DEVELOPING A DECISION SUPPORT SYSTEM USING HEC-RESSIM MODEL FOR OPERATION OF YUVACIK DAM RESERVOIR

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Master of Science Thesis

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Enstitü Müdürü

ABSTRACT

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DEVELOPING A DECISION SUPPORT SYSTEM USING HEC-RESSIM MODEL FOR OPERATION OF YUVACIK DAM RESERVOIR

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Decisions for the effective management of water resources are getting more important due to continuously increasing population and water demand of the world. These decisions require comprehensive and integrated management strategies. One tool that is used to improve water resources management nowadays is decision support systems.

Yuvacık Dam Basin, located in the Marmara region of Turkey with 258 km^2 drainage area, has high flood potential due to its steep topography, mild and rainy climate. Moreover, a considerable snowmelt contribution feeds the streamflow during spring since the elevation ranges between 80 – 1548 m. Effective operation of Yuvacık Dam Reservoir is a challenging task due to its relatively small reservoir capacity with 51.2 hm^3 despite the annual need of 142 hm^3 water demand for city of Kocaeli with a population of 1.5 million. The main motivation of the study is to provide the necessary amount of water without excessively increasing the risk of downstream flooding. The operators need to exceed flood regulation zones increasing the flood risk to take precautions for drought summer periods in order to supply water without any shortage.

HEC-ResSim is selected as the reservoir simulation model. The study is divided into two basic operations; long term operation for daily water supply and short term operation for hourly flood protection purposes. Three different approaches (i.e. seasonal release control, variable guide curve and recession curve release) are tested using 2007 – 2011 data and the combined method that takes the advantages of all approaches is selected as the most suitable method for daily decisions. Hourly operation strategies are also developed applying pre-releases for short term flood operation. The basic idea is to put pre-releases into operation using numerical weather prediction based streamflow forecasts. The release decisions, outflow hydrographs and reservoir levels are analyzed to develop a decision support system. A real time operation of the reservoir is also conducted as a case study for 2012 March – June season.

Keywords : Reservoir simulation, Real time operation, HEC-ResSim, Flood risk, Water supply

ÖZET

Yüksek Lisans Tezi

YUVACIK BARAJI'NIN REZERVUAR İŞLETMESİ İÇİN HEC-RESSIM MODELİ KULLANILARAK KARAR DESTEK SİSTEMİ GELİŞTİRİLMESİ

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Su kaynaklarının etkin yönetimdeki kararlar, sürekli artan dünya nüfusu ve su ihtiyacından dolayı giderek daha fazla önem kazanmaktadır. Bu kararlar, kapsamlı ve birbiri ile entegre yönetim stratejileri gerektirmektedir. Karar destek sistemleri günümüzde, su kaynakları yönetiminin iyileştirilmesinde kullanılan bir araçtır.

Türkiye'nin Marmara Bölgesi'nde yer alan 258 km^2'lik drenaj alanına sahip Yuvacık Baraj Havzası, dik topoğrafyası, ılıman ve yağmurlu iklimi ile yüksek bir taşkın potansiyeline sahiptir. Ayrıca, havza yükseliğinin 80 – 1548 m arasında değişmesi nedeniyle önemli bir kar erime katkısı bahar ayları boyunca nehir akımlarını beslemektedir. 1.5 milyon nüfuslu Kocaeli şehrinin 142 hm^3 olan yıllık su ihtiyacına rağmen 51.2 hm^3'lük nispeten küçük bir hacme sahip Yuvacık Barajı'nın etkili bir şekilde işletilmesi ilgi çekici bir görevdir. Bu çalışmanın motivasyonu mansap taşkın riskini fazlasıyla arttırmadan şehre gerekli olan su miktarını sağlamaktır. Kurak yaz aylarında kesintisiz bir şekilde su temin edebilmeleri için gerekli tedbirleri almak amacıyla, işletmecilerin, taşkın kontrol seviyelerini geçip, taşkın riskini arttırarak işletme yapmaları gerekmektedir.

Rezervuar simulasyon modeli olarak HEC-ResSim seçilmiştir. Çalışma, uzun dönem günlük su teminini ve kısa dönem saatlik taşkın koruma amaçlarını gözeten işletme çalışmaları olarak iki ana işletmeye ayrılmıştır. Günlük kararlar için 2007 – 2011 verileri kullanılarak üç farklı yaklaşım (mevsimsel deşarj kontrolü, değişken hedef eğri ve çekilme eğrisi ile deşarj) test edilmiş ve tüm yaklaşımların avantajlı taraflarını alan kombinasyon metodu en uygun simulasyon modeli olarak seçilmiştir. Saatlik kararlar ise kısa dönem taşkın yönetimi için öncül deşarj uygulamaları ile geliştirilmiştir. Temel fikir sayısal hava tahmin verisine bağlı akım tahminlerinin kullanılarak öncül deşarjların uygulamaya konulmasıdır. Deşarj kararları, çıkış hidrografları ve rezervuar seviyeleri analiz edilerek bir karar destek sistemi geliştirilmiştir. Ayrıca, 2012 Mart-Haziran dönemi için örnek bir gerçek zamanlı işletme çalışması da yapılmıştır.

Anahtar Kelimeler: Rezervuar simulasyonu, Gerçek zamanlı işletme, HEC-ResSim, Taşkın riski, Su temini

To the memory of my beloved grandmother, ***Eşe AVGAN…***

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ABBREVIATIONS AND SYMBOLS

BOT	Build Operate Transfer
CADSWES	Center for Advanced Decision Support for Water and Environmental Systems of the University of Colorado
DEM	Digital Elevation Model
DMS	Dam Management System
DSI	State Hydraulic Works
DSS	Decision Support System
DSSS	Decision Support System Scheme
DSSVue	Data Storage System Visual Utility Engine
ECMWF	European Center for Medium-Range Weather Forecasts
FCL	Flood Control Level
FP	Flow plant
GC	Guide Curve
GIS	Geographic Information Systems
GSM	Global System for Mobile Comminications
GWS 84	World Geodetic System 1984
HEC	Hydrologic Engineering Center
HEC-5	Simulation of Flood Control and Conservation Systems
HMS	Hydrologic Modeling System
IDW	Inverse Distance Weighting
Jython	Java implementation of Python programing language
KGM	Kocaeli Great Municipality
MIKE BASIN	GIS-Based Decision Support for Water Planning & Management
MM5	Mesoscale Model 5
MODSIM	Generalized River Basin Network Flow Model
NWP	Numerical Weather Prediction
ORC	Operating Rule Curve
P	Precipitation

PRM : Prescriptive Reservoir Modeling
ResSim : Reservoir Simulation System
RF : Radio Frequency
RG : Rain Gauge
RH : Relative Humidity
RiverWare : River and Reservoir Operation
S : Streamflow depth
SCADA : Supervisory Control and Data Acquisition
SD : Snow depth
SDP : Stochastic Dynamic Programming
SNOWTEL : Snowpack Telemetry
SWE : Snow Water Equivalent
T : Temperature
TSMS : Turkish State Meteorological Service
USACE : United States Army Corps of Engineers
UTM : Universal Transverse Mercator
VGC : Variable Guide Curve
WTP : Water Treatment Plant

1. INTRODUCTION

1.1. Importance of the Study

Available water is getting scarce due to rapidly increasing world population and effective operation of water resources is becoming one of the most important issues. Several dam reservoirs, hydroelectric power plants, irrigation systems, man-made channels as well as other water structures have been constructed in Turkey. Optimal operations of these systems are challenging tasks due to uncertainty and complexity of the systems. Their management requires comprehensive and integrated decision making strategies. In recent years, systems integrating products and databases using different physical simulation models to improve decisions of the operators are in the agenda. Nowadays, planners, operators and practitioners are in need of new technologies that can be used to quickly develop alternative decisions by representative models.

Bringing solutions to meteorological and hydrological problems, by setting up and using decision support systems is one of the fundamental principles of "Turkish National Hydrological Commission". Support systems including the integration of "data", "model" and "Geographical Information Systems (GIS)" provide opportunity to explore alternative management scenarios in water resources planning and management.

Operation of Yuvacık Dam Reservoir has multi-purpose characteristics, since it must provide flood protection besides water supply concerning the downstream channel capacity. These two functions are in conflict, since each requires reservoir storage volume but uses it in the opposite way. Serving both of these functions requires a tradeoff between them that is defined by the target storage level of the reservoir (the guide curve).

In order to apply certain rules together with a target level, decision support tools are developed and applied to improve real time operation. Basin reservoir modeling systems are effective and useful in the evaluation of real-time operation and alternative planning; in flood events, drought conditions and normal hydrologic conditions. These systems, in the most common form include the integration of hydrologic and reservoir simulation models. Hydrological model is to be used for establishing a relationship between rainfall and runoff and to forecast the inflow to the reservoir by managing time series, spatial and other data types (such as atmospheric forecast data); reservoir model is to be used for creating reservoir operation scenarios according to specific operation rules and current priorities of reservoir.

1.2. Scope of the Study

The purpose of operation studies for reservoirs is to determine; whether the planned reservoir volume is sufficient, economically worth, amount of water releases depending on the relationship between water users and time periods, the amount of water to be held or released in accordance with filling and emptying time periods of reservoirs.

The scope of this thesis is to develop a reservoir simulation integrated decision support tool both for long term water supply and short term flood control purposes for Yuvacık Dam Reservoir. The decision support tool is comprised of operations based on daily water supply and hourly flood protection strategies.

Long term decisions include water supply targets and flood risk managements. Several methods are proposed by the simulation model to decide how much amount of water should be stored or released. Accordingly; three methods are developed taking downstream channel constraint and water supply storage purposes into consideration. In the first method, guide curve is selected as the maximum operation level while spillway is controlled by user defined seasonal rules based on experiences. In the second method, a variable guide curve is developed in order to define different target elevations for different seasons. In the third method, minimum probable future amount of water is calculated by a scripted rule developed in Jython (Java implementation of Python) programming language. 2007 – 2011 data are used to analyze the results of each method. In the final discussion, a combined method enhanced using the advantages of all three method is selected to be recommended to the operators.

In case a probable flood risk on the downstream channel is determined according to flow forecasts; short term simulation models are developed to release water with advance decisions. Since there is no flood event occurred for the selected period of years, flood hydrographs and hypothetical inflows generated by scaled up version of observed ones are used in simulations. A pre-release policy is adopted to evacuate water for upcoming flood events.

It is remarkable that Yuvacık Reservoir is operated using developed long terms strategies during the year 2012, and results are presented. Therefore, the decision support system is developed as an example of user oriented applications, includes a modeling system to be used by professional practitioners instead of the original model developers. Moreover, this study presents a framework for real-time operation of Yuvacık Dam Reservoir.

Chapter 1 describes general information about reservoir system operation and the scope of the thesis. A literature review of reservoir simulation with its development, techniques and several other programs are broadly discussed in the Chapter 2. Study area, reservoir physical conditions and downstream conditions are defined in detail through Chapter 3. Reservoir operation and simulation terms are discussed and utilities of HEC-ResSim program are explained in Chapter 4. The main inputs to the simulation model from statistics through real time applications are presented in Chapter 5. In Chapter 6, both previous year's decisions and new approaches are discussed in terms of long term and short term operations. The release decisions and other outputs are analyzed to propose an improvement in the decision support system. Comparisons of the results and governing strategies are broadly discussed in this chapter. In Chapter 7, real time application of 2012 is given through developed strategies. Finally, conclusions and recommendations are provided with the last chapter.

2. LITERATURE SURVEY

A single or a multiple reservoir system which is composed of various physical components including reservoirs, channels, tunnels, pipelines, pumping stations, hydropower plants, irrigation area and urban water supply systems, operates to supply water for municipal, industrial and irrigation needs, hydropower production, flood control, recreation, navigation or ecological requirements.

Management of these systems from planning to operation is very challenging since the problem deals with many complicated variables, and uncertainties such as, inflows, return flows, storages, diversions, inter/intra-basin water transfers, irrigation, and industrial and/or municipal water supply demands (Rani and Moreira 2010).

Inefficient reservoir operating policies are studied by many researchers and the results of individual decisions and unrealistic technologies benefit / cost analyses are also examined in a comprehensive framework (Chen 2003; Labadie 2004). Many reservoirs are still being operated by a constant rule curve and these curves are usually presented as graphic or tabular form (Yeh 1985) and guides for current storage level, hydro-meterological conditions and spillway releases according to seasonal variation. On the other hand, operators use their personal judgment to decide on target elevations and selected target would be subjective (Akter and Simonovic 2004). Recently many researchers (Guariso et. al. 1986; Oliveira and Loucks 1997; Chen 2003; Labadie 2004) pointed out the inefficient operation problem of current reservoirs due to the subjective operation practices and disuse of up to date technology.

Classic operating policies does not allow for the system analysis within an integrated framework. Simulation models must be evaluated within integrated basin management for development of operation policies, and optimization methods must be used to determine these policies (Tunçok et. al. 1999). A number of system analysis techniques involving simulation and optimization algorithms have been developed and applied over the last several decades to study reservoir systems and also have been reviewed (Yeh 1985; Wurbs 1993; Labadie 2004) at times.

Excess amount of water during wet seasons, water shortage during drought seasons, dam breaks risks during flood seasons require to take challenging decisions by dam operators. In this context, the implementation of optimization methods in water resources projects is one of the very detailed studies. The academic community and research literature have emphasized optimization techniques. Especially very different programming methods have been applied to improve the efficiency of the dam operation. Some of these techniques are: linear, nonlinear, dynamic, stochastic methods and heuristic approaches (Genetic algorithms, Shuffled Complex Evolution, Complex Logic and Artificial Neural Networks) (Tunçok et. al. 1999).

In spite of the development and growing use of optimization techniques, simulation models remain a prominent tool in practice for reservoir system planning and management studies. And also, optimizations of integrated reservoir systems are still difficult for the operators and actual implementations are still limited or have not been sustained. On the other hand, development and application of decision-support tools within the major federal water resources development agencies have focused on simulation models. Optimization models often compute the releases that optimize an objective function without directly addressing the finer details of operating rules. Various strategies can be adopted for applying simulation models. Series of runs are typically made to compare system performance for alternative reservoir configurations, storage allocations, operating rules, demand levels, and/or hydrologic inflow sequences (Wurbs 1993). The most effective tool is to use a simulation model that supports the decision maker to question the operation of the existing reservoir system curves for the different scenarios (Ngo et. al. 2007, 2008; Yeh 1985). For example, Ahmad and Simonovic (2000) developed a tool for evaluating alternative operating rules by changing the reservoir storage allocation, the reservoir levels at the start of the flood season, and the reservoir outflows for Shellmouth reservoir on the Assiniboine River in Canada. In another study, HEC (2002) developed a strategy for implementing a forecast-based advance release (pre-release strategy before flood event) which let operators efficient use of short term forecasting to provide additional flood protection for Folsom Reservoir on the American River.

Looking at the recent history of Yuvacık Dam, several studies have been done. For example; Rao et. al. (2001a) developed robust operating policies for the interim control of Yuvacık Reservoir. The framework developed consist of three stages: (1) generating optimal policies using deterministic optimization models; (2) deriving robust operating rules using artificial neural network and (3) evaluating the identified operating policies through simulation. Although the study conducted for several historical inflow scenarios for initial storage level and releases on each month; it is hard to integrate it with real time application depending its only water supply oriented structure. Moreover; Rao et. al. (2001b) also developed an interactive management system for operational control. The operating rules implemented in the system are based on the rules derived during the operational control strategy through the aforementioned study. A graphical user interface components are added and a preliminary system is developed for Yuvacık Reservoir.

Also, the number and quality of stations are enriched through a scientific project between a university and the private company. During the studies, a vital early warning system was developed and several studies were conducted for the hydrologic modeling part (Gezgin et. al. 2006; Yener et. al. 2007; Keskin et. al. 2007; Şensoy et. al. 2008; Şensoy et. al. 2009).

Although aforementioned studies are conducted for operation of Yuvacık Dam, a decision support system applicable for real time operation that provides several alternatives taking current watershed potential and forecasted inflows into account was an urgent need. As a result; a more analytical and systematic approach for the study of reservoir operation is considered using reservoir simulation approaches. Correct decision information can be provided by a comprehensive computer modeling tool as a decision support system. Power and Sharda (2009) broadly defined a decision support system (DSS) as interactive computer-based systems that help people use computer communications, data, documents, knowledge and models to solve problems and make decisions. The main importance are taken on that DSS are ancillary and auxiliary systems; and they are not intended to replace skilled decision makers. Shim et. al. (2002) also described decision-making process with Figure 2.1. Here, the emphasis is on model development and problem analysis. Once the problem is recognized, alternative solutions are created, and models are then developed to analyze the various alternatives.

Since the reservoir systems are complex concerning allocation and storage decision problem which are affected by many variables; this kind of DSS approach provides multiple choices regarding to problem definition.

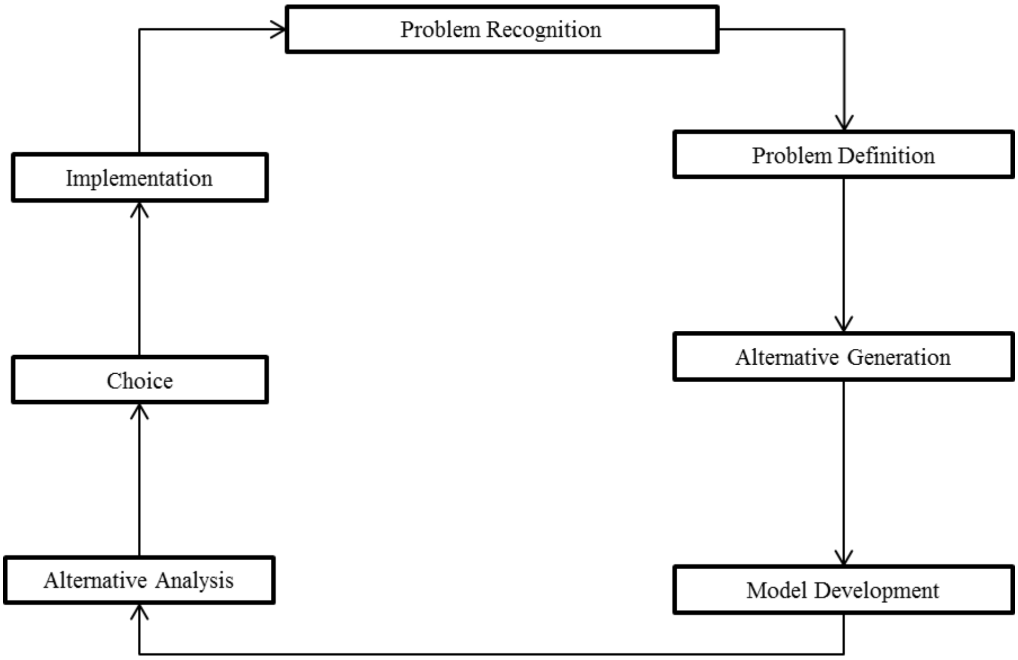


Figure 2.1 The DSS decision-making process (Shim et. al. 2002)

In this study, the simulation procedure is preferred instead of complex optimization techniques; thereby spillway releases are managed with user oriented rules based on experience. The rules are derived using previous years' experimental decisions and directly applied by a model. As a result, a decision support system is developed for both long and short term operations and the simulation model is tested with several alternatives to be used by dam operators.

2.1. Generalized Reservoir-System Simulation Models

Wurbs (1993) describes “generalized” term that is used to refer to model designed to be readily applied to a variety of reservoir/river systems. The user develops the input data for the particular system of interest and executes the model, without being concerned with developing or modifying the actual computer code.

There are several generalized simulation models that are being used for water resources management systems. Wurbs (1993) also gave a brief summary of generalized models that have been applied by water management agencies to support actual planning and/or operation decisions and updated (Wurbs 2005) according to the state of art. The most popular simulation modeling softwares (Table 2.1) had been used in several studies and projects are worth mentioning here:

Table 2.1 Reservoir simulation models (Wurbs 2005)

Short Name	Descriptive Name	Model Development Organization
RiverWare	River and Reservoir Operation	Bureau of Reclamation, TVA, CADSWES http://animas.colorado.edu/riverware/
MODSIM	Generalized River Basin Network Flow Model	Colorado State University http://modsim.engr.colostate.edu
MIKE BASIN	GIS-Based Decision Support for Water Planning & Management	Danish Hydraulic Institute http://www.dhisoftware.com/mikebasin/
HEC-5	Simulation of Flood Control and Conservation Systems	USACE Hydrologic Engineering Center http://www.hec.usace.army.mil/
HEC-ResSim	Reservoir System Simulation	USACE Hydrologic EngineeringCenter http://www.hec.usace.army.mil/

RiverWare Modeling System

RiverWare is developed by the Center for Advanced Decision Support for Water and Environmental Systems of the University of Colorado (CADSWES 2003) and it provides the basic hydrologic capabilities associated with routing streamflow inflows through a river/reservoir system. Watershed runoff at pertinent river system nodes is provided as input. The primary processes modeled are volume balances at reservoirs, hydrologic routing in river reaches, evaporation and other losses, diversions, and return flows. Features are also provided for modeling groundwater interactions, water quality, and electric power economics. Any number of reservoirs and stream reaches can be modeled.

Computational algorithms for modeling reservoir/river system operations are based on three alternative approaches:

1. pure simulation
2. rule-based simulation
3. optimization combining linear programming with preemptive goal programming.

MODSIM Modeling System

MODSIM (2012) is developed by the Colorado State University and the Bureau of Reclamation’s Pacific North West Region. It is a general-purpose reservoir/river system simulation model based on network flow programming designed for analyzing physical, hydrologic, and institutional/administrative aspects of river basin management. The modeling system is designed to support long-term planning (monthly time step), medium-term management (weekly time step), and short-term operations (daily time step). Water is allocated based on user-specified priorities. The user assigns relative priorities for meeting diversion, instream flow, hydroelectric power, and storage targets, as well as lower and upper bounds on flows and storages.

MIKE BASIN

MIKE BASIN (2003) integrates GIS capabilities with reservoir/river system modeling. The model simulates multipurpose, multi-reservoir systems based on a network formulation of nodes and branches. Although the time step is user-selected, solutions are stationary for each time station without flow routing dynamics. Thus, a monthly time step is common. Time series of inflows from catchments to each branch of the stream system are normally provided as input. However, the model can also be connected to watershed precipitation-runoff capabilities provided by the MIKE11.

HEC-3, HEC-5

The HEC-3 (HEC 1981) Reservoir System Analysis for Conservation program simulates operation of reservoir systems for conservation purposes such as water supply, low-flow augmentation, and hydroelectric power. HEC-3 and HEC-5 have similar capabilities for simulating conservation operations, but HEC-3 does not have the comprehensive flood control capabilities of HEC-5.

The HEC-5 (HEC 1998) Simulation of Flood Control and Conservation Systems program has been used in many studies, including investigations of storage reallocations and other operational modifications at existing reservoirs as well as feasibility studies for proposed new projects. The program is also used to support real-time operations.

HEC-5 simulates the sequential period-by-period operation of a multiple-purpose reservoir system for inputted sequences of unregulated streamflows and reservoir evaporation rates. Multiple reservoirs can be located in essentially any stream tributary configuration. The program uses a variable time interval. For example, monthly or weekly data might be used during periods of normal or low flows in combination with daily or hourly data during flood events.

HEC-ResSim

HEC-ResSim eventually replaces the HEC-5 (HEC 1998) Simulation and Flood Control and Conservation Systems model, which has been extensively applied for over 20 years. HEC-ResSim program was developed through many years and version 3.0 was released in 2007 (HEC 2007a). One of the advantages to use ResSim in this study that the streamflow hydrographs provided as input to ResSim with the HEC-HMS Hydrologic Modeling System (HEC 2008) based on precipitation-runoff modeling for the real time operation application. A detail description about the HEC-ResSim is given in Chapter 4. Furthermore, HEC-ResSim is widely used in the world in reservoir modeling studies:

Totoba (2006) applied ResSim for gate regulation in Wadecha – Belbela reservoirs to investigate monthly maximum irrigation potential under inflow scenarios in Ethiopia. Babazadeh et. al. (2007) also used ResSim 2.0 version to evaluate performance of Jirof storage dam and its water supply with reliability, resiliency and vulnerability indices under various scenarios in Iran. Asefa (2011) showed performance of existing and planned power plants effects on agriculture in Omo Gibe river basin. Another study (USACE 2007) is carried out for long term planning of the capacity of the Helmand and Arghandab Rivers and respectively reservoirs, Kajakai and Dahla to support irrigation needs in Helmand Basin and power production at the Kajakai powerhouse. Özbakır (2009) used HEC-ResSim with existing and planned scenarios and searched excess water potential of Seyhan and Ceyhan River Basins for energy production and water supply multi-reservoir systems. Another application for flood control purposes is applied in Delaware River Basin to develop flood damage reduction strategies (USACE 2010). The purpose of developing HEC-ResSim reservoir operation model was to evaluate the potential flood mitigation opportunities from existing reservoirs, in particular, the ability of reservoirs to reduce flood crests.

2.2. Real Time Operation with HEC-ResSim

Since the decisions are strongly based on the streamflow into the reservoir, the real time operation of a reservoir requires knowing future streamflow values. To that end, several valuable studies are applied that integrates forecast data with hydrological modeling. Anderson et al. (2002) integrated the precipitation forecast from the Mesoscale Model 5 data (MM5) model with HEC-HMS (HEC 2008) for obtaining runoff forecasts in North California. Haberlandt (2010) carried out a study in Upper Leine river basin of Germany to discuss suitability of HEC-HMS and other hydrological models to be used as a part of decision support systems.

