0.00	0	0.00	0	0.34	1	0.00	0
11:00	190.98	0.44	1	0.00	0	0.00	0	0.00	0	0.00	0
12:00	275.78	0.00	0	0.00	0	0.00	0	0.45	1	0.00	0
13:00	261.49	0.48	1	0.00	0	0.00	0	0.46	1	0.00	0
14:00	230.55	0.39	1	0.00	0	0.00	0	0.00	0	0.00	0
15:00	210.07	0.50	1	0.00	0	0.00	0	0.00	0	0.00	0
16:00	211.80	0.63	1	0.00	0	0.00	0	0.00	0	0.61	1
17:00	176.51	0.40	1	0.00	0	0.00	0	0.00	0	0.00	0
18:00	192.76	0.55	1	0.00	0	0.00	0	0.00	0	0.00	0
19:00	211.86	0.59	1	0.00	0	0.00	0	0.00	0	0.00	0
20:00	181.93	0.47	1	0.00	0	0.00	0	0.00	0	0.00	0
21:00	179.47	0.41	1	0.00	0	0.00	0	0.00	0	0.00	0
22:00	194.35	0.53	1	0.00	0	0.00	0	0.00	0	0.00	0
23:00	185.18	0.46	1	0.00	0	0.00	0	0.00	0	0.00	0

Table C-52 CODE I and II Results of Forecasted DDC (29.06.2008)

Hours	Demand	Valve Openings									
	(m^3/hr)	V1		V2		V3		V4		V5	
	CODE	I	II	I	II	I	II	I	II	I	II
00:00	159.15	0.35	1	0.00	0	0.00	0	0.00	0	0.00	1
01:00	107.61	0.25	1	0.00	0	0.00	0	0.00	0	0.00	1
02:00	90.07	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1
03:00	71.32	0.00	0	0.00	0	0.00	0	0.00	0	0.35	1
04:00	81.23	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1
05:00	78.89	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1
06:00	91.42	0.00	0	0.19	1	0.00	0	0.00	0	0.00	1
07:00	107.55	0.00	0	0.24	1	0.00	0	0.00	0	0.00	1
08:00	112.36	0.16	1	0.00	0	0.00	0	0.00	0	0.00	1
09:00	161.95	0.39	1	0.00	0	0.00	0	0.00	0	0.00	1
10:00	145.66	0.33	1	0.00	0	0.00	0	0.27	1	0.00	1
11:00	175.95	0.37	1	0.00	0	0.00	0	0.00	0	0.00	1
12:00	208.93	0.00	0	0.00	0	0.00	0	0.35	1	0.00	1
13:00	216.15	0.41	1	0.00	0	0.00	0	0.37	1	0.00	1
14:00	235.77	0.41	1	0.00	0	0.00	0	0.00	0	0.00	1
15:00	193.37	0.46	1	0.00	0	0.00	0	0.00	0	0.00	1
16:00	189.65	0.47	1	0.00	0	0.00	0	0.00	0	0.52	1
17:00	165.21	0.34	1	0.00	0	0.00	0	0.00	0	0.00	1
18:00	175.43	0.40	1	0.00	0	0.00	0	0.00	0	0.00	1
19:00	167.03	0.37	1	0.00	0	0.00	0	0.00	0	0.00	1
20:00	197.72	0.52	1	0.00	0	0.00	0	0.00	0	0.00	1
21:00	171.21	0.38	1	0.00	0	0.00	0	0.00	0	0.00	1
22:00	154.75	0.36	1	0.00	0	0.00	0	0.00	0	0.00	1
23:00	157.98	0.39	1	0.00	0	0.00	0	0.00	0	0.00	1

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MS	METU Civil Engineering	2002
BS	METU Civil Engineering	1999
High School	Atatürk Anadolu High School	1994

WORK EXPERIENCE

Year	Place	Enrollment
2007-2011	MoEF	Manager
2007	DSI	Manager
2003-2007	DSI	Project Engineer
1999-2003	METU Civil Engineering Department	Research Assistant

FOREIGN LANGUAGES: English