Runoff forecasting is also done for this study in which Numerical Weather Prediction (NWP) Mesoscale Model 5 (MM5) data is integrated into a hydrological model to obtain runoff forecast for Yuvacık Dam Reservoir for one and two day ahead (ÇAYDAG 2012, Uysal et al. 2011; Yavuz et. al. 2012a, 2012b). The details would be discussed in another thesis study by Yavuz (in preparation, 2012).

Finally, this study summarizes the capabilities and range of applications to develop a Decision Support System for real time water supply and flood control operation of Yuvacık Dam Reservoir using HEC-ResSim 3.0. The study is basically divided into two parts; long term operation for water supply and short term operation control. Daily streamflow forecasts, current snow water equivalent of the basin and observed reservoir level data are integrated with reservoir simulation to be used as a daily decision support tool. However, in case of high streamflow forecast values that will create a flood risk, hourly pre-release policies are integrated with simulation model to evacuate excess water from spillways.

3. STUDY AREA

Yuvacık Dam (Figure 3.1) is the main source of water supply for Kocaeli Great Municipality (KGM) and surrounding areas, providing water for a population of some 1.5 million in addition to the rapidly expanding industrial base of the region. Drainage basin of Yuvacık Dam Reservoir (Figure 3.2) is located within the boundary of Marmara Basin in the northwestern part of Turkey with an area of 258 km^2. The basin is between 40^o 30’ – 40^o 41’ northern latitudes and 29^o 48’ – 30^o 08’ eastern longitudes and elevation ranges between 80 – 1548 m. The reservoir lake has a surface area of 1.70 km^2 and 12 km away from Kocaeli city center.

Water treatment plant and 142 km of pipeline which is capable of supplying up to 480 mega liters per day have been operating since 1999. The earth-filled dam is 108 m high and 400 m wide with a storage capacity of approximately 42 hm^3 at spillway level of 159.95 m and the maximum storage volume is 56 hm^3 at maximum operating level of 169.30 m with closed spillway gates. The operation is based on the provision of some 142 hm^3 treated water per year.

The 12 km length downstream reach passes initially from a narrow valley near a rural district and thereafter flows into the Marmara Sea after a sharp curvature by a manmade channel next to industrial and urban areas. Hence, the maximum amount of water to be released is set as 100 m^3/s by the regional water authority taking the drainage discharge conditions into consideration although the spillway capacity is 1560 m^3/s. The reservoir spillway is operated by radial gates behind which excess water is stored especially during flood seasons (late February to June) and operations require release regulation through downstream.

Figure 3.1 Satellite image of Yuvacık Dam (Google Earth, June 2012)

Figure 3.2 Location of Yuvacık Dam Basin (Google Earth, June 2012)

3.1. Geographical Information Systems (GIS) based Maps

Primarily, Geographical Information Systems (GIS) based maps of Yuvacık Basin and its subbasins are generated using ArcGIS 9.3 (http://www.esri.com) computer program. These maps are used both for the hydrological model and also reservoir simulation models as a watershed visualization tool at the background.

Digital Elevation Model (DEM) is generated using digitized 1/25.000 scale contour maps (Figure 3.3). Datum and projection system is manually set as World Geodetic System 1984 (WGS 84) and Universal Transverse Mercator (UTM) 35th North Zone, respectively.

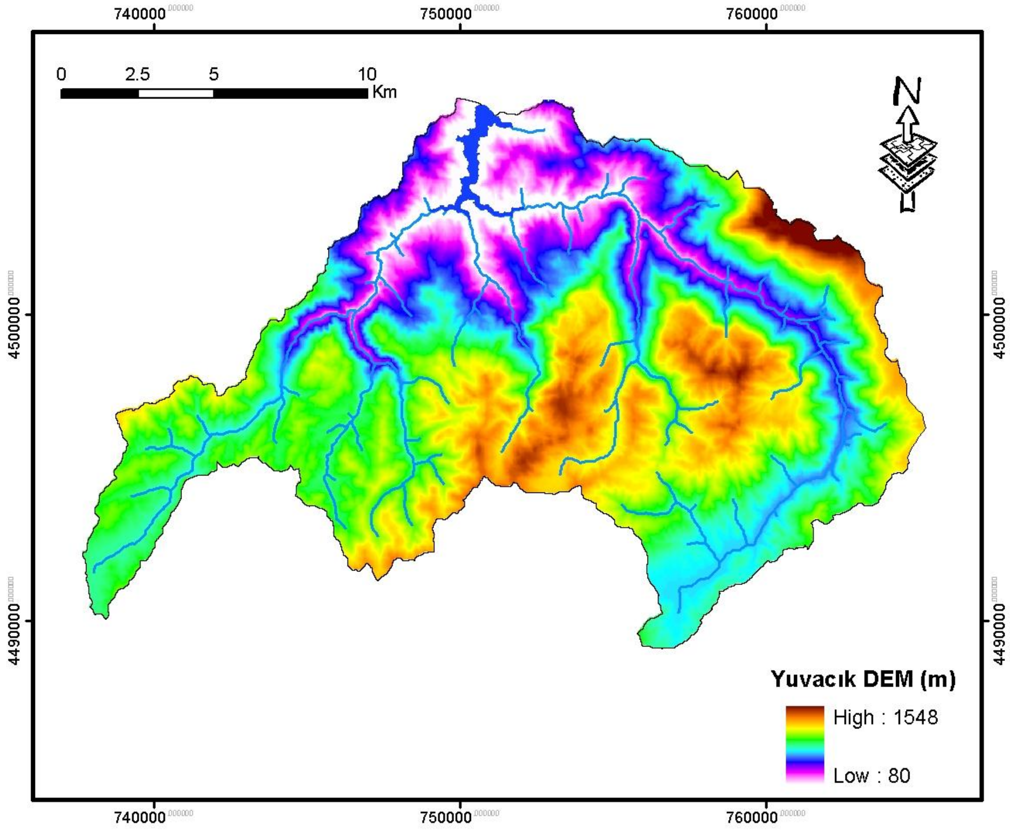


Figure 3.3 Digital Elevation Model (DEM) of Yuvacık Basin

Yuvacık Basin is mainly composed of deep valleys originating in the south and almost parallel flowing streams ending up in the north regions of the basin. Three main land cover types are classified as forest and agricultural land and pasture lands (Yener 2006). The basin is divided into 4 subbasins which are delineated according to flow plants FP1, FP2 and FP3 (Kirazdere, Kazadere, Serindere, respectively) using DEM, and the area between the reservoir lake and other subbasins is called as the contributing subcatchment (Figure 3.4).

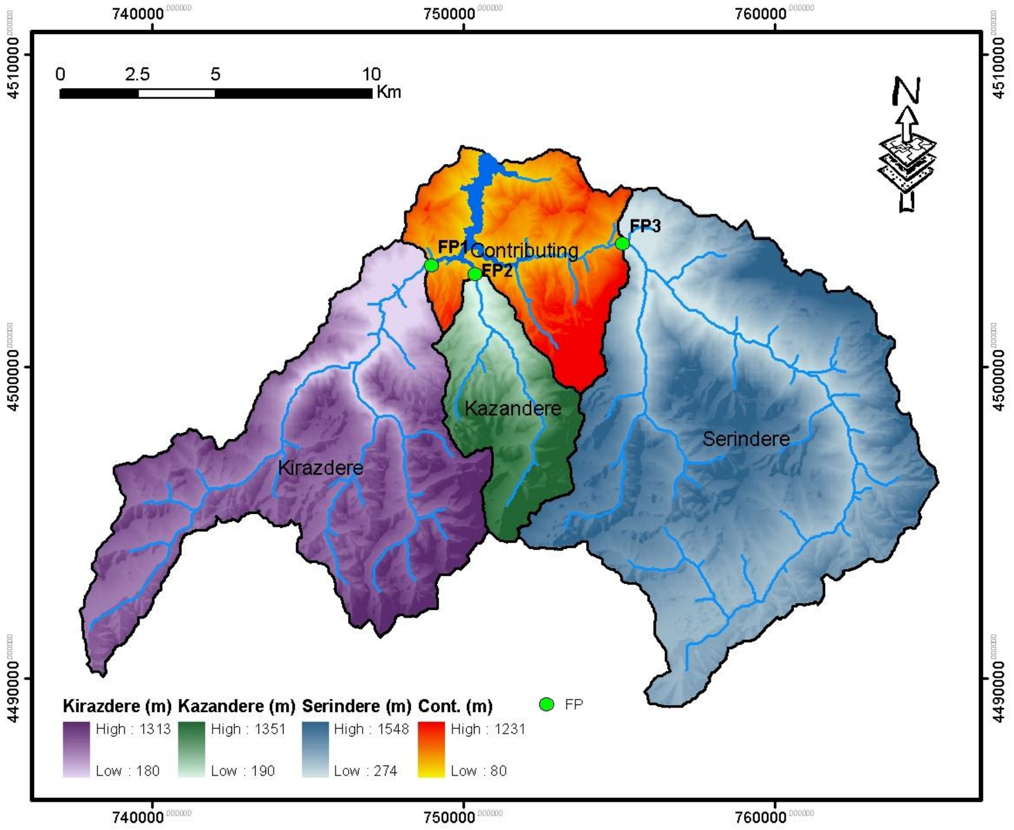


Figure 3.4 Yuvacık Dam Basin & Subbasins with stream network

Hypsometric curve of the whole catchment is generated using DEM of the basin (Figure 3.5) and hypsometric mean elevation is calculated through this curve as 893.22 m.

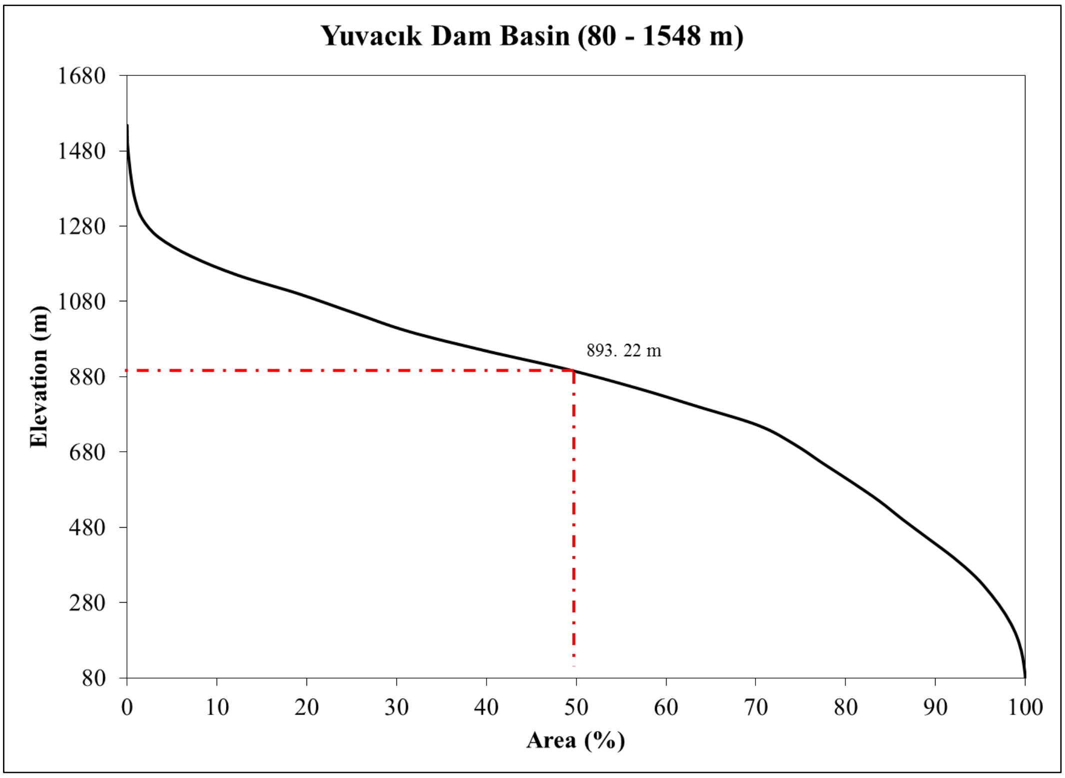


Figure 3.5 Hypsometric curve of Yuvacık Basin

3.2. Hydro-meteorological Data

Hydro-meteorological data are necessary for flow estimation and also used to clarify the water potential that helps reservoir operator to take decision during gate operation.

Several meteorological stations in and around the basin are installed and data are collected and transmitted online with 5 minutes time step. The number and quality of stations are enriched through a previous scientific project between a university and the private company, and hydrological modeling studies were carried out. Characteristics and properties of stations (Rain gauges and flow plants) are summarized in Table 3.1.

Table 3.1 Properties of stations

Station ID:	Location	Latitude (N)	Longitude (E)	Data Type*	Time interval	Data Transfer**	Elevation (m)
RG-1	**İSU Hacı Ömer**	**40° 38’ 52.5”**	**29° 57’ 25”**	**P**	**5 Minutes**	**RF**	**188**
RG-2	**Aksığın**	**40° 38’ 21.8”**	**29° 57’ 54.9”**	**P**	**5 Minutes**	**RF**	**320**
RG-3	**Servetiye**	**40° 38’ 09”**	**29° 56’ 52.9”**	**P**	**5 Minutes**	**RF**	**460**
RG-4	**Serindere**	**40° 38’ 05.8”**	**30° 00’ 06.1”**	**P**	**5 Minutes**	**RF**	**520**
RG-6	**Spillway**	**40° 40’ 27.4”**	**29° 58’ 19.3”**	**P**	**5 Minutes**	**RF**	**178**
RG-7	**Tepecik**	**40° 37’ 38.1”**	**29° 59’ 25.4”**	**P, SD, T, RH**	**5 Minutes** **Daily**	**GSM**	**700**
RG-8	**Aytepe**	**40° 36’ 02.4”**	**29° 56’ 08.4”**	**P, SD, T, RH**	**5 Minutes** **Daily**	**GSM**	**953**
RG-9	**Kartepe**	**40° 39’ 21.0”**	**30° 05’ 44.0”**	**P, SD, T, RH**	**5 Minutes** **Daily**	**GSM**	**1340**
RG-10	**Çilekli**	**40° 32’ 30.1”**	**30° 02’ 38.7”**	**P, SD, T, RH**	**5 Minutes** **Daily**	**GSM**	**805**
RG-11	**Kazandere**	**40° 37’ 12.2”**	**29° 57’ 08.4”**	**P, T, RH**	**5 Minutes** **Daily**	**GSM**	**732**
RG-12	**Hacı Osman**	**40° 33’ 01”**	**29° 49’ 08”**	**P, SD, T, RH**	**5 Minutes** **Daily**	**GSM**	**865**
FP-1	**Kirazdere**	**40° 38’ 33.1”**	**29° 56’ 38.8”**	**S**	**5 Minutes**	**RF**	**185**
FP-2	**Kazandere**	**40° 38’ 22.6”**	**29° 57’ 37.9”**	**S**	**5 Minutes**	**RF**	**180**
FP-3	**Serindere**	**40° 38’ 48.5”**	**30° 01’ 01.1”**	**S**	**5 Minutes**	**RF**	**284**

***S:** Streamflow depth, **P:** Precipitation, **SD:** Snow depth, **T:** Temperature, **RH:** Relative Humidity, **RG:** Rain gauge, **FP:** Flow plant

** **RF**: Radio Frequency, **GSM**: Global System for Mobile Communications

Precipitation is measured at all stations (RG-1, RG-2, RG-3, RG-4, RG-6, RG-7, RG-8, RG-9, RG-10, RG-11, and RG-12) in and around the basin (Figure 3.6). RG-1 and RG-6 (Figure 3.7) are installed without a heater since they are located at lower altitudes, on the other hand RG-2 (Figure 3.8), RG-3, RG-4 are installed and equipped with a heater. Besides; snow depth, temperature and relative humidity are measured at RG7, RG-8, RG-9 and RG-10, RG-11 (except snow depth) and RG-12 in addition to precipitation. An additional antifreeze equipment is used for rain gauges RG-11 and RG-12 to provide precipitation measurements for cold temperatures especially at higher elevations.

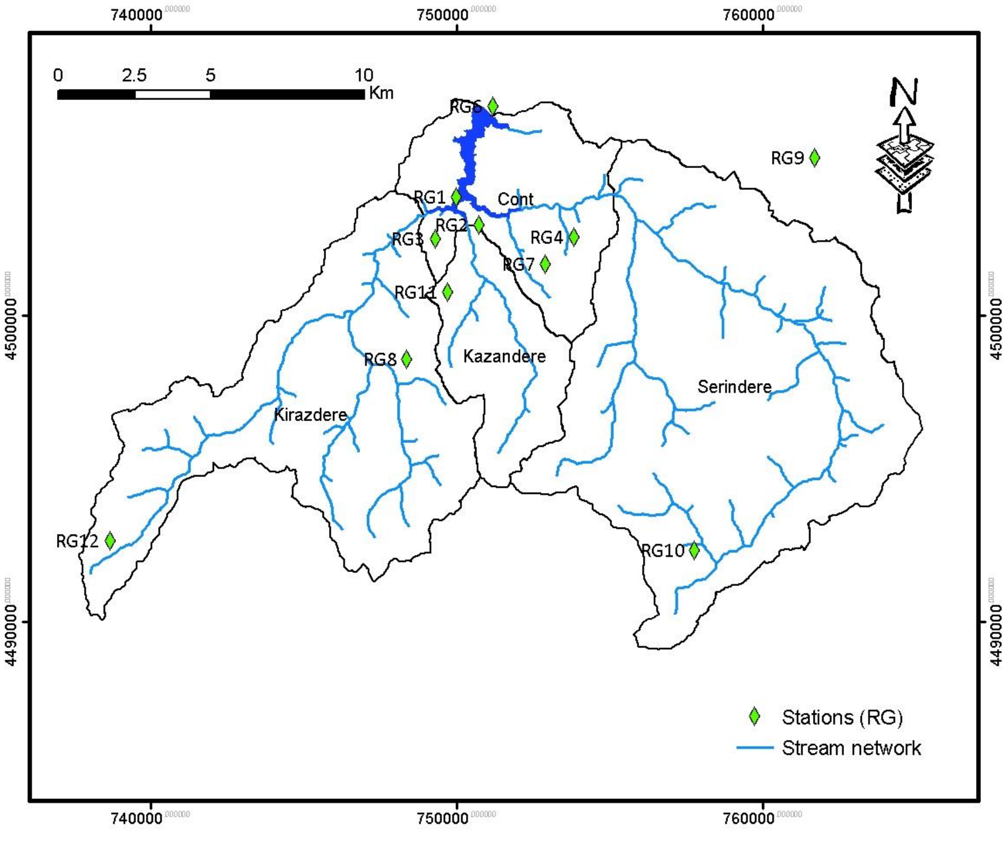


Figure 3.6 Meteorological instrumentation network

Figure 3.7 Rain-gauge (RG-6) located near the spillway without a heater (178 m)

Figure 3.8 Rain-gauge (RG-2) located near at Aksığın village with a heater (320 m)

3.2.1. Precipitation

The data collected at precipitation gauges give point values of precipitation, whereas areal mean values are necessary in most hydrologic studies. Areal mean precipitation is calculated using Thiessen Polygons Method for each subbasin (Figure 3.9) and mean annual precipitation exemplified for the water year of 2009 (Figure 3.10).

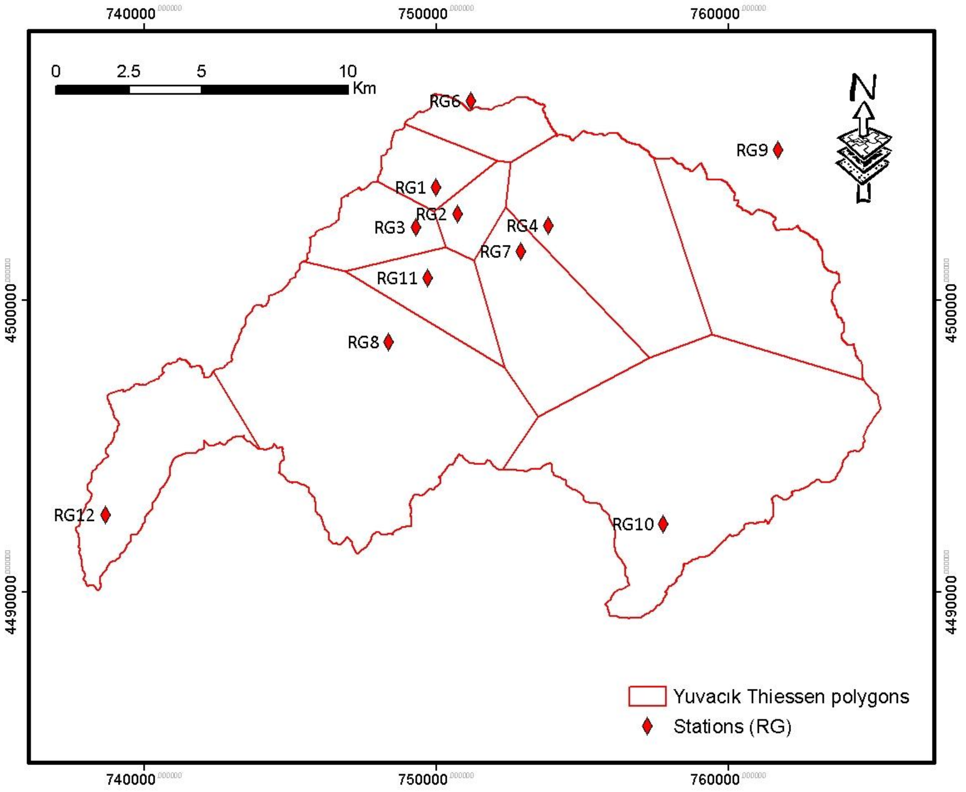


Figure 3.9 Distribution of Thiessen polygon

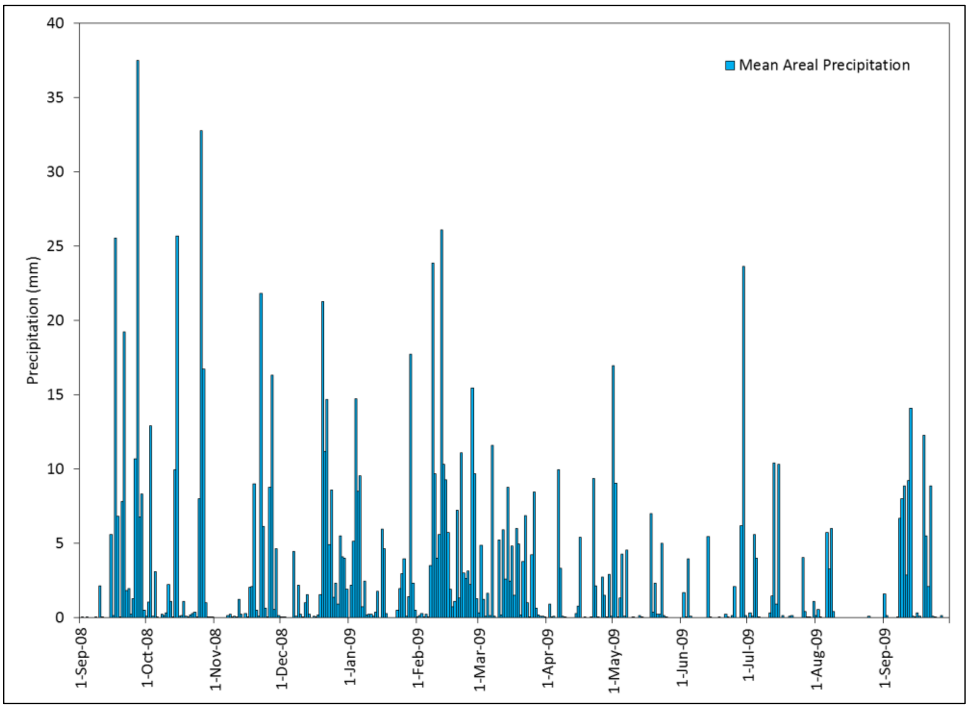


Figure 3.10 Mean areal precipitation (2009 water year)

3.2.2. Temperature

The temperature is a necessary variable especially during snow melting period for degree-day accounting hydrological models. An example of temperature measurements are shown for the water year of 2009 (Figure 3.11).

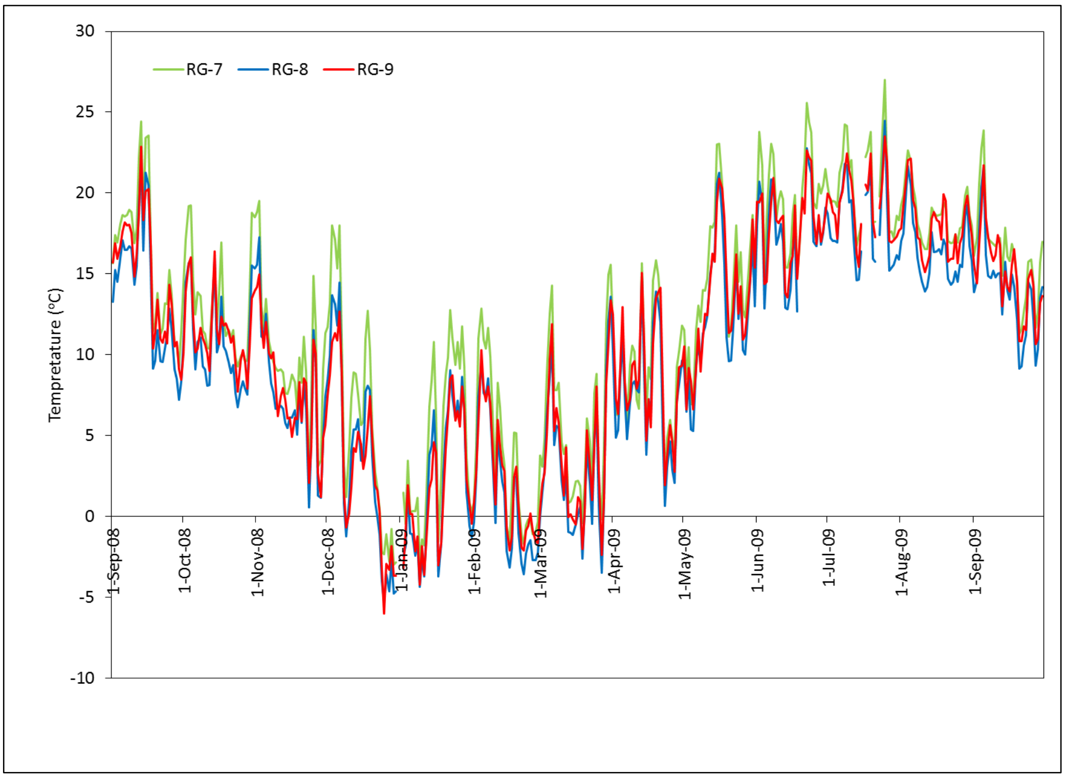


Figure 3.11 Temperature data (2009 water year)

3.2.3. Snow Measurement

Since the basin elevation ranges between 80 – 1548 m, precipitations are observed as snowfall at higher altitudes during December to February. This situation causes snow accumulation and high snowmelt contribution during early spring months.

Snow depth is measured at several snow stations (RG7, RG8, RG9, RG10, and RG12) in and around the basin continuously. Moreover, snow course points were determined to measure both snow depth and snow water equivalent (SWE) values using snow tubes (Figure 3.12). These data (Figure 3.13) are directly used as input in both hydrological modeling for streamflow estimation and reservoir simulation studies for release decisions especially during melting period.

Hydrological models which count for snow and melt relationship necessitate a division of basins into elevation zones to calculate snowmelt runoff. Thus, each subbasin that is used in hydrological model is divided into inter-consistent elevation zones (A, B and C bands).

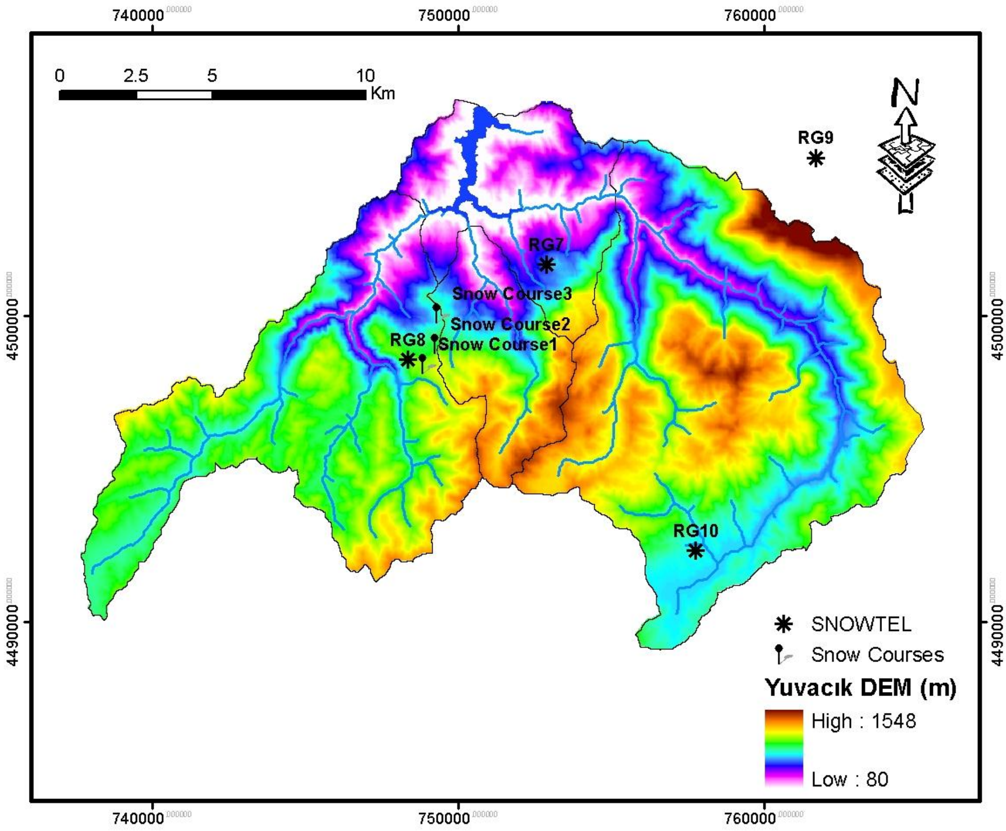


Figure 3.12 Snow measurement (SNOWTEL and Snow Courses)

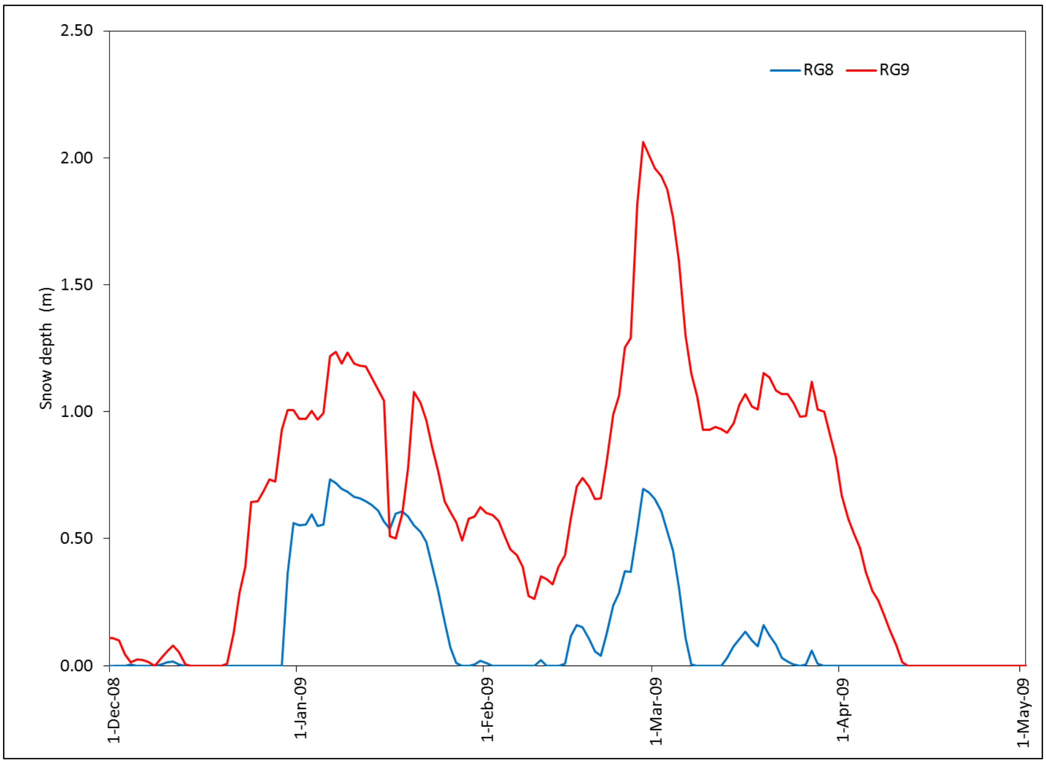
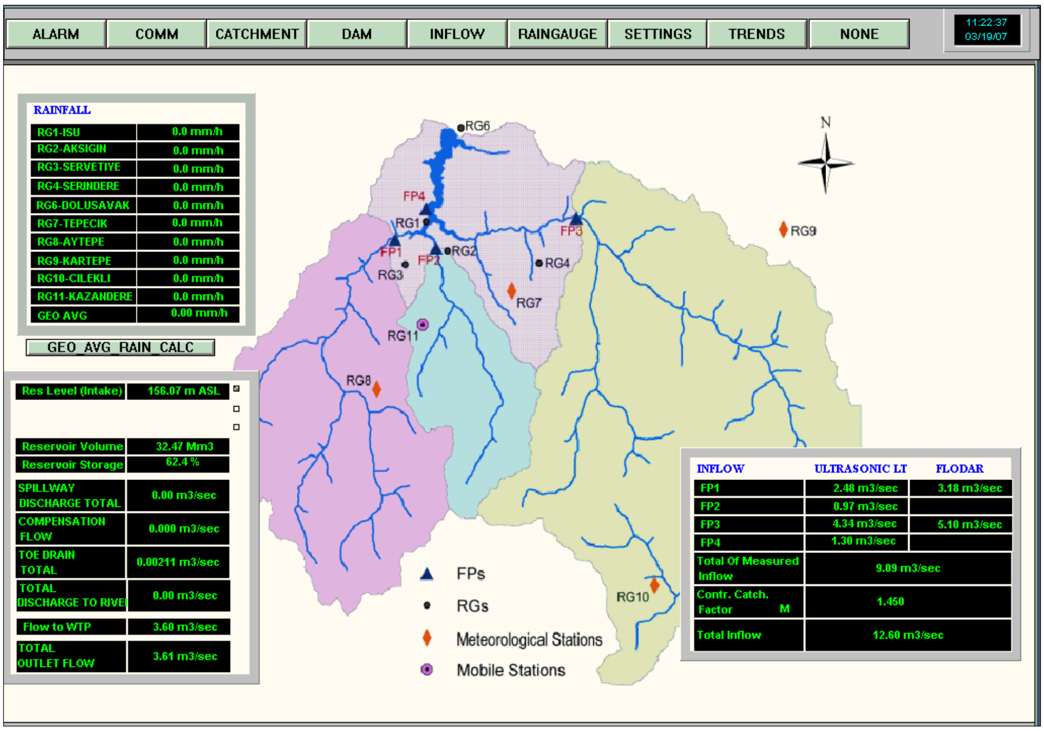


Figure 3.13 Snow depth at RG-8 and RG-9 (2009 snow period)

3.2.4. Dam Management System

The data have been continuously collected from automated stations and controlled by integrated Dam Management System (DMS) (Figure 3.14). The system was developed by a part of SCADA (Supervisory Control and Data Acquisition) system by the reservoir operators and it provides observation and control of any breakdown or problems related to flow plants, rain gauges, outlet works etc.



RAINFALL	
RG1-ISU	0.0 mm/h
RG2-AKSIGIN	0.0 mm/h
RG3-SERVETIYE	0.0 mm/h
RG4-SERINDERE	0.0 mm/h
RG6-DOLUSAVAK	0.0 mm/h
RG7-TEPECIK	0.0 mm/h
RG8-AYTEPE	0.0 mm/h
RG9-KARTEPE	0.0 mm/h
RG10-CILEKLI	0.0 mm/h
RG11-KAZANDERE	0.0 mm/h
GEO AVG	0.00 mm/h

Res Level (Intake)	156.07 m ASL
Reservoir Volume	32.47 Mm3
Reservoir Storage	62.4 %
SPILLWAY DISCHARGE TOTAL	0.00 m3/sec
COMPENSATION FLOW	0.000 m3/sec
TOE DRAIN TOTAL	0.00211 m3/sec
TOTAL DISCHARGE TO RIVEI	0.00 m3/sec
Flow to WTP	3.60 m3/sec
TOTAL OUTLET FLOW	3.61 m3/sec

INFLOW	ULTRASONIC LT	FLODAR
FP1	2.48 m3/sec	3.18 m3/sec
FP2	0.97 m3/sec	
FP3	4.34 m3/sec	5.10 m3/sec
FP4	1.30 m3/sec	
Total Of Measured Inflow	9.09 m3/sec	
Contr. Catch. Factor M	1.450	
Total Inflow	12.60 m3/sec	

Figure 3.14 Dam Management System

3.3. Downstream channel constraints

Large capacity of the spillways and outlet works provide a flexibility for the operators. Spillway capacity, sluice way capacity for the maximum water level and maximum water supply pipe capacity are 1560 m^3/s, 58 m^3/s and 36.6 m^3/s, respectively.

The importance of this study is that water is hold behind the radial gates during spring months due to the relatively small capacity of the reservoir, and the gates must be opened to release the excessive amount of water especially during snowmelt period when the river discharges are increasing. However, the spillway releases are constrained by downstream conditions. Thus, operational decisions are important whilst spillway gates are operated.

Upper limits for reservoir releases to the downstream channel are studied separately by the governmental offices before. This limit was set to 100 m^3/s between the years 2004 – 2006, after rehabilitation works done by governmental authorities; the limit is set up to 200 m^3/s. The downstream channel layout is presented below Figure 3.15.

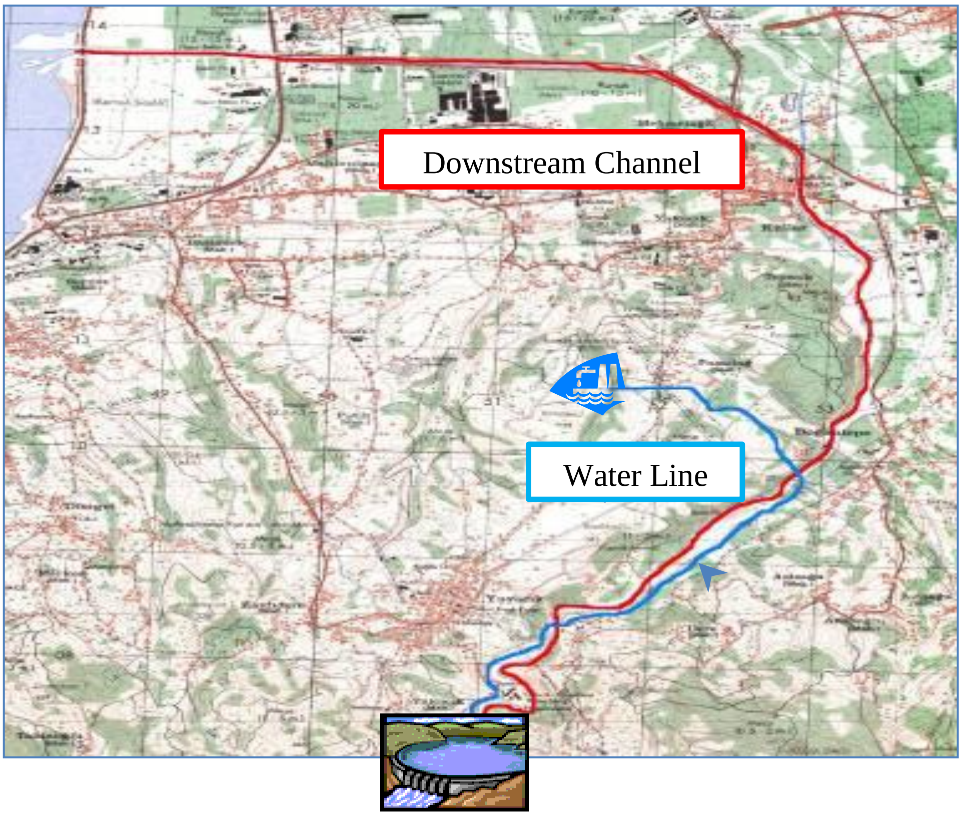


Figure 3.15 Downstream channel (Gezgin 2009)

In addition to these, flow that contributes from downstream subbasins highly decreases channel capacity in times of flood. One storm event which is observed on 29 October 2010 even proved the associated situation. Although spillway was not operated during this event, photos (Figure 3.16 and 17) summarize the importance of the area of interest. Therefore; the operators are targeted 100 m^3/s as an upper limit during normal operation condition and 200 m^3/s for the extreme flood event conditions.

Figure 3.16 Downstream channel section at 7+800 km

Figure 3.17 Downstream channel section at 11+400 km

4. RESERVOIR SIMULATION MODELING

4.1. Reservoir System Operations

Reservoir system involves several elements like reservoir lake, junctions, streams, natural and man-made channels, outlet works, reaches, diversions etc. Operation of these structures necessitates organized strategies and operating plans. A decision support system based reservoir system operation is developed for an effective management by means of a simulation model. The main methodology in this thesis is based on generating the simulations of a basin/reservoir system. A simple simulation model is a representation of a system used to predict the behavior of it under alternative set of conditions. Alternative executions of a simulation model are made to analyze the performance of the system under varying conditions, such as alternative operating policies (Wurbs 1993).

Wurbs (2005) categorized reservoir system operations as:

- operations during normal hydrologic conditions from the perspective of optimizing the present day-to-day, seasonal, or year-to-year use of the reservoir system
- operations during normal hydrologic conditions from the perspective of maintaining capabilities for responding to infrequent hydrologic extremes expected to occur at unknown times in the future
  - ❖ maintaining empty flood control storage capacity
  - ❖ maintaining reliable supplies of water
- operations during hydrologic extremes
  - ❖ operations during flood events
  - ❖ operations during low flow or drought conditions

Yuvacık Dam is also subjected to aforementioned operations, so the simulation models that will support each decision are investigated through this thesis. Before developing a simulation model and analyzing the simulation results; “simulation” terminology and “HEC-ResSim model” is discussed below in detail.

4.2. Reservoir Operation Rules

The main problem especially for a controlled/gated reservoir is how much water should be stored behind the radial gates or released. An operating plan or release policy is a set of guidelines for determining the quantities of water to be stored and to release or withdraw from a reservoir or system of several reservoirs under various conditions. Storing more water rather than current need increases flood risk especially for relatively small capacity reservoirs.

Reservoir operation can be simply applied with a simulation model by dividing the total storage capacity into designated pools (Figure 4.1).

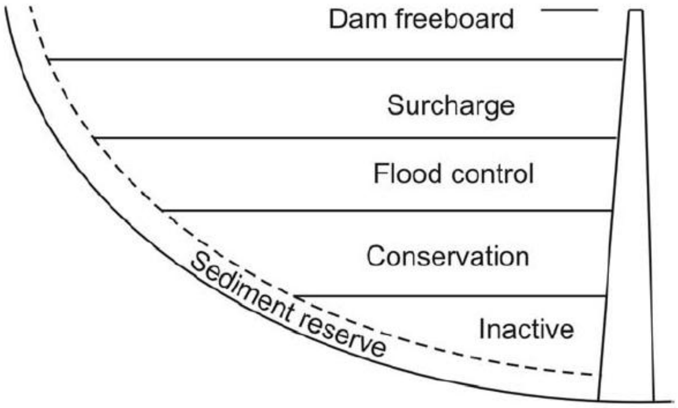


Figure 4.1 Reservoir pools (Wurbs 2005)

The surcharge pool is essentially uncontrolled storage capacity above the flood control pool (or conservation pool if there is no designated flood control storage capacity) and below the maximum design water surface. Major flood events exceeding the capacity of the flood control pool encroach into surcharge storage.

Flood control pool is indispensable one which provides allowable space volume in times of a flood, or other immediate water level increases. Gated spillways allow the top of flood control pool elevation to exceed the spillway crest elevation. Upper part of the flood control pool is defined as the maximum operation level (Figure 4.2).

Conservation pool stores water for different purposes, such as municipal and industrial water supply, irrigation, navigation, hydroelectric power, and instream flow maintenance, involve storing water during periods of high streamflow and/or low demand for later beneficial use as needed. Conservation storage also provides opportunities for recreation. The reservoir water surface is maintained at or as near the designated top of conservation pool elevation as streamflows and water demands allow. Drawdowns are made as required to meet the various needs for water. Upper part of the conservation pool, target elevation, is named as ‘Guide Curve’ in HEC-ResSim if not defined otherwise. Thus, basic operation of the reservoir is adjusted according to this guide curve.

Inactive part is associated with dead storage that means no release or water withdraw is made within this zone. It is fed by sediment reserve and an upper level generally serves as a lower elevation for sluiceways.

The desirable reservoir storage or elevation at various times of the year may be shown by a general rule curve (Figure 4.2). The terms, rule curve or guide curve are typically used to denote operating rules which define ideal or target storage levels and provide a mechanism for release rules to be specified as a function of storage content. Rule curves may be expressed in various formats such as water surface elevation or storage volume versus time of the year (Asefa 2011).

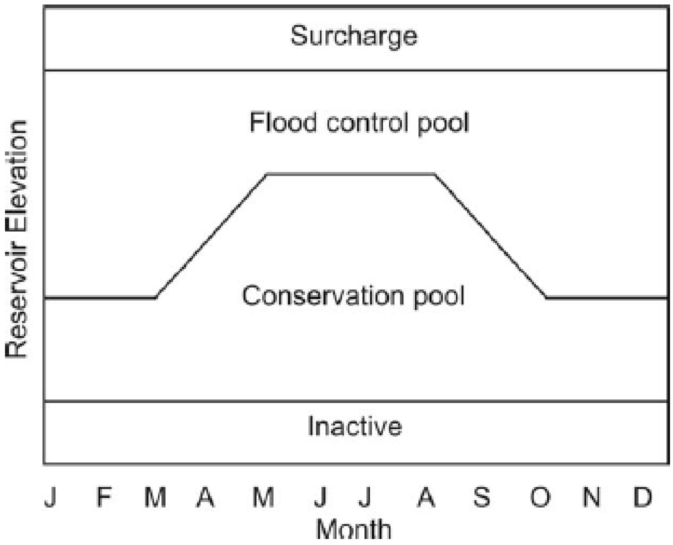


Figure 4.2 Operation rule curves (Wurbs 2005)

In spite of the fact that rule curves are generated for basic operation for any reservoir, they are generally independent from current watershed water potential and condition of the operation. Also, multi-purpose reservoirs generally do not have direct and foreknown operational guide curves. The curves could be generated concerning the purpose of the target as well. This circumstance creates conflicting objectives sometimes.

4.3. Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim)

HEC-ResSim (Reservoir System Simulation) developed by USACE (U.S. Army Corps of Engineers Hydrologic Engineering Center) is chosen to achieve the reservoir simulation studies. HEC-ResSim 3.0 (HEC 2007a) is a computer program applicable in hydrologic and hydraulics of reservoir system simulation models. It is used for research in water resources management being conducted to explore the link between decisions support system and reservoir simulation. Software and documents are free of charge and can be downloaded from HEC’s internet page (http://www.hec.usace.army.mil/software/hec-ressim/). Current documents involve Quick Start Guide (HEC 2007b), User Manuel (HEC 2007a) and release notes.

Multi-purpose and multi reservoir systems are simulated by means of special algorithms that are developed for particular purpose. Program features provide a flexibility to represent the real operation in an easy manner and many time steps are included within a program.

A newer and beta version HEC-ResSim 3.1 is provided from its original developers and used throughout this thesis. In spite of the fact that the beta version is similar to version 3.0, some new modeling approaches including new features (especially variable guide curve approach) are also used in the study. General summary is described below, more detailed documentation can be found in HEC-ResSim 3.0 User Manual (HEC 2007a).

4.3.1. History

HEC-ResSim is the successor to “HEC-5, Simulation of Flood Control and Conservation Systems" program (HEC 1998). ResSim is comprised of a graphical user interface (GUI), a computational program to simulate reservoir operation, data storage and management capabilities, and graphics and reporting facilities. The Data Storage System, HEC-DSS (HEC 1995 and HEC 2006) is used for storage and retrieval of output of time-series data.

4.3.2. Modules

ResSim offers three separate sets of functions called “*Modules*” that provide access to specific types of data within a watershed. Three modules are *Watershed Setup*, *Reservoir Network* and *Simulation*. Each module has a unique purpose and associated set of functions accessible through menus, toolbars, and schematic elements. Figure 4.3 illustrates the basic modeling features that are available in each module.

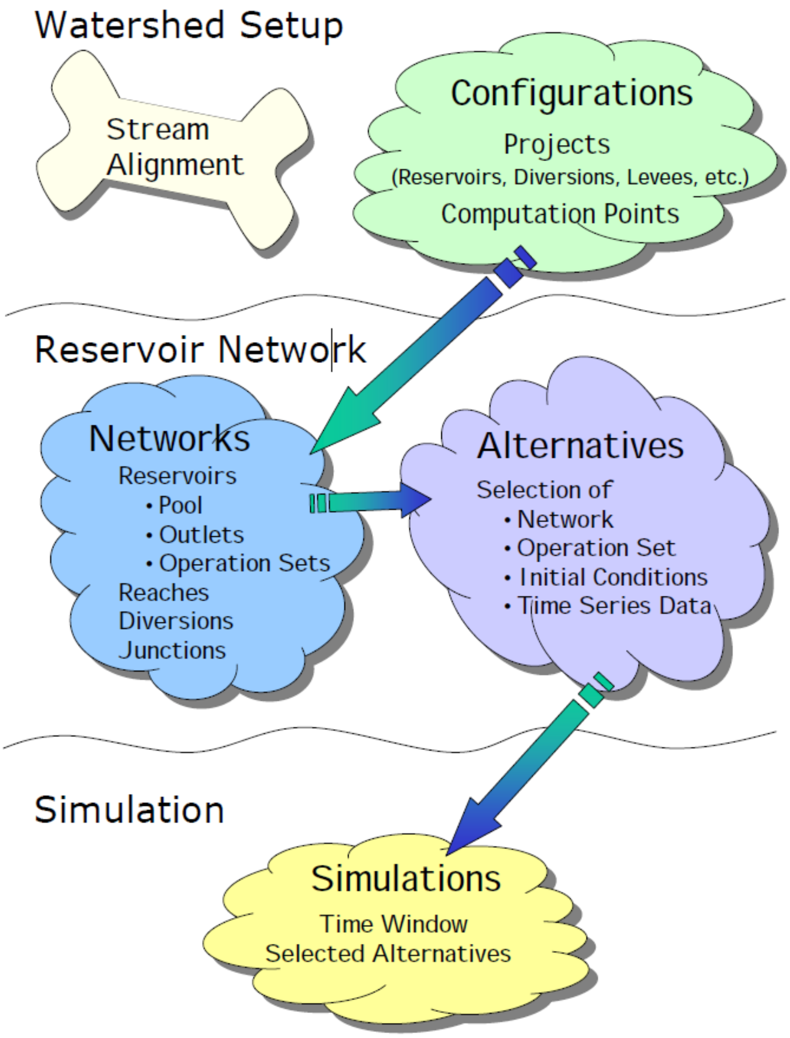
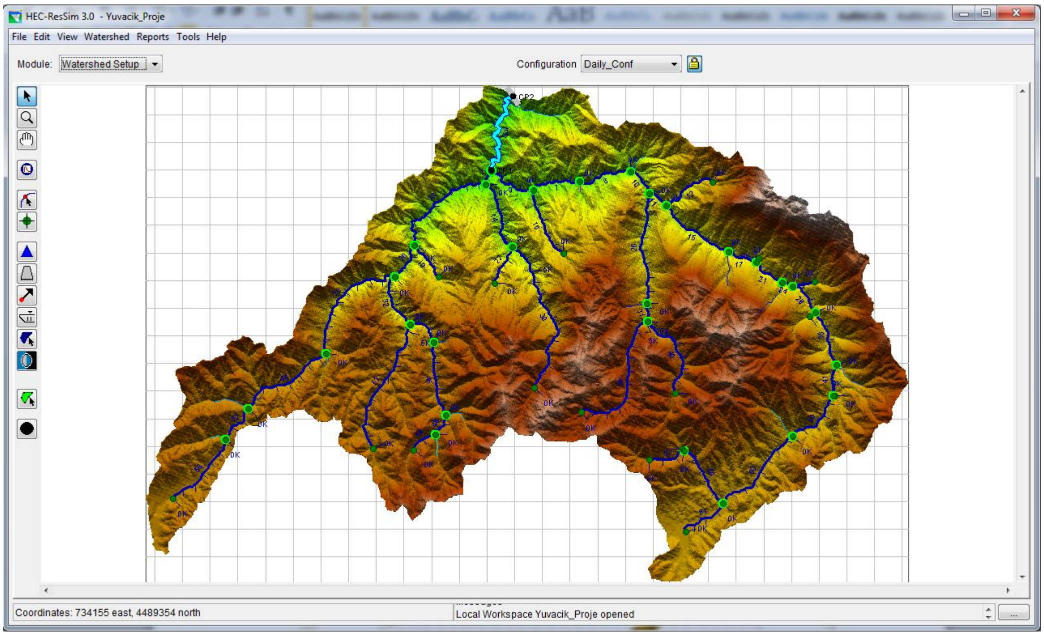


Figure 4.3 ResSim Module Concepts (HEC 2007a)

4.3.3. Watershed Setup Module

Watershed Setup Module generally consists of background data for the whole project. These data can easily be put into module as streams, projects (e.g. reservoirs, levees), gage locations, impact areas, time-series locations, hydrologic and hydraulic data etc. Also, a GIS based coordinated maps that represents the watershed are used as a project layout in the module (Figure 4.4) and stream elements are converted from vector elements of the map directly. The main purpose is to maintain common layout that combines watershed and reservoir elements into one single module.



HEC-ResSim 3.0 - Yuvacik_Proje

Module: Watershed Setup

Configuration Daily_Conf

Coordinates: 734155 east, 4489354 north

Local Workspace Yuvacik_Proje opened

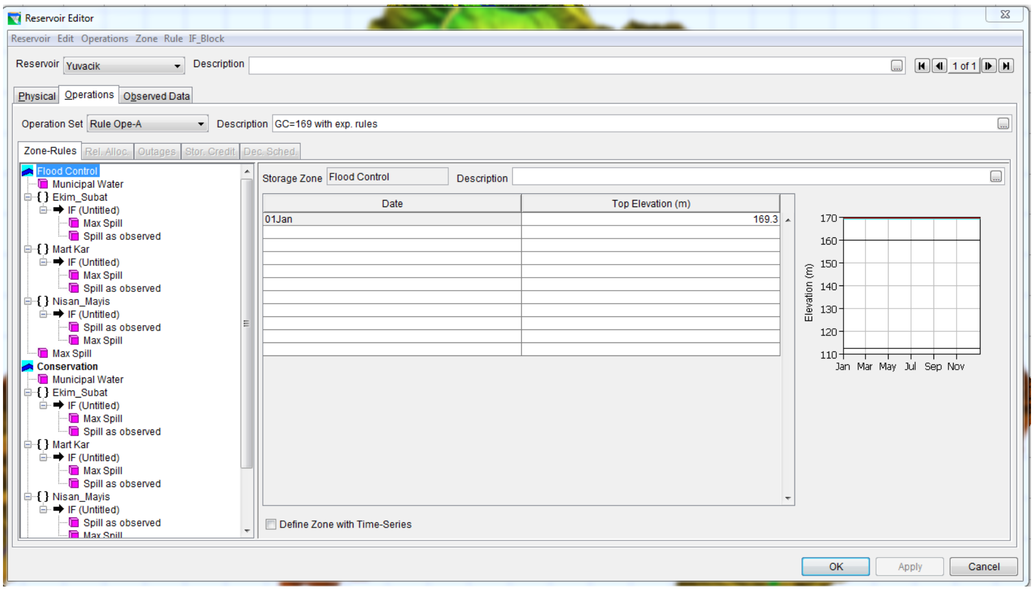
Figure 4.4 Watershed Setup Module in Yuvacık Basin and elements of the system

4.3.4. Reservoir Network Module

A reservoir network represents a collection of watershed elements connected by routing reaches and purpose is to isolate development of the reservoir model from the output analysis. This module provides user to create reservoir network elements. The physical and operational data that describe an operation plan or scheme upon which it can base its decision are provided into model using these elements.

An operation set (Figure 4.5) consists of three basic features: *Zones*, *Rules* and the identification of the *Guide Curve*. Decision logic of the program is related with zones, rules and guide curve.

- Zones are operational subdivisions of the Reservoir Pool. Each zone is defined by a curve describing the top of the zone.
- Rules represent the goal and constraints upon the releases.
- Guide Curve is the target elevation.



Reservoir: Yuvacik

Operation Set: Rule Ope-A — Description: GC=169 with exp. rules

- Flood Control
  - Municipal Water
  - { } Ekim_Subat
    - IF (Untitled)
      - Max Spill
      - Spill as observed
  - { } Mart Kar
    - IF (Untitled)
      - Max Spill
      - Spill as observed
  - { } Nisan_Mayis
    - IF (Untitled)
      - Spill as observed
      - Max Spill
  - Max Spill
- Conservation
  - Municipal Water
  - { } Ekim_Subat
    - IF (Untitled)
      - Max Spill
      - Spill as observed
  - { } Mart Kar
    - IF (Untitled)
      - Max Spill
      - Spill as observed
  - { } Nisan_Mayis
    - IF (Untitled)
      - Spill as observed
      - Max Spill

Storage Zone: Flood Control

Date	Top Elevation (m)
01Jan	169.3

☐ Define Zone with Time-Series

Figure 4.5 Operation set of ResSim

Decision Logic:

The basic decision logic for water storage or releases is based upon the Guide Curve that describes target elevation. Firstly, physical data including both lake and outlet works narrow the allowable range. Secondly; rules and IF-THEN-ELSE statements restricts this range (Figure 4.6). Finally; release or storage decisions are done with respect to guide curve regarding mutual rule restrictions (Figure 4.7).

Rules can also be classified as comprehensive release limits and only effective in times of accurate definitions. For instance; a rule can be defined as maximum release rule as a function of date and it provides to control channel capacity through the downstream channel.

The rule limit is only effective since the amount of water will be released within the guide curve range. On the other hand, ResSim provides “specified rule types” which eliminates Guide Curve and release the desired amount of water although the target elevation is not achieved. It should also be noted that; ordering of rules is important in terms of execution priority.

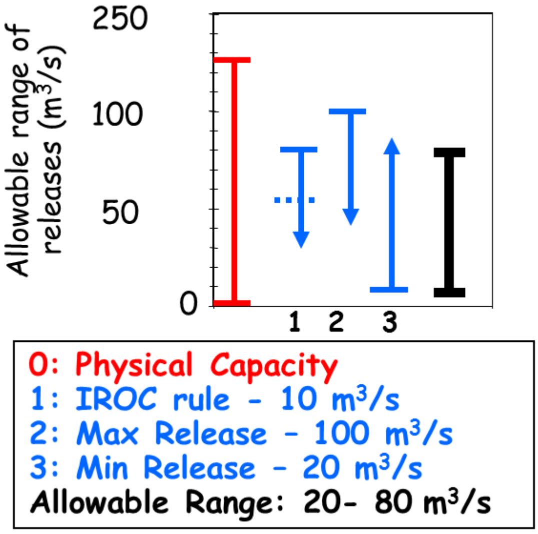


Figure 4.6 Allowable range (modified from Klipsch 2007)

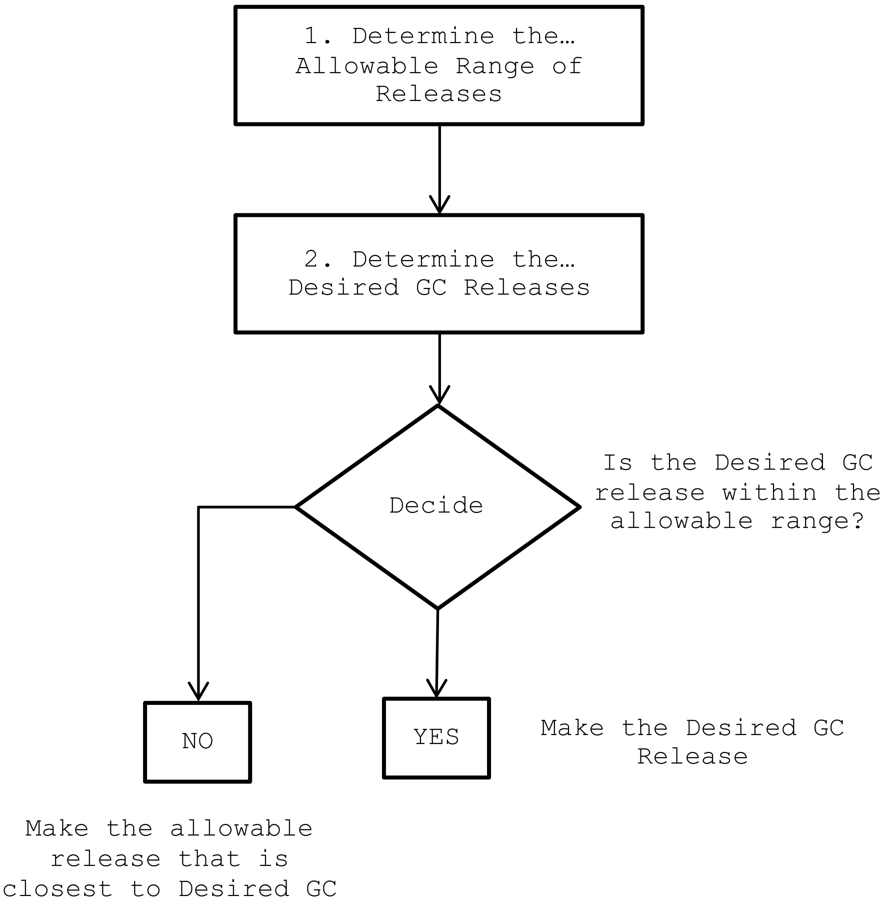


Figure 4.7 HEC-ResSim Basic decision logic (modified from Klipsch 2007)

Rule types can be different depending on where the rule is applied (pool, dam, or outlet). The rules that apply to “Reservoir Pool” are typically relevant to “Storage or Elevation”, whereas the rules that apply to “Dam or an Outlet” are relevant to “Flow” (HEC 2007b).

Rule types indicated in Quick Start Guide (HEC 2007b), are described briefly below.

Rules for the Reservoir Pool include the following:

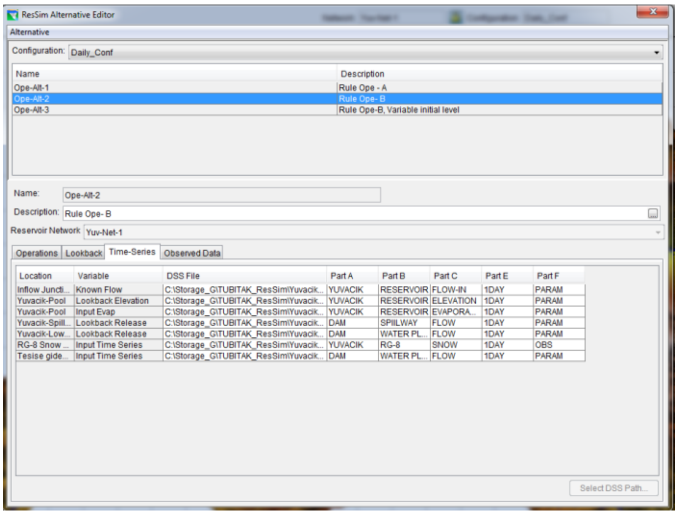
- ✓ *Release Function*: Maximum, Minimum or Specified Release as a function of Date, Date and Time, Model Variable, or External Variable.
- ✓ *Downstream Control Function*: Minimum or Maximum Flow or Stage target or constraint (at a downstream location) as a function of Date, Date and Time, Model variable, or External Variable.
- ✓ *Tandem Operation*: Release based on balancing pool with a downstream reservoir.
- ✓ *Induced Surcharge*: Special flood control operation using gate regulation parameters.
- ✓ *Flow Rate of Change Limit*: Allowable change when increasing or decreasing release values.
- ✓ *Elevation Rate of Change Limit*: Allowable change when increasing or decreasing pool elevation values.
- ✓ *Script*: User-defined scripting available that dramatically increases the flexibility of reservoir operations.

Rules for reservoir dam, controlled outlets, outlet groups, and diverted outlets include the following:

- ✓ *Release Function*: Maximum, Minimum or Specified Release as a function of Date, Date and Time, Model Variable, or External Variable.
- ✓ *Flow Rate of Change Limit*: Allowable change when increasing or decreasing release values.
- ✓ *Script*: User-defined scripting available that dramatically increases the flexibility of reservoir operations.

4.3.5. Alternatives

An alternative (Figure 4.8) is comprised of an operation set, lookback data that form the initial condition, time series data that include junction node flows, initial time series data, external variables, observed data and other time series as well. Simulation type (instantaneous or period average), simulation time step and several features are excluded within alternative in earlier version of the program. Each alternative can be chosen in advance and compared with each other in simulation module. Time series data can be defined as DSSVue (Visual Utility Engine) files.



Configuration: Daily_Conf

Name	Description
Ope-Alt-1	Rule Ope - A
Ope-Alt-2	Rule Ope- B
Ope-Alt-3	Rule Ope-B, Variable initial level

Name: Ope-Alt-2
Description: Rule Ope- B
Reservoir Network Yuv-Net-1

Location	Variable	DSS File	Part A	Part B	Part C	Part E	Part F
Inflow Juncti...	Known Flow	C:\Storage_G\TUBITAK_ResSim\Yuvacik...	YUVACIK	RESERVOIR	FLOW-IN	1DAY	PARAM
Yuvacik-Pool	Lookback Elevation	C:\Storage_G\TUBITAK_ResSim\Yuvacik...	YUVACIK	RESERVOIR	ELEVATION	1DAY	PARAM
Yuvacik-Pool	Input Evap	C:\Storage_G\TUBITAK_ResSim\Yuvacik...	YUVACIK	RESERVOIR	EVAPORA...	1DAY	PARAM
Yuvacik-Spill...	Lookback Release	C:\Storage_G\TUBITAK_ResSim\Yuvacik...	DAM	SPIILWAY	FLOW	1DAY	PARAM
Yuvacik-Low...	Lookback Release	C:\Storage_G\TUBITAK_ResSim\Yuvacik...	DAM	WATER PL...	FLOW	1DAY	PARAM
RG-8 Snow ...	Input Time Series	C:\Storage_G\TUBITAK_ResSim\Yuvacik...	YUVACIK	RG-8	SNOW	1DAY	OBS
Tesise gide...	Input Time Series	C:\Storage_G\TUBITAK_ResSim\Yuvacik...	DAM	WATER PL...	FLOW	1DAY	PARAM

Figure 4.8 Alternative editor

4.3.6. Simulation Module

Simulation module provides user to configure and create a simulation through existing reservoir network and user defined alternatives with specified time intervals (30 minutes, or 1 day etc.). Once reservoir model is complete and alternatives defined, Simulation Module is used to configure the simulation:

- ✓ Simulation time window,
- ✓ Computation interval,
- ✓ Alternatives to be analyzed.

5. SIMULATION DATA

Data is essential for all hydrological and simulation models in water resources studies. In this thesis, a simulation model is put into operation for varying conditions with respect to several approaches. Reservoir simulation model is developed for both long term and short term operations, therefore the data used in the model changes daily to hourly time steps.

The reservoir simulation data are basically divided into three categories; these are the reservoir physical data, daily operational data, and hourly data. The daily operational data is collected minute time based and converted to daily scale to be used in the model as long term decision variables. On the other hand; daily average temperature and daily total precipitation numerical weather prediction data are used to forecast a day ahead reservoir inflow forecasts.

5.1. Reservoir Physical Data

The terms reservoir/river system, reservoir operation, or river basin management "modeling system" are used synonymously to refer to computer modeling systems that simulate the storage, flow, and diversion of water in a system of reservoirs and river reaches (Wurbs 2005). Since the simulation is based on computational estimation of several variables for operational decisions, the physical data is essential for any reservoir simulation studies so that it provides to define initial ranges.

The main characteristic of Yuvacık Dam is summarized in Table 5.1 below.

Table 5.1 Basin, dam reservoir and facilities physical characteristics (modified from DSI 1983)

Dam/Reservoir Name	**Yuvacık Dam**
Basin	Marmara Basin
Rivers	Kirazdere, Kazandere, Serindere
Type	Earth filled
Purpose	Municipal and industrial water supply
Start of operation	18 January 1999
Drainage Area	258 km^2
Annual Mean Flow (Water Year)	184 hm^3
Annual Mean Precipitation (Water Year)	1038 mm/year
Effective Volume (at Max Operating Elevation)	51.12 hm^3
Max Storage Level	169.3 m
Min Storage Level	112.5 m
Max Storage Volume	55.95 hm^3
Min Storage Volume	4.83 hm^3
Number of Spillway Gates	4
Spillway Max Capacity	1560 m^3/s
Spillway Crest Level	159.95 m
Dam Crest Level	172.5 m
Sluiceway Capacity (at Max Water Level)	58 m^3/s
Sluice Outlet Level	66.5 m
Max Downstream Channel Capacity	100-200 m^3/s

It should be noted that volume behind the spillway (the storage between max operation and spillway crest levels) is equal to 14.51 hm^3; and maximum avaliable volume (the storage between max operation and inactive levels) is equal to 51.12 hm^3 (Table 5.2).

Table 5.2 Yuvacık Reservoir volumes and lake surface with respect to critic elevations

Definition	**Elevation**	**Volume (hm^3)**	**Surface (km^2)**
Min Operation	112.50	4.83	0.35
Spillway Crest	159.95	41.45	1.42
Max Operation	169.30	55.95	1.72
Max water	169.80	56.83	1.74

Reservoir modeling system can be a solution to develop decision support system if the real situation of the physical characteristics of the reservoir lake and the dam elements are well defined into the model. Therefore, first constraints for reservoir simulation are physical data that define lower and upper limits for operating rules.

In this part, physical data that form the first constraints and release capacity are explained. These are;

1. Physical data related to the reservoir
   a. Elevation – area – volume curve
   b. Reservoir lake evaporation
2. Physical data related to controlled outlets
   a. Spillway discharge curve
   b. Sluiceway discharge curve
   c. Water supply discharge curve
3. Downstream channel constraints

5.1.1. Physical data related to the reservoir

First of all, elevation – area – volume curve that relates storage capacity to elevation must be defined into reservoir system. By this means, water level readings can be converted to current water capacity and lake surface area. This curve was computed during dam design period in 1983, and further updated throughout the last bathymetry study in 2005. Old and new curves are quite similar to each other. The updated curve is presented below in Figure 5.1.

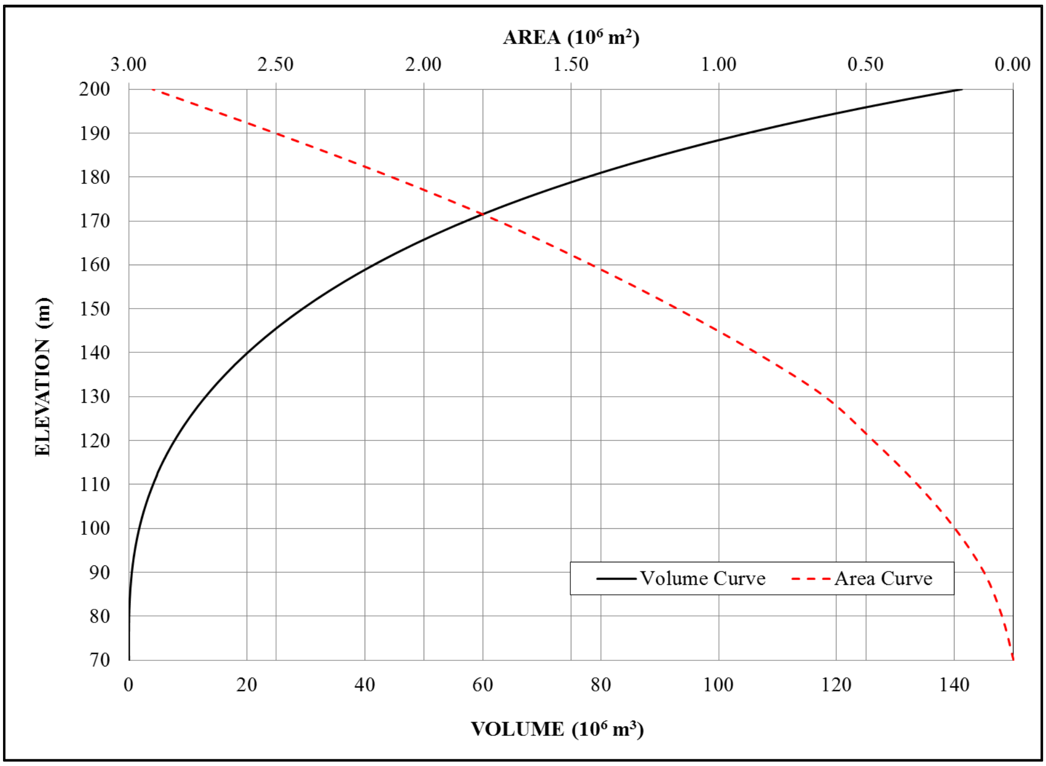


Figure 5.1 Elevation – volume – area curve of Yuvacik reservoir (Akifer 2005)

Possible losses in the reservoir lakes are generally considered as seepage and evaporation. The seepage assumed to be zero in the system. Evaporation is measured daily near spillway using an evaporation pan (Figure 5.2) and daily evaporation is calculated. The average values are calculated using the data belong to 2006 – 2011 and used in the simulation for this period (Table 5.3).

Figure 5.2 Evaporation pan

Table 5.3 Average evaporation values (2006 – 2011)

Months	Evaporation (mm/day)
January	0.63
February	0.86
March	1.38
April	1.71
May	2.82
June	3.86
July	4.11
August	3.73
September	2.51
October	1.29
November	1.03
December	0.61

5.1.2. Physical data related to spillway and outlet works

Reservoir releases to the river are made through spillways and outlet works. Spillways provide the capability to release high flow rates during major floods without damage to the dam and appurtenant structures. Spillways are required to allow flood inflows to safely flow over or through the dam, regardless of the reservoir contains flood control storage capacity. Spillways may be gated or uncontrolled. A controlled spillway is provided with crest gates or other facilities that allow the outflow rate to be adjusted.

There are four controlled radial gates (Figure 5.3) in Yuvacık Dam and maximum capacity of spillway is 1560 m^3/s in case of using all of them. Since, the spillway is operated by adjustable gates; discharge curve must be defined into model. The spillway discharge curve with respect to different gate openings for four gates is shown in Figure 5.4. Two middle gates and other two gates are used alternatively for each year to provide maximum life time to prevent cavitation of spillway flow canals.

(a) (b)

(c)

Figure 5.3 (a) Hydraulic vanes (b) Radial gate, (c) Spillway channel

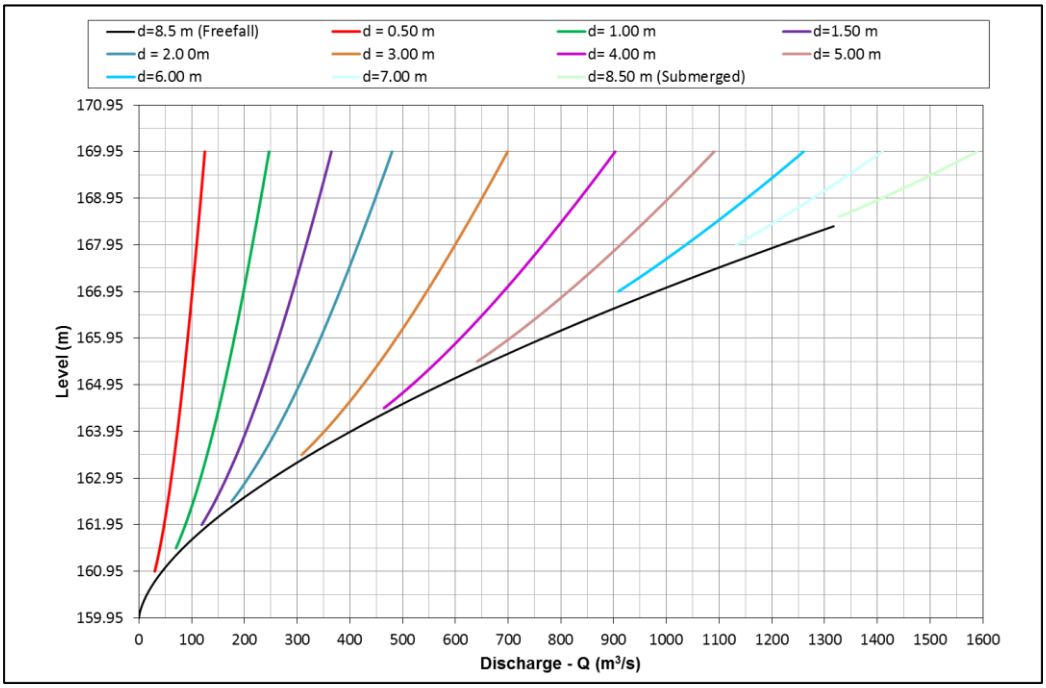


Figure 5.4 Spillway discharge curve for four gates with respect to different gate openings (DSI 1983)

The major portion of the storage volume in most reservoirs exists below the spillway crest. Flows over the spillway can occur only when the storage level is above the spillway crest. Outlet works are used for releases from storage both below and above the spillway crest. Discharge capacities for outlet works are typically much smaller than that for spillways.

Outlet works are used to release water for downstream water supply diversions, maintenance of instream flows, and other beneficial uses. Flood control releases may also be made through outlet works. An outlet works typically consists of an intake structure in the reservoir, one or more conduits or sluices through the dam, gates located either in the intake structure or conduits, and a stilling basin or other energy dissipation structure at the downstream end. Location of the spillway and outlet works are shown in Figure 5.5.

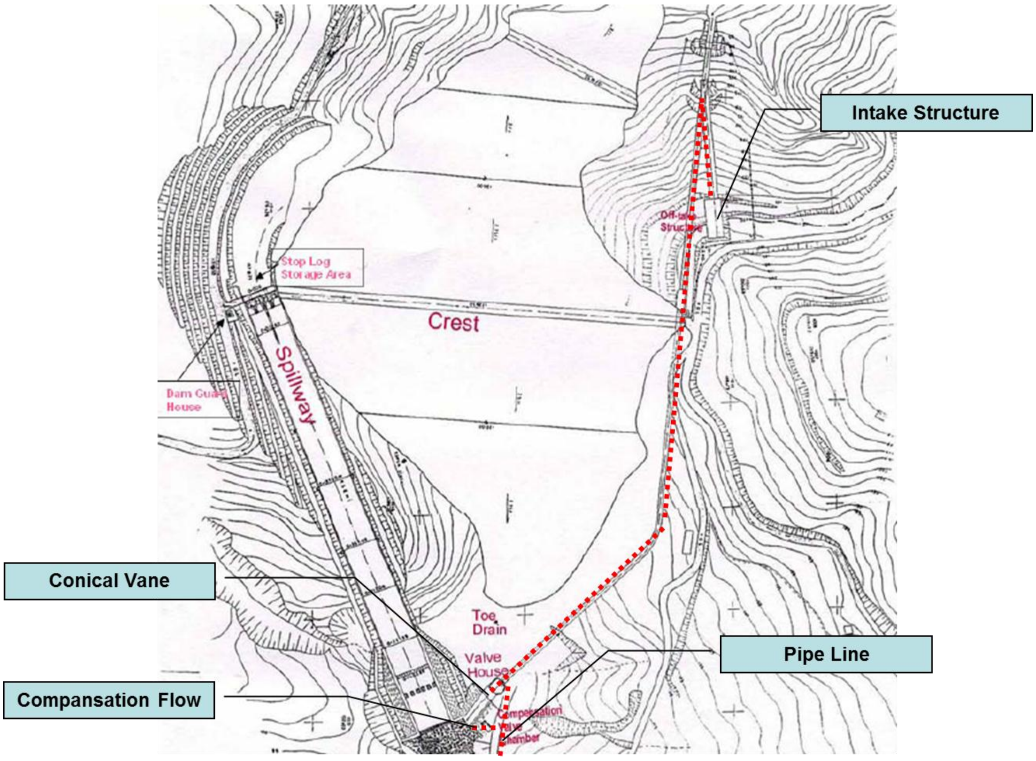


Figure 5.5 Location of spillway and outlet works (Thames Water 2001)

A concrete diversion tunnel with 5.00 m circular cross-section which was built during dam construction to prevent the site flooding is used afterwards as a water supply conduit and combined with intake structure. After dam body construction was completed, the derivation tunnel had completed its duty, and the ductile iron pipe with 2.00 m cross-section (pressure pipe line) had been located inside that tunnel.

The pressure pipe line is divided into two main pipes before water supply distribution. A Howell Bunger conical vane with 2.00 m circular cross-section was located to one pipe is used as a relief sluice for emergency cases. This vane has not being used during normal operation condition, but was used for tests several times. On the other hand, second pipe is further divided into two pipes also; one of them is 1.60 m circular pipe which was connected to Water Treatment Plant (WTP) for Kocaeli city water demand, the other is used to maintain downstream compensation flow (minimum 50 l/s and maximum 300 l/s recommended by Ministry of Agriculture) between June – October. The discharges of these pipes are controlled by online flow-meters without a need for rating curve. The organization of outlet works is simplified in Figure 5.6 below.

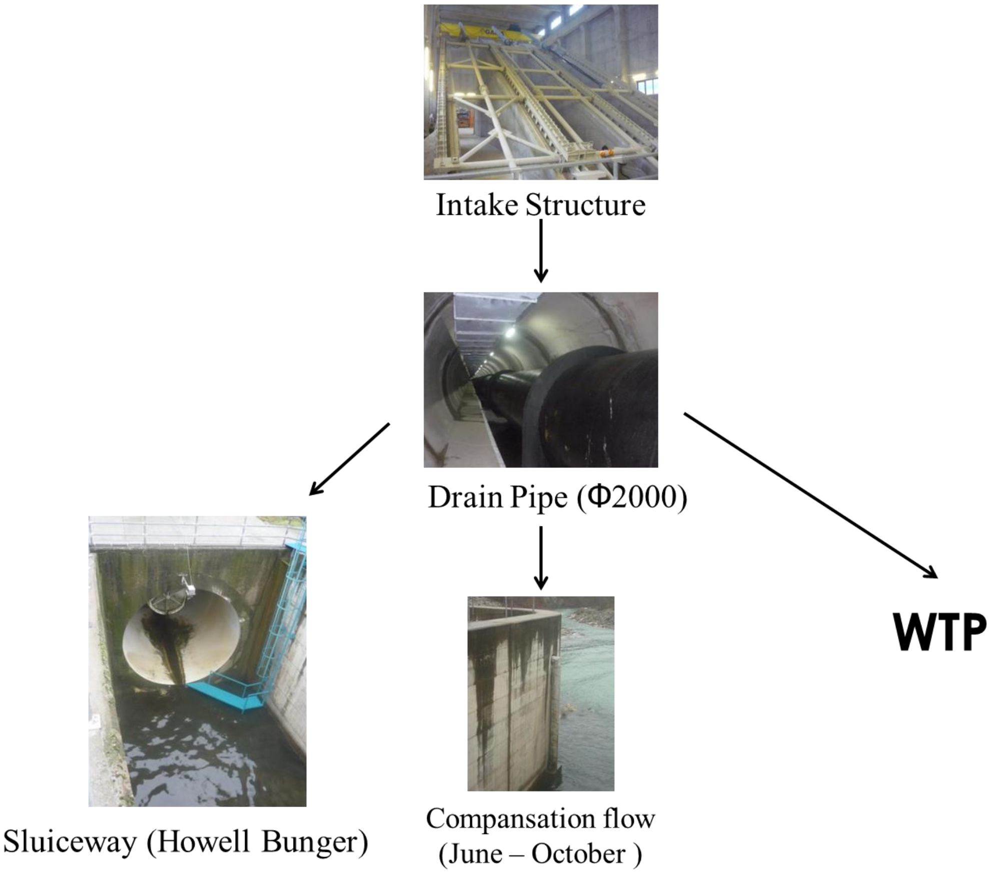


Figure 5.6 Organization of outlet works

5.2. Reservoir Operation Data

Reservoir operations are controlled using Dam Management System which is introduced in Chapter 3. The operation of the system is generally based on hydro-meteorological data that is collected in 5 minute time intervals using installed automated stations in and around the basin. The main inputs into the system (hereinafter; reservoir lake is defined as a system which receives several inputs and outputs) are observed inflow, reservoir elevation, evaporation, spillway releases, water consumption flow, compensation flow (Figure 5.7).

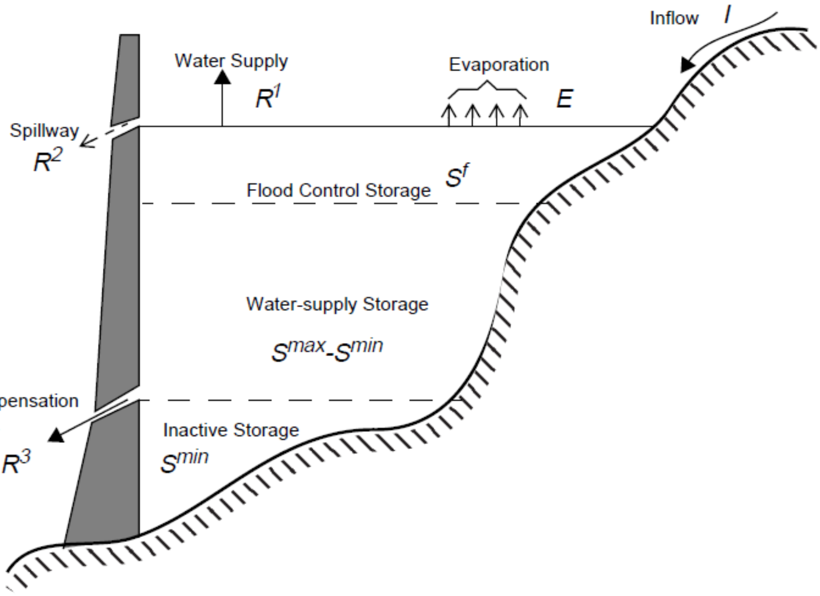


Figure 5.7 Reservoir system inputs and outputs

Simulation of the water resource system is based on water accounting procedures which are associated with conservation of mass. Since, for most reservoir/river system analysis applications, water is a constant density fluid, conservation of mass implies conservation of volume as well. In a general form, the mass balance or quantity equation for reservoirs can be formulated as:

$$S_t = S_{t-1} + I_t - R_t^1 - R_t^2 - R_t^3 - E \tag{5.1}$$

Where;

S_t is the reservoir storage at the end of time, t

S_{t-1} the reservoir storage at the end of previous time, t-1

I_t is the total volume of inflow into the reservoir at time, t

$R^1{}_t$ is the total volume of water supply flow at time, t

$R^2{}_t$ is the total volume of spillway release at time, t

$R^3{}_t$ is the total volume of compensation flow at time, t

E is the volume of evaporation at time, t

Dam reservoir elevation observations are the backbone of reservoir operation studies. Level readings are converted to inflow volumes into reservoir by means of storage-area-elevation curves. Real time operation of a reservoir can be achieved only with continuous reservoir level observation.

Thus, daily mean reservoir elevations are used in the long term simulation studies. Figure 5.8 represents reservoir elevations together with inflow and water consumption data in between 2007 – 2011 for Yuvacık Dam Reservoir.

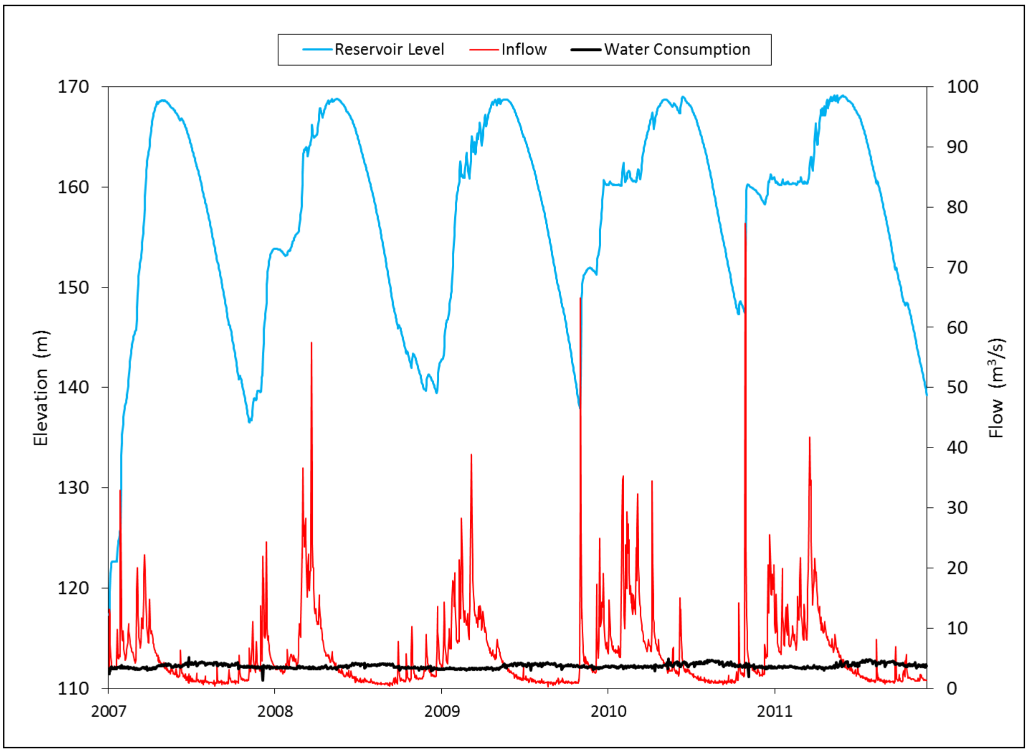


Figure 5.8 Reservoir elevation, inflow and water consumption in between 2007 – 2011

Inflow into a reservoir is one of the important indicators of storage decision. A change in inflows (increasing or decreasing) directly affects daily decisions. Reservoir inflow data are investigated while analyzing previous decisions. Inflow data belong to period 2007 – 2011 are shown in Figure 5.9. Statistical details are discussed for in next section.

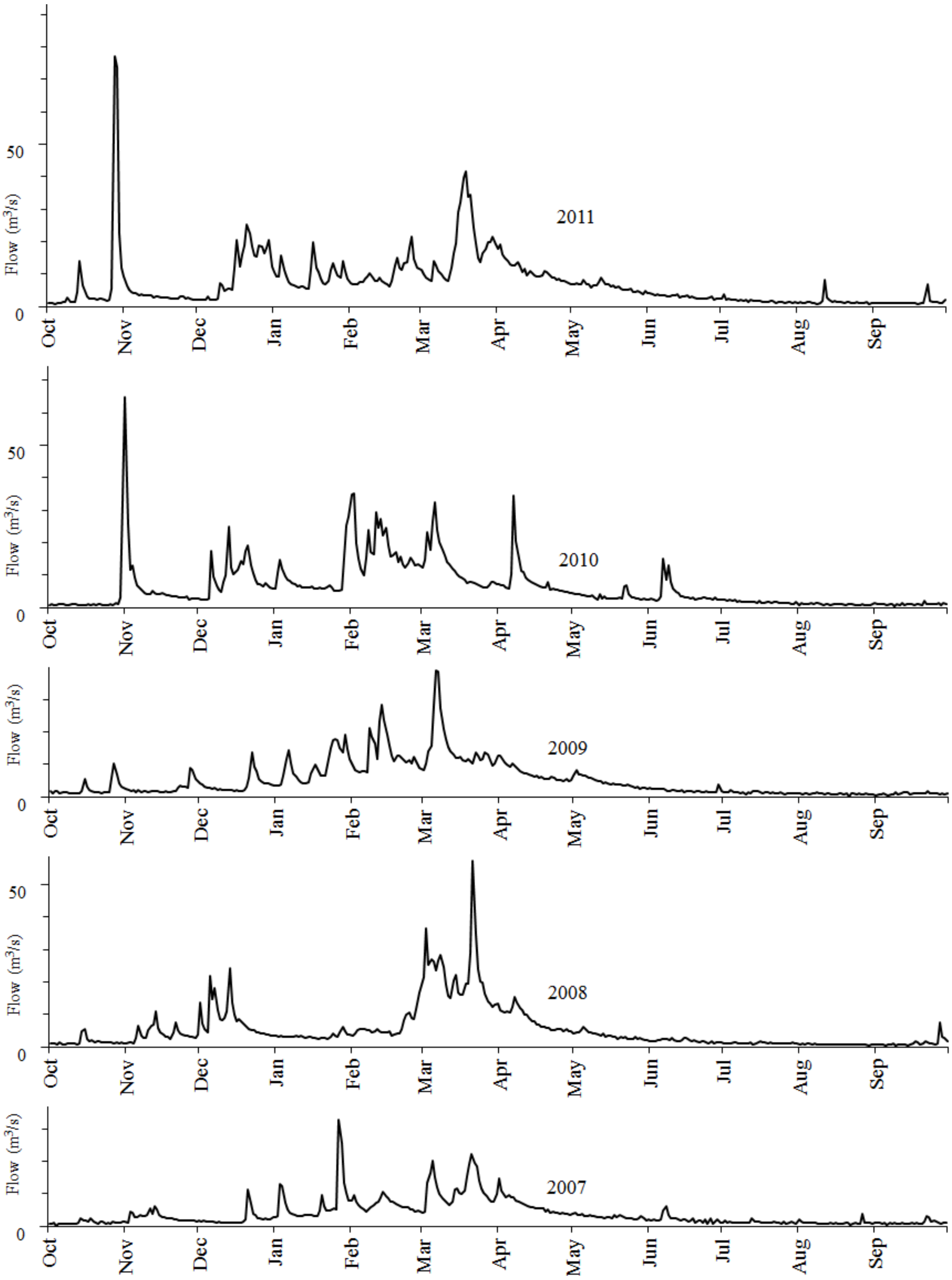


Figure 5.9 Inflow into the reservoir (2007 – 2011 water years)

5.3. Statistical Analyses

Statistical data provide decision makers to understand both previous hydrological conditions and also operator’s point of view through these conditions. Furthermore, new decision approaches can be developed in the light of previous year imperfections and experiences. First of all, pool elevation, flow and volume statistics are calculated according to previous operation data between the water years 2007 and 2011.

Lake elevation (also storage) of 2009, 2010 and 2011 years are higher compared to that of others (Figure 5.10) since a flood event occurred on fall period. From the maximum level and storages, it is understood that reservoir was operated at a full capacity in terms of long term management strategies and this corresponds to March – May months.

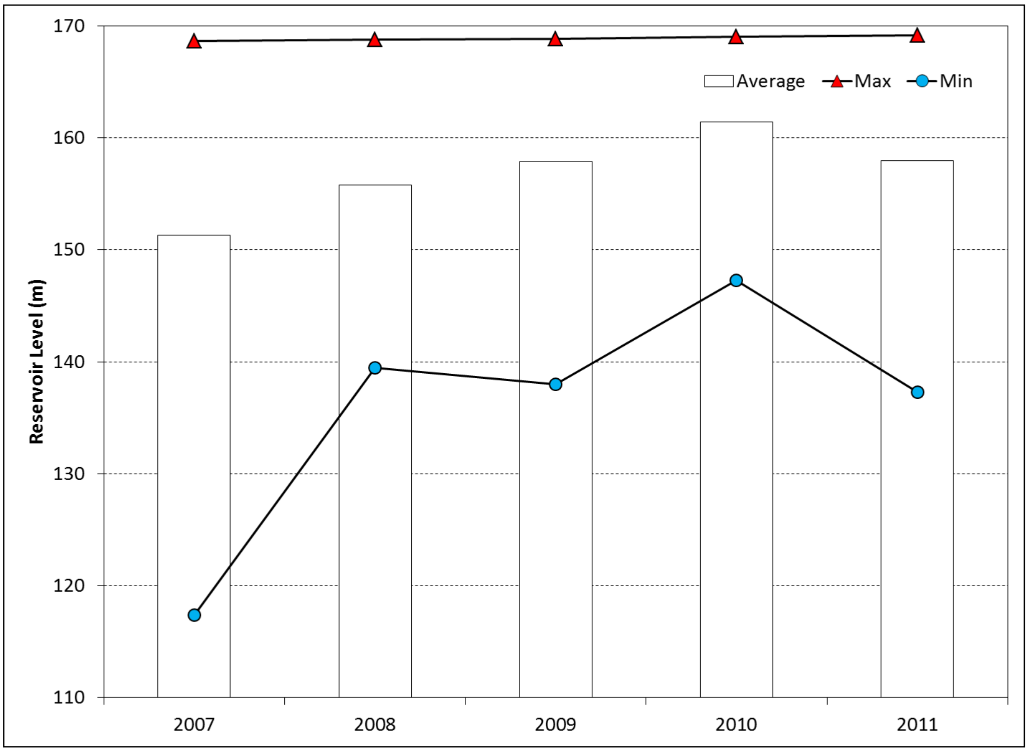


Figure 5.10 Reservoir elevation statistics with respect to 2007 – 2011 water years

Maximum values observed in inflow into reservoir, and their occurrence in terms of timing is very important in the sense of floods. Flood events can occur in a very short time period (daily or hourly) and these may take place when the reservoir lake level is high. For these situations, the updated discharge forecasts are needed. The average values of inflow into reservoir increase from 2009 to 2010 as can be seen in Figure 5.11. The main reason is the occurrence of fall floods which increase average and maximum values.

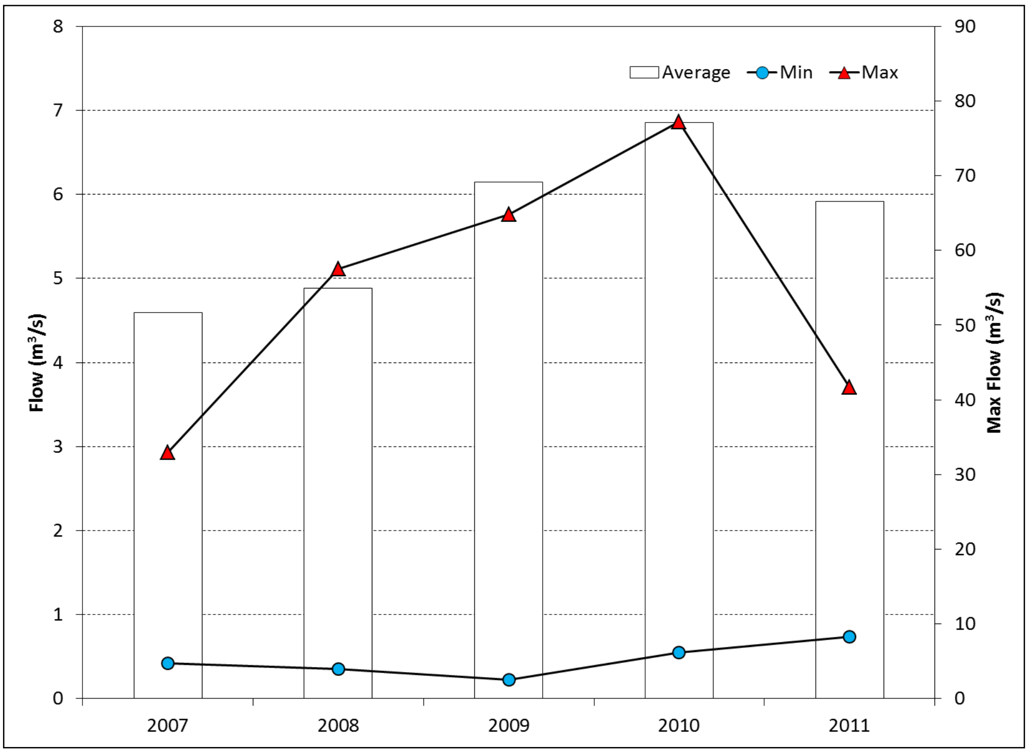


Figure 5.11 Total inflow into reservoir, statistics for 2007 – 2011 water years

Although reservoir inflows are evaluated on daily basis, annual total inflow into reservoir, and annual total release from the spillway and annual total water treatment plant assessments are crucial for the long term investigation. Hence, a graph is prepared and presented in Figure 5.12. Inflow into reservoir is approximately 150 – 180 hm^3 according to these analyses for the predetermined period. It is observed that there is no spillway flow in 2007. On the other hand, annual spilled amount of water is approximately 40 hm^3 according to this graph. The water treatment plant flow (demand) remains almost same throughout the water years.

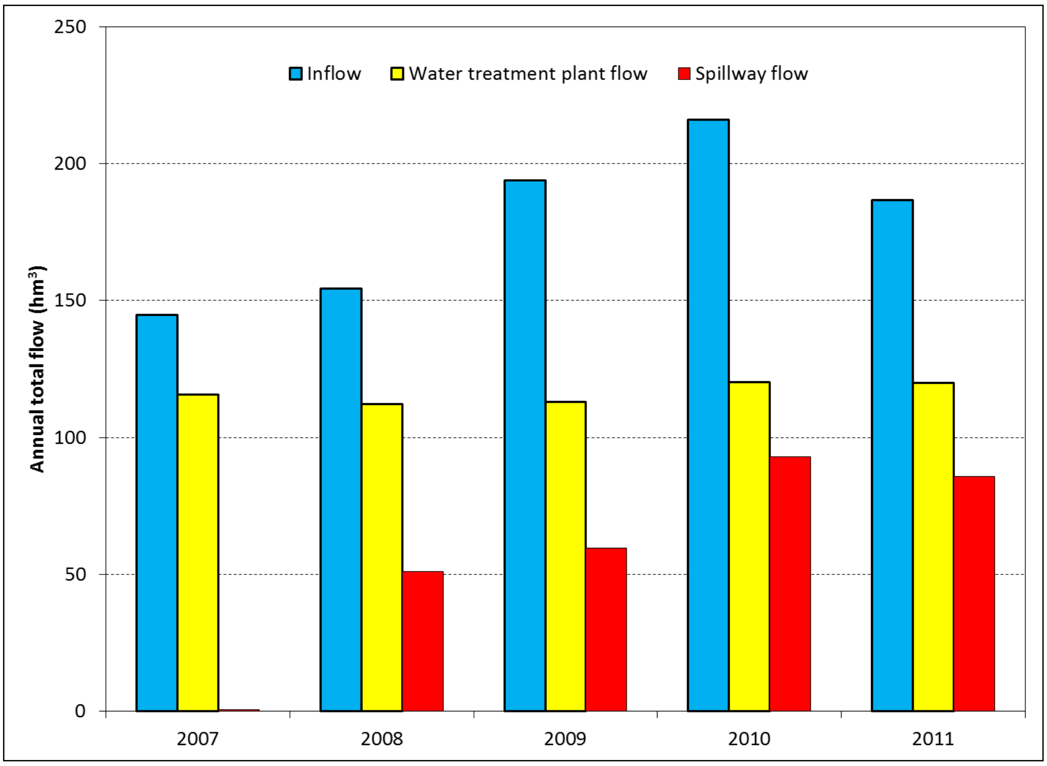


Figure 5.12 Annual total dam flow statistics with respect to 2007 – 2011 water years

5.4. Numerical Weather Prediction (MM5) Data

Meteorological variables are direct inputs to the hydrological models. The meteorological variables that are used in the application both temporally and spatially vary. Forecasting the current status of the weather few days ahead with the help of mathematical models of the atmosphere is called as Numerical Weather Prediction (NWP). Accuracy of hydrological flow forecasts directly depend on meteorological forecast data.

Turkish State Meteorological Service (TSMS) is the responsible governmental organization for providing weather forecasts both in quantitative and qualitative form. Since Turkey is one of the member state of the European Center for Medium-Range Weather Forecasts (ECMWF), forecast data received from ECMWF by TSMS are used as boundary conditions to Mesoscale Model 5 (MM5) modeling system developed by Pennsylvania State University/National Center for Atmospheric Research to generate finer resolution forecast products both temporally and spatially to the end users (Figure 5.13). Therefore; daily mean temperature and daily total precipitation MM5 data are used in hydrological model application that computes runoff forecasts.

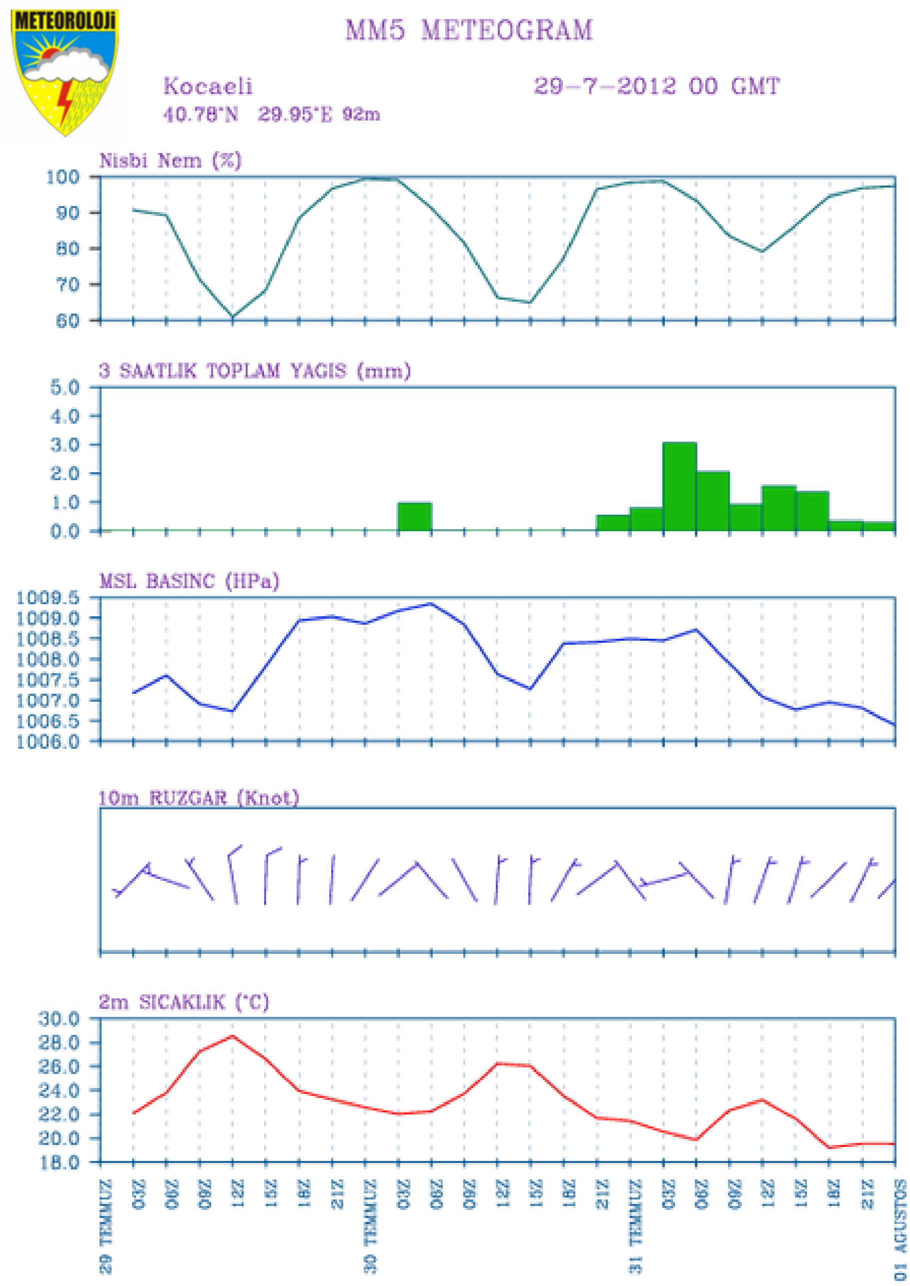


Figure 5.13 MM5 Meteogram for 29 July 2012 (http://www.mgm.gov.tr)

There are 54 MM5 pixels in and around the basin in gridded format with 4.5 km resolution. Precipitation values are distributed using Inverse Distance Weighting (IDW) which is the most widely used deterministic multivariate distribution method. IDW calculates unknown points with a weighted average of the values available at the known points. Figure 5.14 represents an example for daily total precipitation distribution of MM5 forecast over the whole catchment.

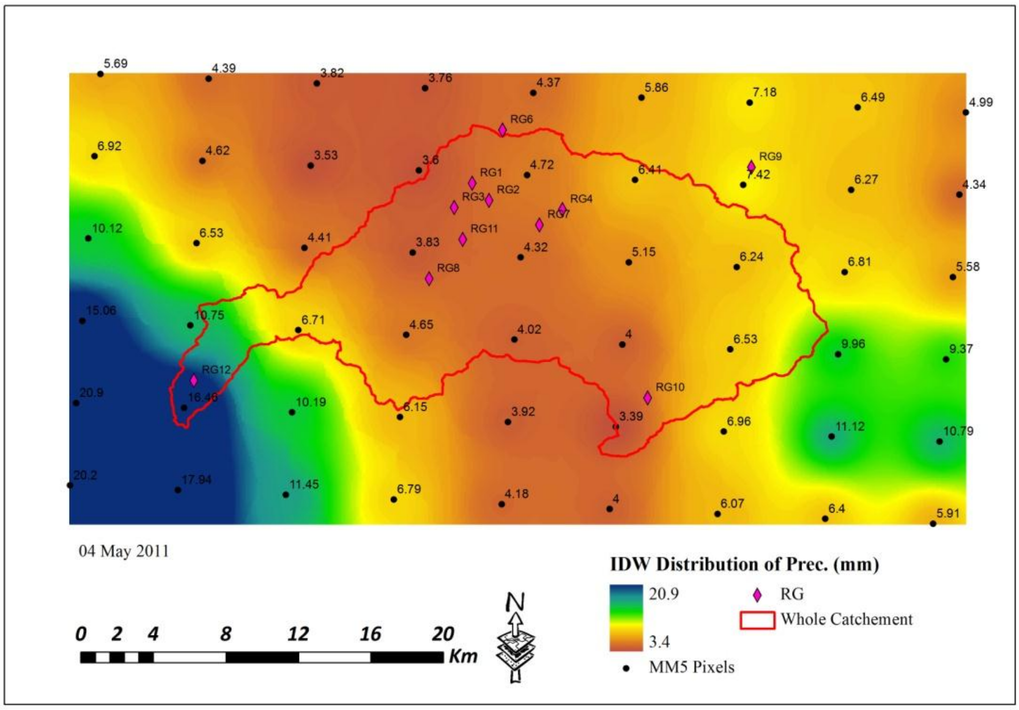


Figure 5.14 MM5 total precipitation distribution for 04 May 2011

Since DEM used for NWP data is coarse, actual topography can be different from MM5 elevation maps. Therefore; MM5 data is compared with ground observations to reduce biases due to topography before to be used in the model.

5.5. Flood Hydrographs and Hypothetic Inflow Data

Scenario based simulation modeling is a general approach for these kinds of reservoir simulation studies. Simulating and testing probable several possible events provide user to analyze and take precaution before real time event occurs. Although the initial conditions can easily be set at different levels, inflow data must be provided to the model as a time series.

Hypothetical event scenarios are generated either using scaled up version of observed data (details are provided in Section 6.3) or flood hydrographs for different return periods. Flood hydrographs for the basin are presented in Figure 5.15.

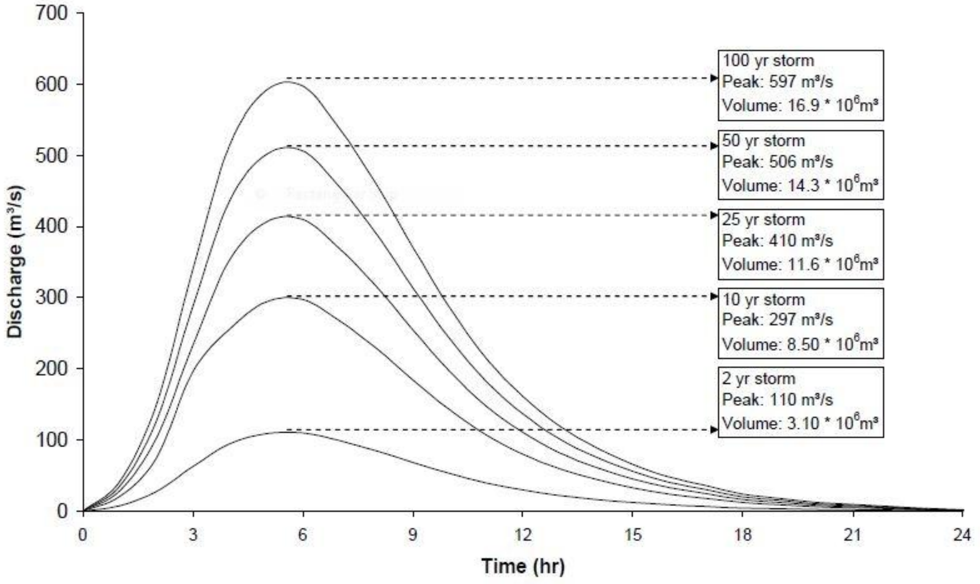


Figure 5.15 DSI hydrographs, peak flows and total volume (6-hrs storm) (DSI 1983)

5.6. Runoff Forecasting using HEC-HMS Hydrological Modeling

HEC-HMS (Hydrologic Modeling System) (HEC, 2008) hydrological modeling program that is developed by USACE (U.S. Army Corps of Engineers Hydrologic Engineering Center) is used for runoff forecasting. It is designed to simulate the precipitation-runoff process of dendritic watershed systems and applicable to a wide range of geographic areas for solving a broad range of problems.

Yavuz et al. (2012a, 2012b) calibrated and validated the model parameters (initial range, initial discharge and etc.) for various rainfall and snowmelt events. Daily inflows are forecasted using calibrated and validated model parameters with MM5 data for 2012 and a part of the forecast results are presented in Figure 5.16 Details are presented in the master of science thesis by Yavuz (in preparation, 2012). The results from flow forecast are directly used through improved simulation system, so this will be a guide for the operator’s decisions. The process can be automated, yielding a valuable tool for reservoir management. Since there is no observation which induces flood risk during 2007 – 2012 water years, several scenarios including flood hydrographs and observations are used in short term operational studies (Section 6.3).

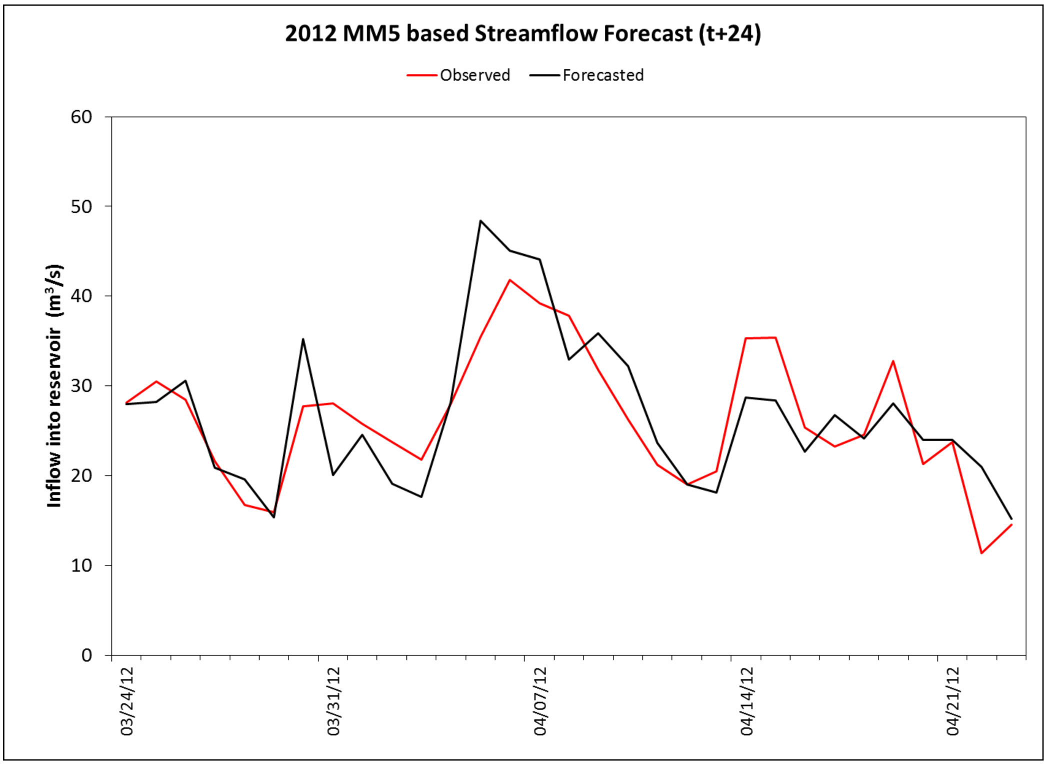


Figure 5.16 Runoff forecast for March and April of 2012 (Yavuz 2012a)

6. DEVELOPMENT OF A DECISION SUPPORT SYSTEM

The planning studies for Yuvacık Dam Reservoir were initiated in 1983 by State Hydraulic Works (DSI 1983) and the reservoir, built by Build-Operate-and-Transfer (BOT) agreement, has been operating since 1999 by a private company.

Since most of the dam reservoirs are operated by DSI, operation of a reservoir by a private company is one of the pioneer applications in Turkey. At the beginning, the private company had taken a consultancy on the reservoir operation policy. Consultant university prepared a final report (New Castle 2001) and a dam manual (Thames Water 2001) in which they developed strategies as; "Long term control strategies for water supply", "Long term control strategies for flood control" and "Short term control strategies for flood control." These strategies depend mainly on the limited data used in the planning report of DSI and studies are done with several methods. In long term control strategies reports, they computed and suggested Operating Rule Curves (ORCs) for water supply and monthly Flood Control Levels (FCLs) for flood protection. From these reports, it is obvious that there is a conflict between ORCs and FCLs. In other words, the water supply strategy avoids using FCLs in the long term operation. On the other hand, FCLs recommend upper storage levels to attenuate different probable flood events. It is significant that the reports highlight the importance of real time runoff forecasting for the effective management of the reservoir.

Even though these strategies helped managers to take decisions and actions for the operation of the reservoir, they were looking for new opportunities using a decision support system including runoff forecasting. Moreover, a relatively drought period occurred in 2006 had a great impact on the vision of operators and operational decisions.

Although, operators take decisions by considering several parameters and use spreadsheet programs (Excel etc.) for several scenarios; there is no easy, objective, effective and robust technique or decision support tool for reservoir operation. The importance of operation is brought to agenda especially during snow melting period (February – March) and flood risk months (April – June).

Daily decisions are taken to define the amount of water stored and released depending on current conditions. However, decisions should be taken in hourly basis during a serious flood event. Regarding to these circumstances, operation of Yuvacık Dam Reservoir is evaluated; simulations are done for two basic time scales. These are "*Long Term Operation*" for daily decisions and "*Short Term Operation*" for hourly decisions. Flow diagram in Figure 6.1 describes the priority and decision mechanism for both long term and short term approaches.

To that end; 2007 to 2011 years data are taken as main input and reservoir simulations are done for long term operations. Firstly, recommended curves (ORCs and FCLs) are assessed through simulations. Moreover, three approaches are developed and tested, and then several scenarios (hypothetical data and flood peak hydrographs) are tested in short term studies.

First of all; observed inflow into the reservoir, reservoir storage (in terms of lake elevation) and spillway discharges are evaluated for the years 2007 – 2011. On the other hand, water years are classified as drought/wet years according to climate conditions. Mean precipitation of the basin and total volume of inflow into the reservoir are the main criteria for this classification. Regarding to these criteria, 2007 and 2011 water years are classified as drought and wet years, respectively. 2010 water year is a relatively wet year whereas 2008 and 2009 water years are classified as average years.

Effective management of Yuvacık Dam Reservoir directly related with accurate operation of water stored behind the radial gates. Reservoir volume is approximately 51.2 hm^3, which is 3-4 times less than the approximate annual inflow volume of 180 hm^3. This situation causes the spill of excess water through the downstream channel. Figure 6.2 illustrates operational elevations which are directly used in the reservoir simulation modeling.

A target lake elevation or a seasonally variable guide curve is used to take decisions during reservoir operation simulations. A guide curve is a unique curve for a reservoir and it is associated with the upper part of a conservation zone. Therefore, by this curve, water is stored in a conservation zone while flood control zone controls excess water by supplying storage volume.

Identifying a unique guide curve is not applicable for Yuvacık Reservoir due to its relatively small capacity and constraint downstream channel. Providing an annual need of water (142 hm^3) for the long-term policy does not allow a freeboard volume for flood attenuation and permanent retention especially during spring and summer months. Therefore, flood control levels that normally would have been considered as guide curves conflict with long term water supply target. So, the main issue is to determine a guide curve to control releases.

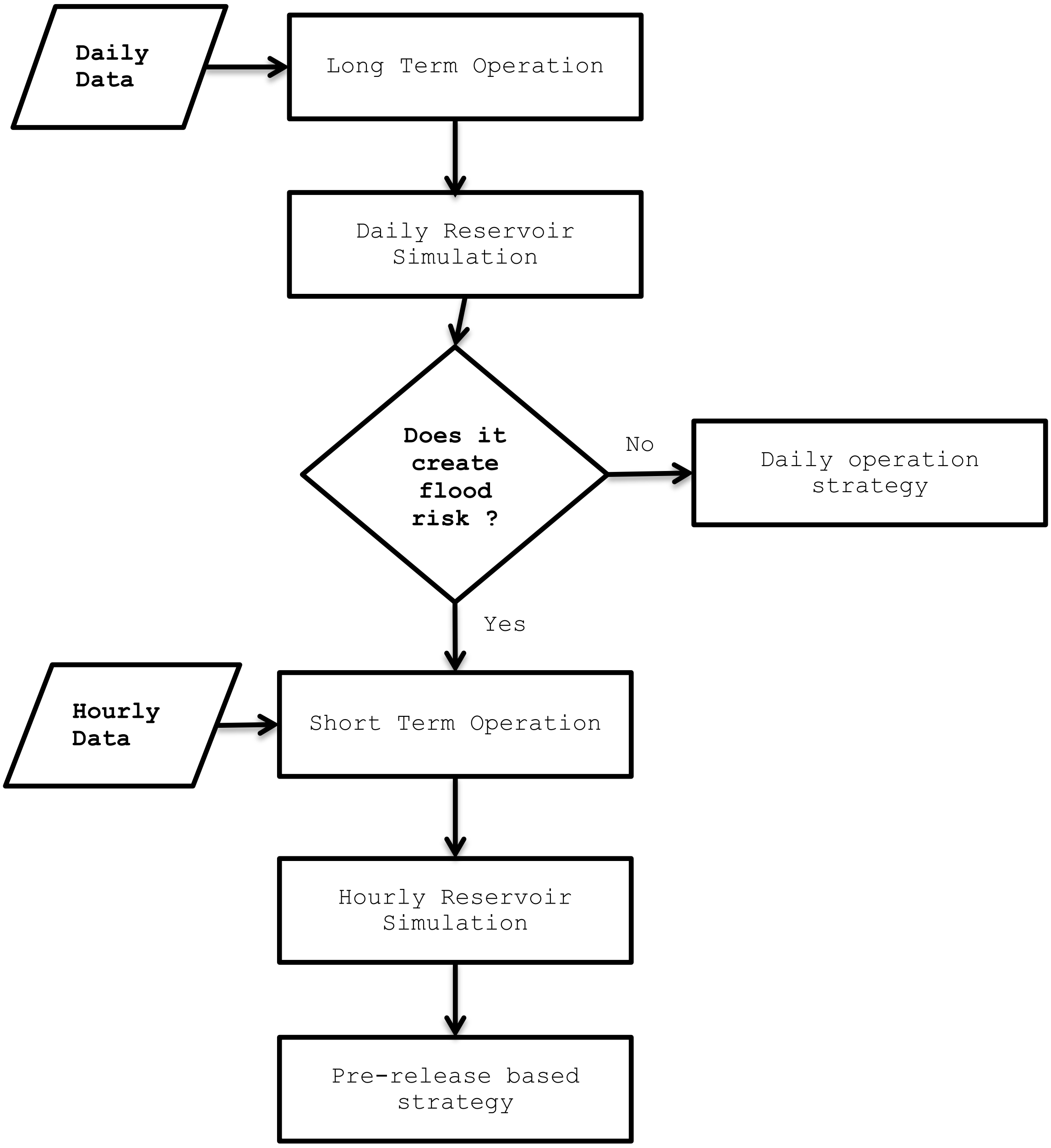


Figure 6.1 Flow diagram of operational strategy

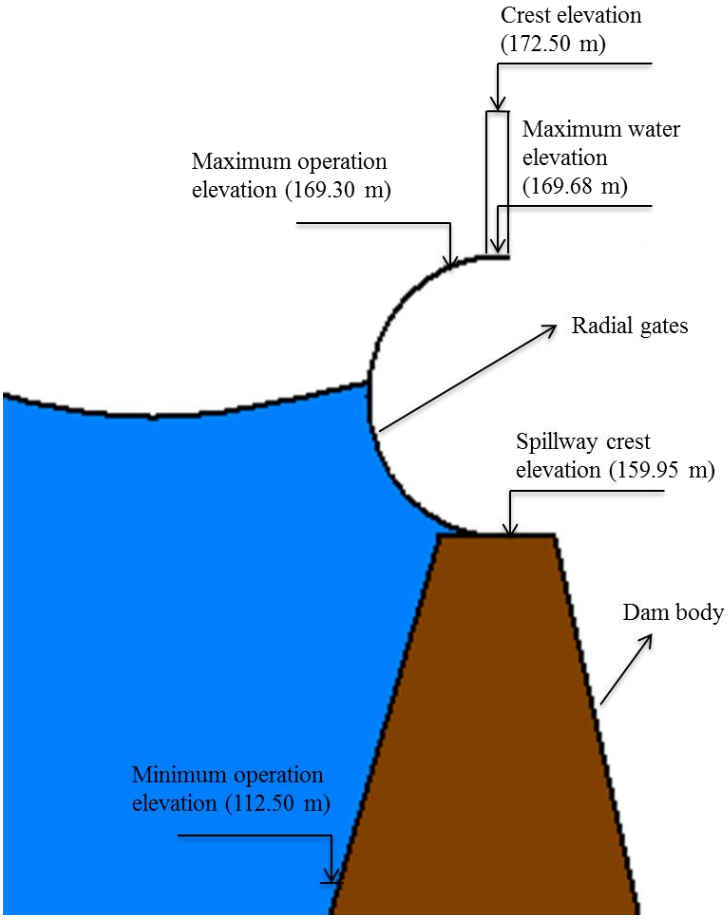


Figure 6.2 Critical elevations for reservoir operation

6.1. Assessment of Current Operation Rules and Strategies

After construction of the dam, operational curves and rules for different purposes are developed by New Castle University (2001) to be used for reservoir operation. These are grouped under three headings as “Long Term Control Strategies for Water Supply”, “Long Term Control Strategies for Flood Regulations” and finally “Short Term Control for Flood Regulations”. Long term strategies are applicable for reservoir simulations with further discussions on the conflict between water supply and flood control levels. This situation even validates urgent need for the development of a decision support system for real time operation.

Hence, the main purpose in this section is to investigate the applicability and usefulness of these strategies and curves for real time operation with HEC-ResSim model.

6.1.1. Assessment of Long Term Control Strategies for Water Supply

The main objective for this part is to investigate the usage of “Operating Rule Curves” (ORCs) (Figure 6.3) as introduced in New Castle (2001). The curves were calculated using the stochastic dynamic programming (SDP) methodology taking the variability of reservoir inflows into account (New Castle 2001).

The upper rule curve implies that excess water above this level should be released from the reservoir. If the reservoir storage drops below the middle rule curve, a reduction for water supply is expected to meet most of the demand in the remaining part of the water year.

Since it is desired to operate the reservoir without any flood risk and water shortage, it is clear that although Upper Level is reliable for water shortage it is not suitable for the flood control. Since this curve does not point out any release rule, this strategy increases serious hazard risks.

Considering the sustainability of water supply, these curves are used to define drought zones in practice. In Drought Management Plan (2005) prepared by national, local authorities and the company, these curves are used to determine alarm levels (Figure 6.4). On the basis of these three curves; reservoir is divided into five seasonally variable alarm levels according to different level of alerts. The operating level can be checked for drought conditions, and water level is reported to KGM for any precaution.

As a result of this part, Long Term Control Strategies for Water Supply curves are classified as not useful for simulation and real time operation directly.

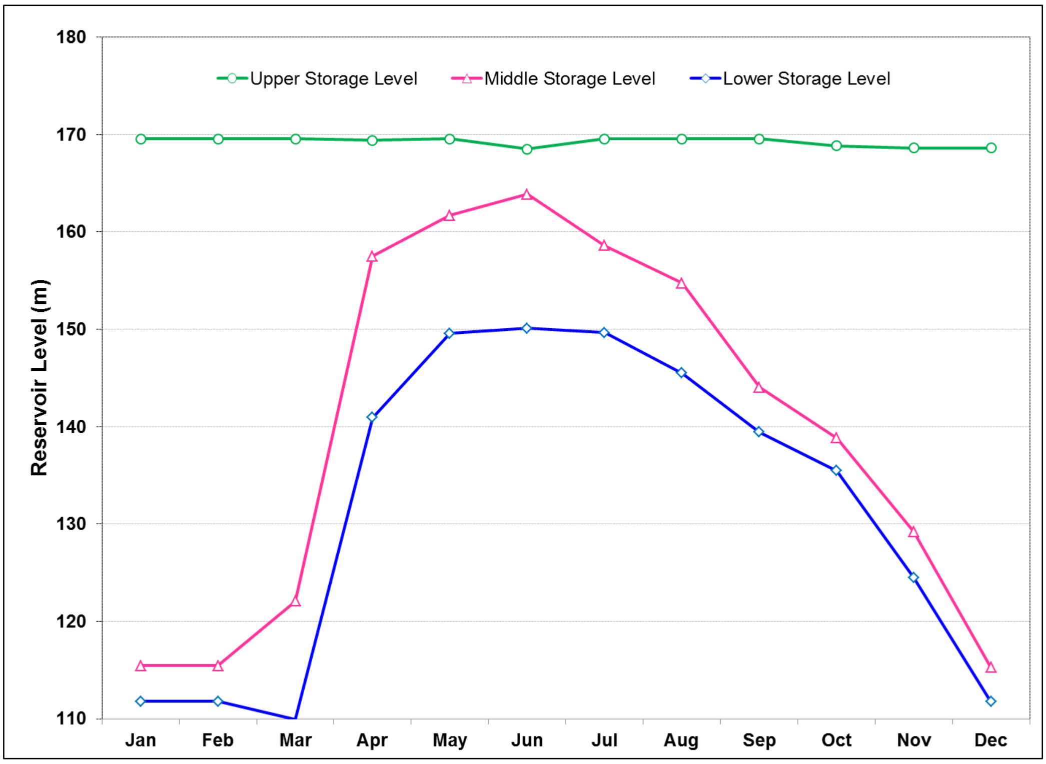


Figure 6.3 Operating rule curves based on long term water supply strategies (New Castle 2001)

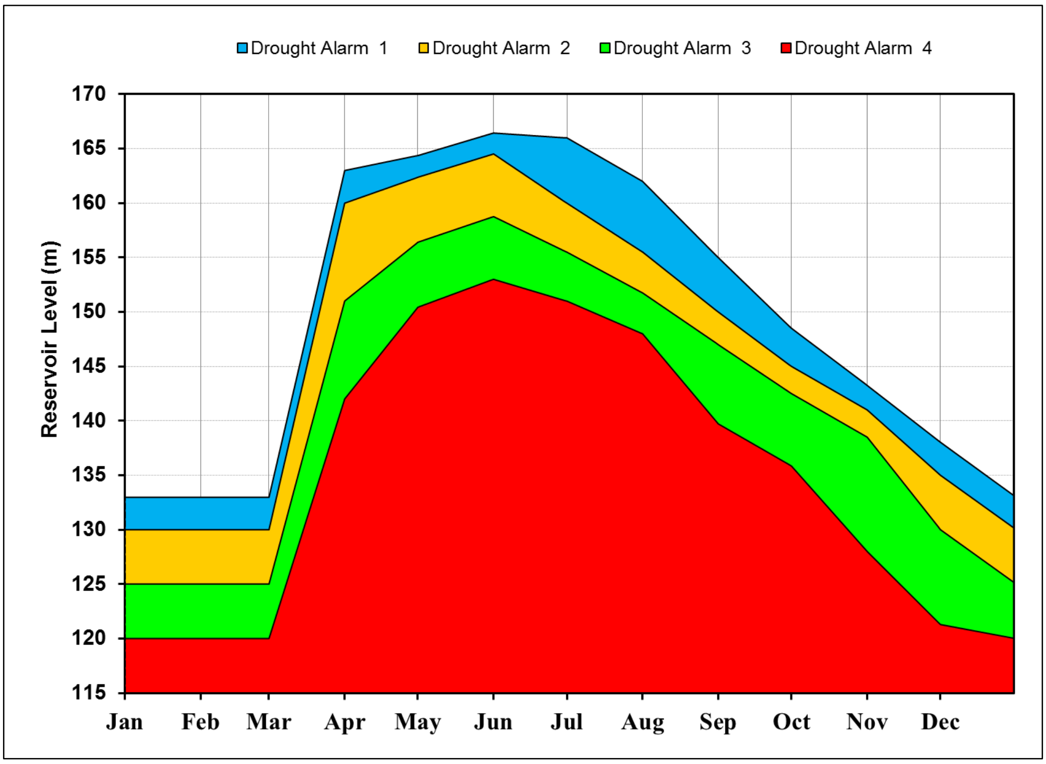


Figure 6.4 Drought alarm levels (Drought Management Plan 2005)

Descriptions of the levels in the Drought Management Plan are as follows:

- Alarm level 1 : Drought watch

State: Water demand is satisfied, but there is a risk of drought.

- Alarm level 2 : Drought warning

State: Planned water consumption will not be satisfied.

- Alarm level 3 : Declaration of drought

State: Storage capacity is under current need.

- Alarm level 4 : Emergency drought situation

State: Storage capacity is in minimum and water consumption is not being satisfied.

- Alarm level 5: Full drought situation

State: This level is fictitious since it is full drought situation. Water resources are out of order, and water consumption is never being satisfied.

6.1.2. Assessment of Long Term Control Strategies for Flood Control

The main objective for this part is to investigate the usage of “Flood Control Levels (FCLs) (Table 6.1) as guide curves.

The methodology of the development of the flood-regulation policy involves two stages (New Castle 2001):

- ✓ Flood frequency analysis and
- ✓ Reservoir routing of the design flood hydrograph to determine the outflow from the reservoir

Therefore; the design flood hydrographs of various return periods in all seasons of the year were routed through the reservoir. For each initial storage level, the operation is optimized by means of dynamic programming so as to minimize the maximum outflow subjecting to the constraints that the maximum storage level does not exceed the elevation of 169.3 m (Newcastle 2001).

Table 6.1 Flood control levels (FCL) according to different probable flood peaks (New Castle 2001)

Month	Q_{100} Level	Q_{250} Level	Q_{500} Level
1	168.00	168.00	167.56
2	168.00	168.00	167.56
3	168.00	168.00	167.56
4	167.50	165.70	163.40
5	168.00	168.00	167.56
6	166.70	165.00	162.50
7	168.00	168.00	167.56
8	168.00	168.00	167.56
9	168.00	168.00	167.56
10	166.70	165.00	162.50
11	166.70	165.00	162.50
12	166.70	165.00	162.50

In HEC-ResSim model, “Rules” express user oriented water release limits and they are either a function of time or any other variable. One rule or rule set may be applied into any operation zone(s) and its priority may vary. It is essential to add two basic rules into the simulation model.

Rule 1 – Water allocation for city requirement (Water supply rule)

In all cases, the specific amount of water should be withdrawn from the reservoir to the treatment plant. This rule is applied into all zones except inactive (112.5 m), level indicating the amount of water supplied.

Rule 2 – Maximum amount of spillway release

Maximum spillway release limit is set to 100 m^3/s considering downstream conditions.

Finally, applicability of a flood control level (FCL) as a guide curve is analyzed using ResSim and the results are discussed below. Since there is no certainty about the possible future flood, the first problem is to decide which level (Q_{100}, Q_{250} and Q_{500}) should be taken as a guide curve. In this section, Q_{100} and Q_{500} FCL levels are used as conservation level (guide curve) using HEC-ResSim. Application results are compared with observed levels and spillway releases.

Simulated and observed levels are nearly close to each other in early April 2007 according to the results (Figure 6.5). The initial level was low due to previous year conditions and all the inflows were stored without any spillway discharge, thus reservoir was replenished for the whole year. It is observed that both levels (simulated and observed) falls down 1st, 2nd and 3rd alarm levels, but simulation level is 1 m lower than observed one in these months due to slightly higher spillway release during April. High inflow event occurred on October prevents the decrease of the level and provides storage for both operations.

Spillway discharges in simulations are quite similar to that of operation when Q_{100} FCL is used for the years 2008 and 2009 (Figures 6.6 and 6.7). Storage levels are different than each other in March. FCL simulation is acting in the sense of storage in March which causes instantaneous decrease in April by releasing relatively high flows for the year 2008. However, it should be noted for both of them that only one day release in June leads a difference in water levels for further periods indicating the importance of timing and amount of release in operation. Simulation levels reach to 2nd Alarm level contrary to observations. On the other hand, levels decrease to 1st, 2nd and 3rd Alarm levels respectively for the year 2009.

FCL operation provides early storage which is greatly different than the observed one and this early storage is observed till mid-April causing extended period of flood risk. The releases are continuous for the simulations and discrete for the observations concerning stepwise release strategy.

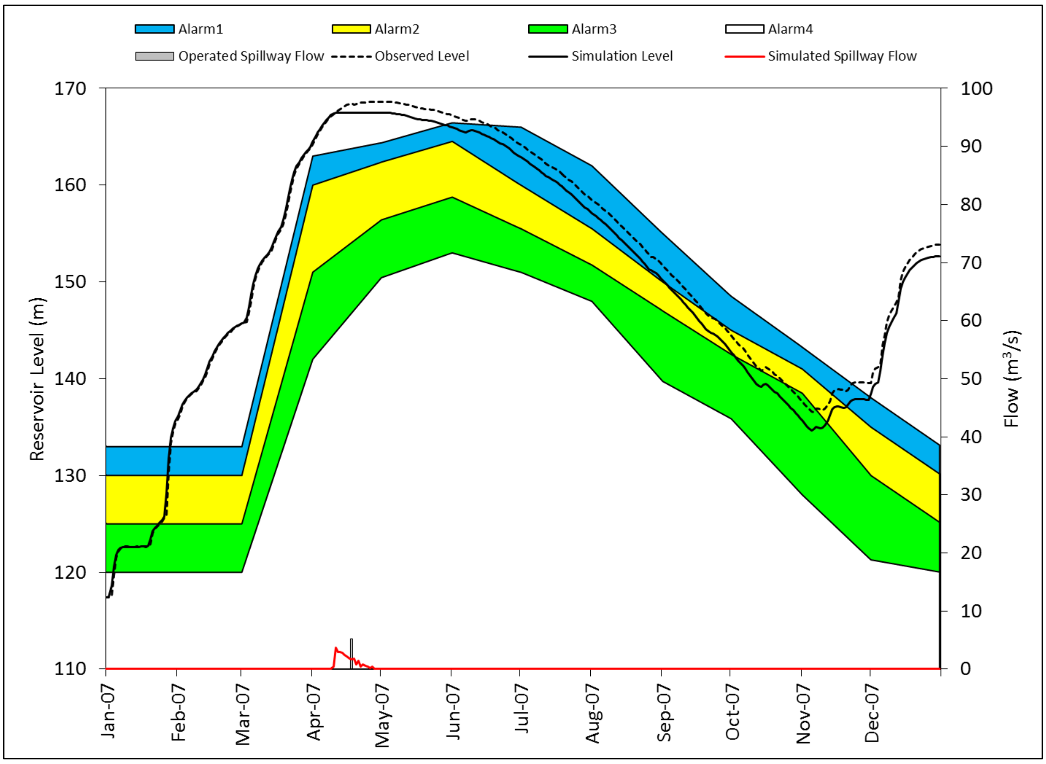


Figure 6.5 Reservoir simulation according to Q_{100} FCL (2007)

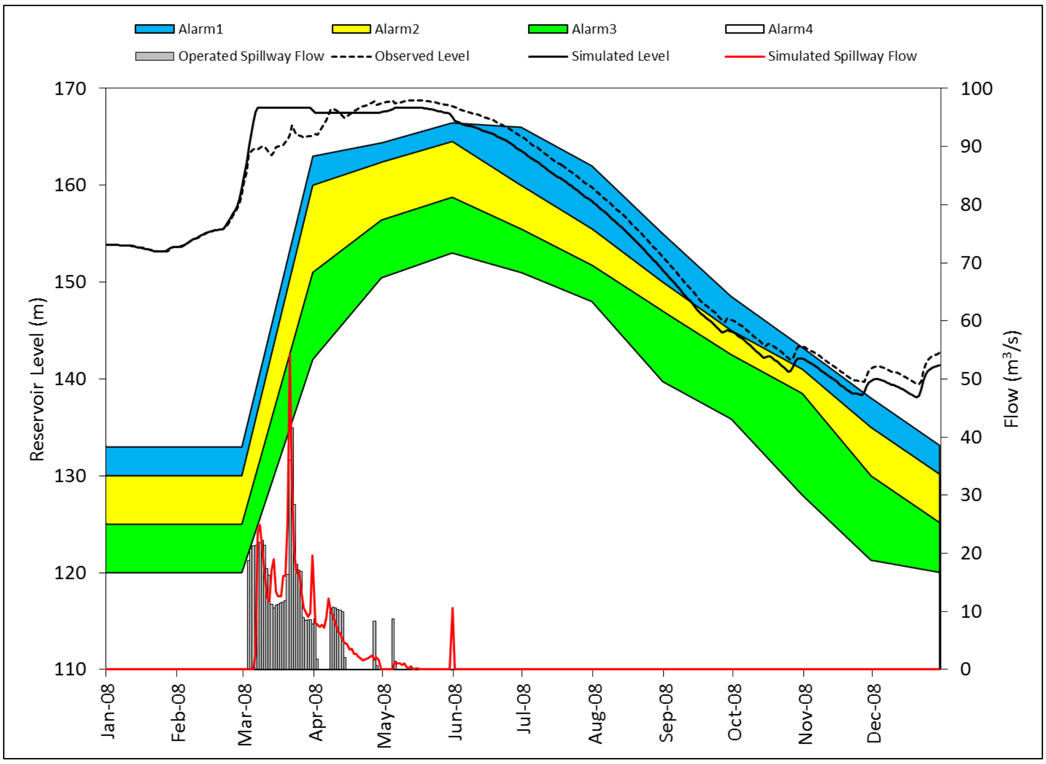


Figure 6.6 Reservoir simulation according to Q_{100} FCL (2008)

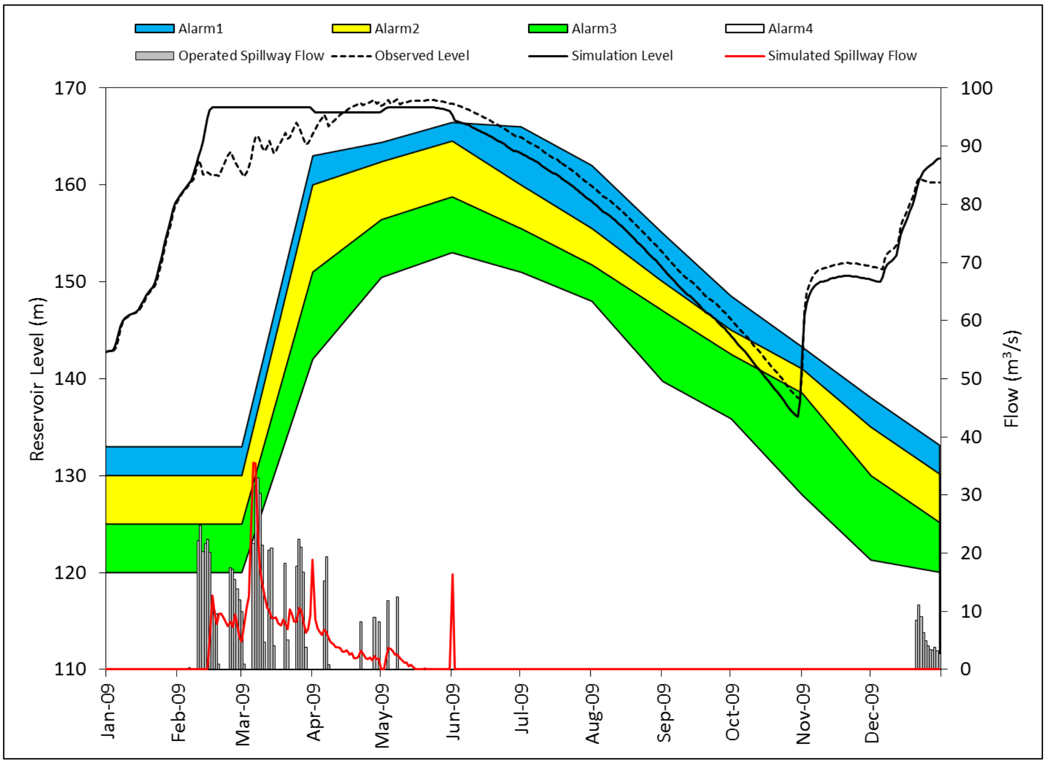


Figure 6.7 Reservoir simulation according to Q_{100} FCL (2009)

It is interesting that high inflow events were observed at the end of October for both 2010 and 2011 water years (Figures 6.8 and 6.9). Both years are wet years and reservoir reaches its maximum level almost at the end of January. This situation caused water release even in January. Early storage requires a continuous operation of spillway which is not feasible mechanically.

Finally, Q_{500} FCL is set as a guide curve and results are compared with observations. It is clear that to use Q_{500} FCL level as a guide curve is impossible. Only two years applications are presented to show the results for the years 2008 and 2009 (Figure 6.10 and 11). It is remarkable that spillway discharges reach up to 90 – 100 m^3/s during the transition periods between months.

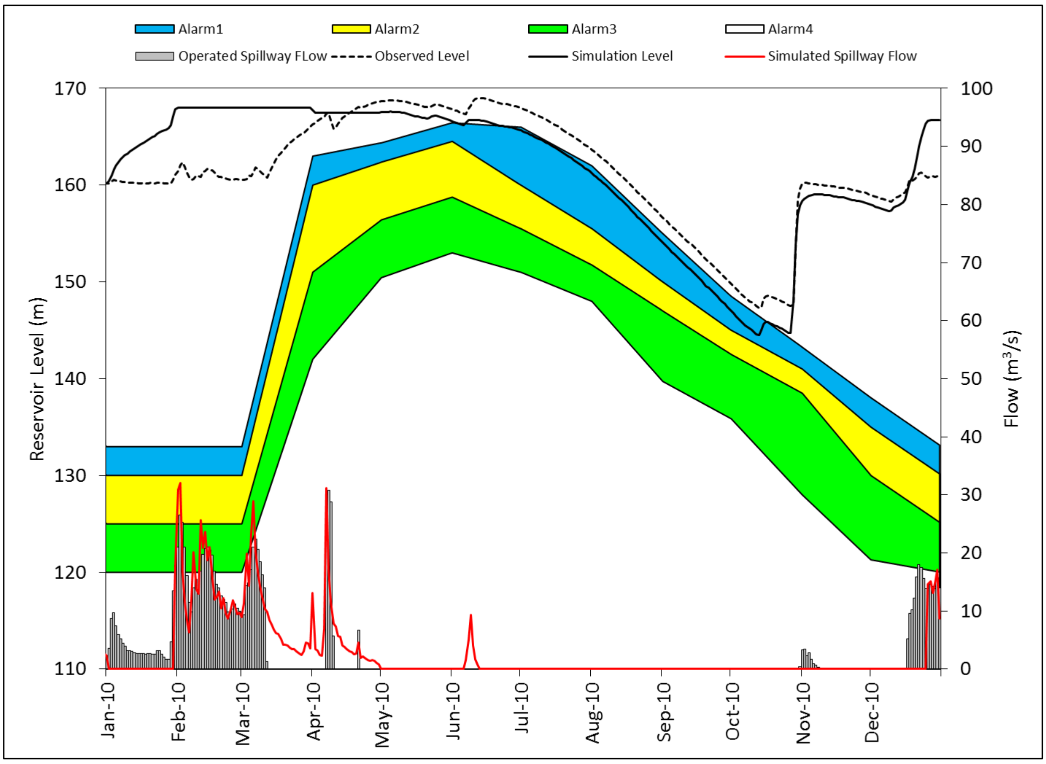


Figure 6.8 Reservoir simulation according to Q_{100} FCL (2010)

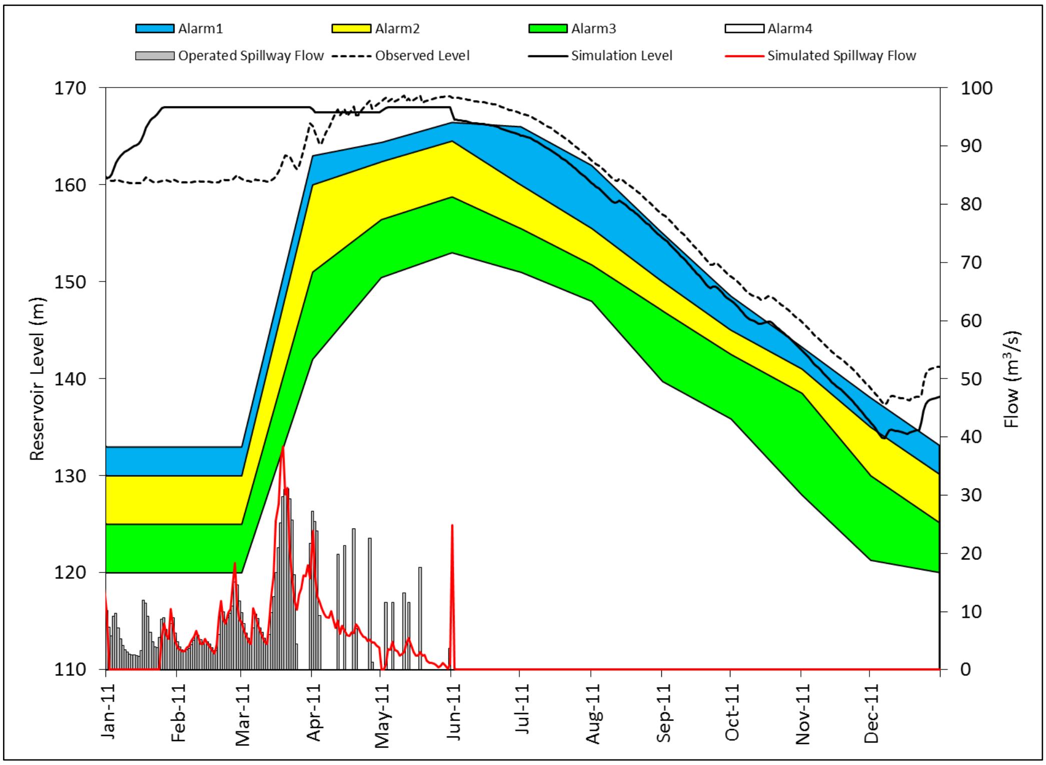


Figure 6.9 Reservoir simulation according to Q_{100} FCL (2011)

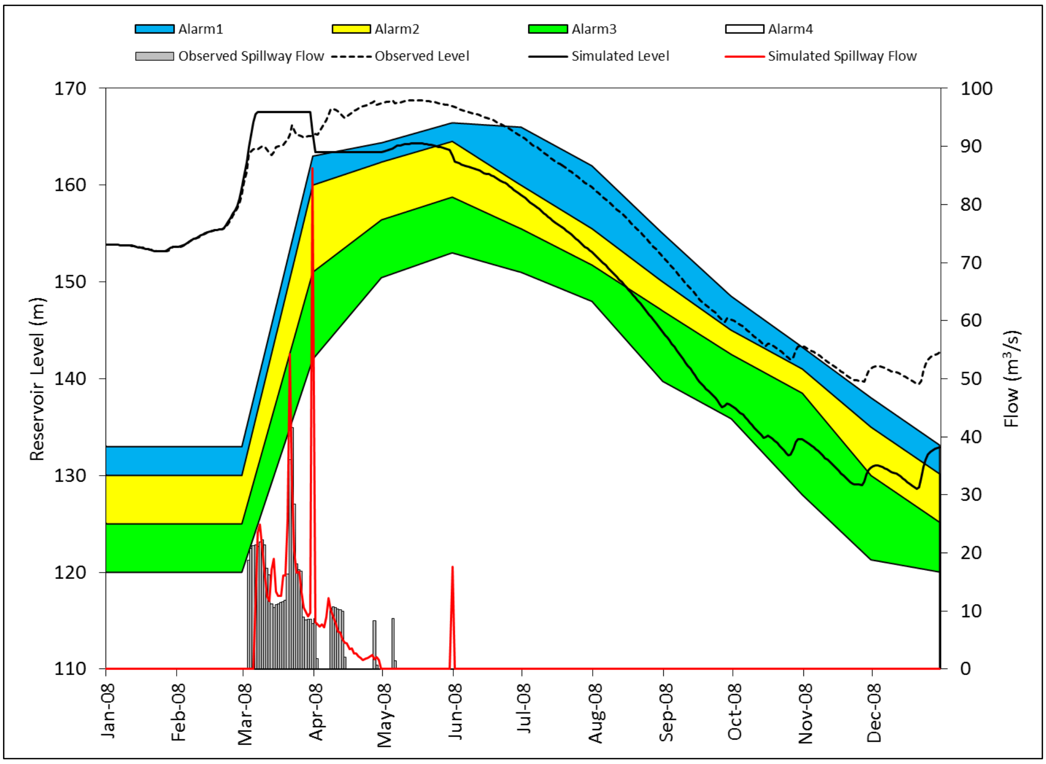


Figure 6.10 Reservoir simulation according to Q_{500} FCL (2008)

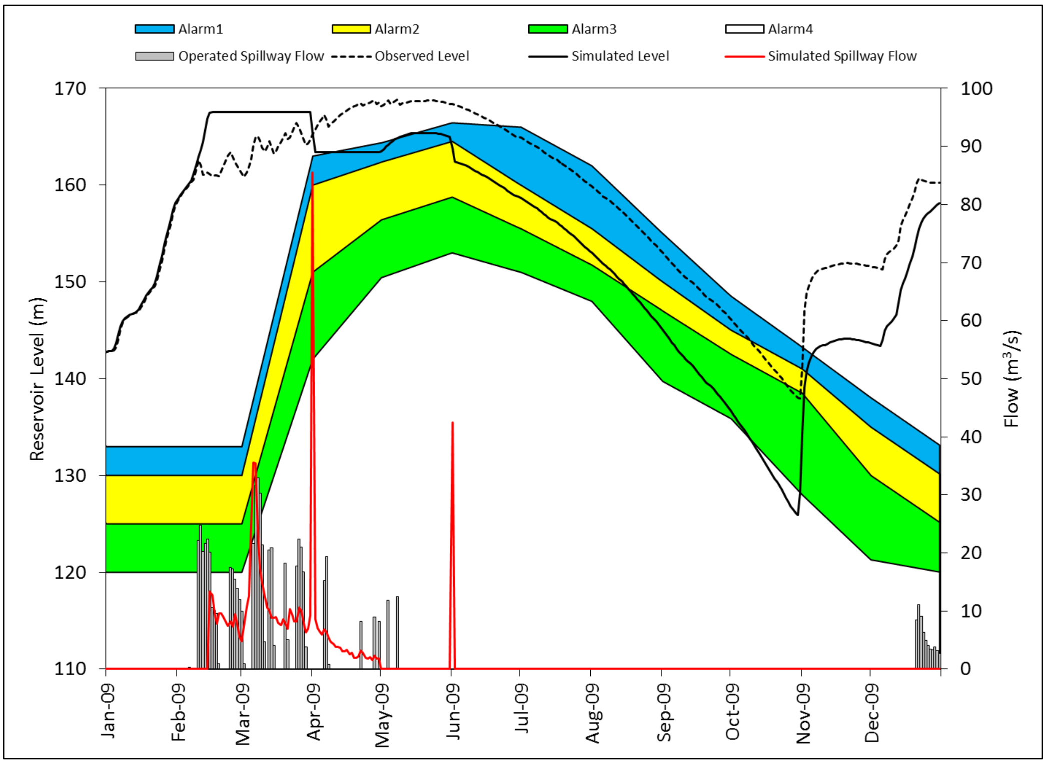


Figure 6.11 Reservoir simulation according to Q_{500} FCL (2009)

Since FCLs are based on monthly strategies, sudden change in FCL necessitates higher spillway discharges during month transitions. However, operators should take decisions to provide smooth transitions concerning inflow into reservoir and spillway discharges.

6.2. Development of New Strategies for Long Term Operation

The main motivation is to develop new and objective operational strategies concerning reservoir volume, inflow, flood risk and demand. Inflow is increasing due to snowmelt and effective rainfall events during March – June, thus serious contribution to the storage is observed in this period. For this reason, a certain amount of water is required to be released to the downstream channel by the spillway, through which the maximum volume for flood attenuation would be provided in the reservoir.

Experiences from the previous operations (Figure 6.12) showed that daily decisions must be taken following the procedure as: The level must be adjusted to spillway crest elevation in between October – March, unless serious inflow increases and downstream channel risks are not observed. The level should be increased step by step according to the snow accumulation condition in between March – June, and finally the reservoir elevation should reach to a peak value when inflows are equal to outflows which occur around in mid-May. Stepped operation, which means operation of spillway once in a week, is preferred during April and May in order to spill excess water continuously.

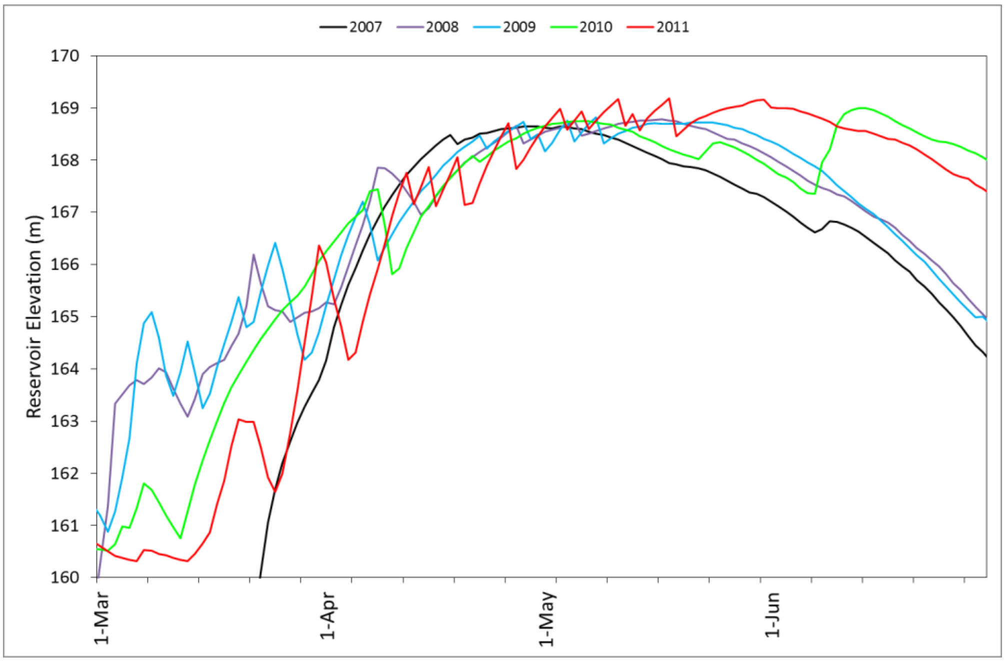


Figure 6.12 Observed reservoir elevations for the period of March – June (2007 – 2011)

Although operational strategies require taking downstream channel capacity into consideration, the primary goal of Yuvacık Dam Reservoir is to provide sustainable water for the whole year. Therefore, in the first step; a decision on daily lake level must be taken according to long term water supply strategies for the real time operation. On the other hand, concerning time to peak and time of concentration, short term flood operation decisions are determined in hourly basis in case of downstream flood risk. Due to these reasons; A Decision Support System Scheme (DSSS) (Figure 6.13) using a mathematical water budget based simulation model HEC-ResSim is developed for Yuvacık Reservoir. It accounts for several variables and long term to short term transition steps. New strategies are also developed using previous year’s experiments and operational rules.

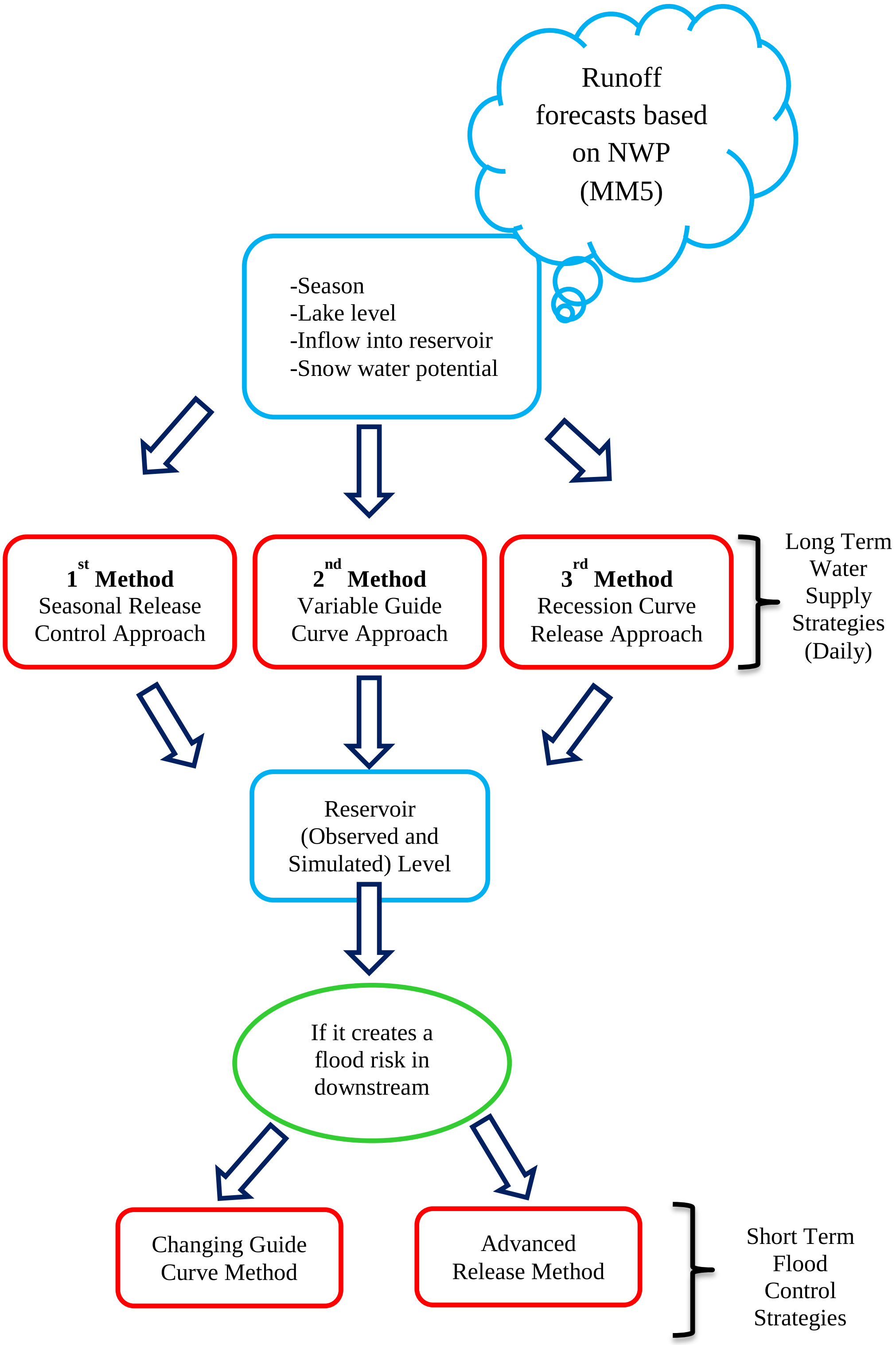


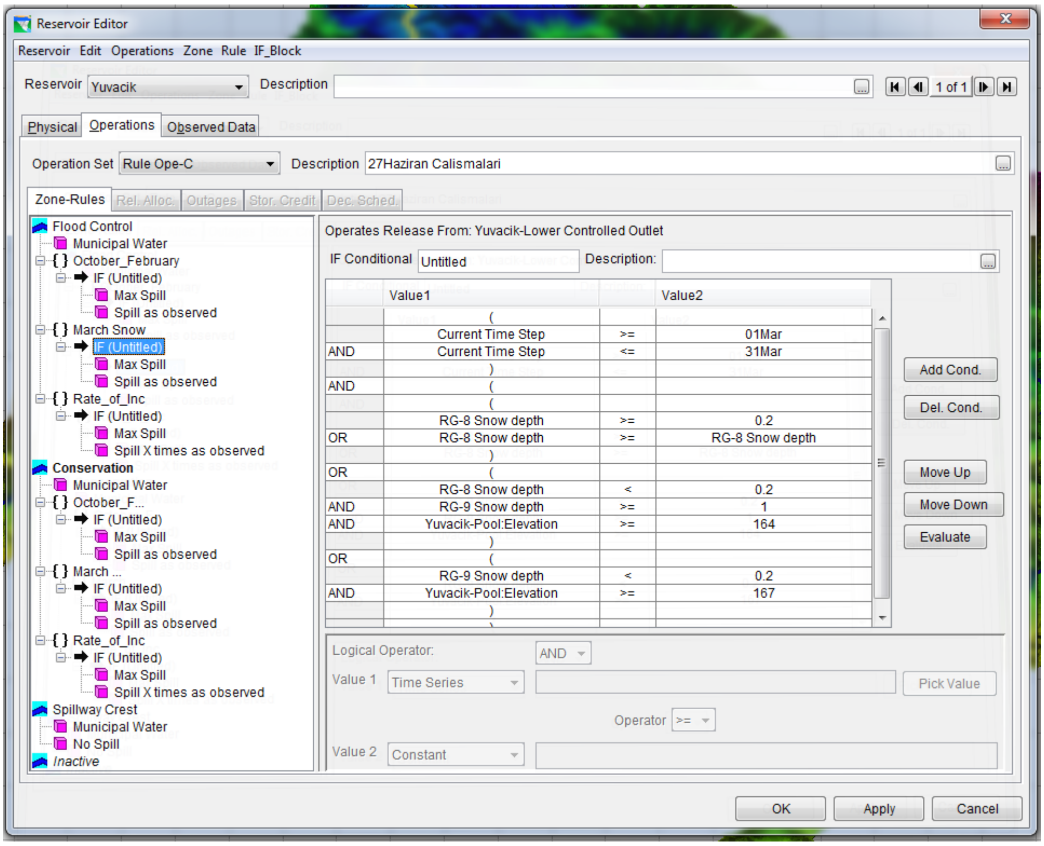
Figure 6.13 Decision Support System Scheme (DSSS)

The decisions mainly depend on the season, the lake level, the inflows and the snow water potential. Since, hereafter long term decisions are examined in daily time basis simulations, it is more appropriate to simulate years as a water year concept (01 Oct – 30 Sep). Daily time step is used for long term reservoir modeling studies with ResSim according to Figure 6.13, reservoir is divided into 4 zones (explained in detail in Section 6.3.1) for each method application.

Although the downstream channel capacity is 100 m^3/s, it is desired to spill as low as possible amount of water to reduce flooding risk of the channel. Moreover, tributary streamflows through lateral creeks at the downstream even may decrease this limit. Nevertheless, maximum spillway limit is reduced to 40 – 50 m^3/s by rules unless a higher value is required through simulations.

6.2.1. Seasonal Release Control Approach (Method 1)

In this part of the study, the target elevation is set as 169 m for water supply. However, spillway releases are controlled by user defined forcing rules. To that end, experience decisions of the previous years (2007 – 2011) are analyzed and decisions are converted into ResSim rules. After all, ResSim rule sets are developed with IF-THEN-ELSE statements (Figure 6.14). The rules used in this method are presented below associated with zones to represent ResSim Operation structure.



Reservoir: Yuvacik

Description:

Operation Set: Rule Ope-C

Description: 27Haziran Calismalari

Operates Release From: Yuvacik-Lower Controlled Outlet

IF Conditional: Untitled

Description:

	Value1		Value2
	(		
	Current Time Step	>=	01Mar
AND	Current Time Step	<=	31Mar
	)		
AND	(		
	(		
	RG-8 Snow depth	>=	0.2
OR	RG-8 Snow depth	>=	RG-8 Snow depth
	)		
OR	(		
	RG-8 Snow depth	<	0.2
AND	RG-9 Snow depth	>=	1
AND	Yuvacik-Pool:Elevation	>=	164
	)		
OR	(		
	RG-9 Snow depth	<	0.2
AND	Yuvacik-Pool:Elevation	>=	167
	)		

Logical Operator: AND

Value 1: Time Series

Operator: >=

Value 2: Constant

Figure 6.14 General operation of 1st approach in ResSim

1) Flood Control Zone (169.30 – 169.00 m): This zone is defined between maximum operation (169.30 m) and conservation level. Since conservation is managed by dominant release rules, the volume of this pool is varied regarding to water potential. This can be done by decreasing water level by continuous spillway flows. The rules applied for this zone are entirely same with *Conservation Zone*.

2) Conservation Zone (169.00 – 159.95 m): Upper part of the conservation pool is defined as "Guide Curve" as a default in ResSim. ResSim will decide on specific amount of water stored or released with respect to GC unless set of rules restrict GC.

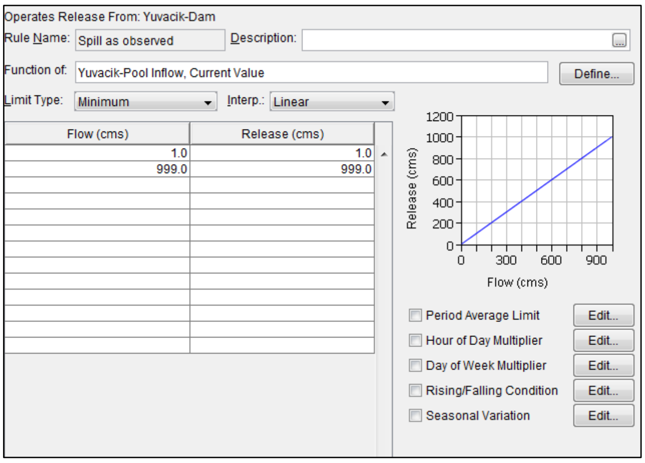
<u>*The rules are:*</u>

1st Rule:

First of all, a rule is defined to provide flow into water treatment plant. Hence, a specified release rule is defined as a function of external variable (observed water treatment plant flow) that controls release from a predefined outlet in the physical data. This external variable is defined as time-series of observed water supply from the treatment plant, so that the required (observed) amount of water is withdrawal in any condition, unless water is not available in the reservoir.

2nd Rule set:

It is observed that reservoir elevation is kept under spillway crest level of 159.95 m from October to February. It means that the water is not kept behind the radial gates. Two rules are defined to maintain this release with an *IF Statement*. The rule named "spill as observed" controlling the releases from Yuvacık Dam (total outflow both from spillway and water treatment plant) is defined as a function of current inflows (Figure 6.15).


Operates Release From: Yuvacik-Dam

Rule Name: Spill as observed

Description:

Function of: Yuvacik-Pool Inflow, Current Value

Limit Type: Minimum

Interp.: Linear

Flow (cms)	Release (cms)
1.0	1.0
999.0	999.0

☐ Period Average Limit

☐ Hour of Day Multiplier

☐ Day of Week Multiplier

☐ Rising/Falling Condition

☐ Seasonal Variation

Figure 6.15 "*Spill as observed"* rule screen shot

The relation between inflow and release is linear; therefore inflow will be released through predefined location (outlet). It advices to release should be on the minimum as much as inflow value if the statement described below equation (6.1) occurs:

$$\begin{gathered}(\text{Pool:Elev\_Cur} \geq 159.95)\ \&\&\ (\text{Cur\_TS} \geq 01\text{Oct}\ \&\&\ \text{Cur\_TS} \leq 31\text{Dec})\ \text{II} \\ (\text{Cur\_TS} \geq 01\text{Jan}\ \&\&\ \text{Cur\_TS} \leq 01\text{Mar})\end{gathered} \tag{6.1}$$

Where;
&& is AND
II is OR
Pool:Elev_Cur is the pool elevation at current time step
Cur_TS is current time step

A maximum release rule is defined as a function of date as an assumed downstream channel capacity of 100 m^3/s. However, this limit is changed during long terms simulations to avoid instant high releases.

3^{rd} Rule set:

Critical operational decisions have to be taken during March- April, due to both decreasing snow depth in the basin and increasing streamflow hydrograph as a result of snowmelt. Fully open spillway gate strategy is changed during these months by taking snow and inflow conditions into consideration. The most important decision is to decide when the gates will be closed and stepwise storage will take start. Therefore, an if-then-else statement is obtained by trial-error procedure and used in this rule. Several options are tested by simulations and the last one is defined without a time restriction. This provides user to control and decide the date by conditional rules and avoid subjective decisions changing person to person.

It should be noted that when RG-8 snow depth is greater than 0.2 m and the snow depth increases day by day; release from spillway is continued.

Moreover, the level should not exceed 164 m, if RG-9 snow depth is greater than 1.0 m, and the pool elevation should not exceed 167 m in any condition. Two rules are defined to maintain this release with *IF Statement*. The same “spill as observed” rule is applied. It advices to release at least the incoming flow value, if the statement described below (6.2) occurs:

$$
\begin{aligned}
&(\text{Cur\_TS} \geq \text{01Mar} \;\&\&\; \text{Cur\_TS} \leq \text{20Apr}) \;\&\& \\
&((\text{RG-8:SD\_Cur} \geq 0.2)\ \text{II}\ (\text{RG-8:SD\_Cur} \geq \text{RG-8:SD\_Prev}))\ \text{II} \\
&(\text{RG-8:SD\_Cur} < 0.2) \;\&\&\; (\text{RG-9:SD\_Cur} \geq 1 \;\&\&\; \text{Pool:Elev\_Cur} \geq 164)\ \text{II} \\
&(\text{RG-9:SD\_Cur} < 0.2 \;\&\&\; \text{Pool:Elev\_Cur} \geq 167))
\end{aligned}
\tag{6.2}
$$

Where;
&& is AND
II is OR
Cur_TS is current time step
RG-8:SD_Cur is the snow depth (RG-8) at current time step
RG-8:SD_Prev is the snow depth (RG-8) at previous time step
RG-9:SD_Cur is the snow depth (RG-9) at current time step
RG-9:SD_Prev is the snow depth (RG-9) at previous time step
Pool:Elev_Cur is the pool elevation at current time step

4rd Rule set:

Each inflow fluctuation cause an undulation in the level in case of reservoir elevation is greater than 167 m during April and May. A precipitation event observed during this period shows rapid recession that is different from general trend. Operators prefer to spill the water during these kinds of storm events and when the inflow starts to recede spillway gates are closed. Hence, a set of rule is developed to control high inflows in this period. This situation is carried out to the program by an IF_THAN_ELSE statement that also includes a state variable written in Jython language (Figure 6.16). By mean of this state variable;

inflow rates (6.3) are greater or equal to 1 is defined into the model and releases are defined accordingly.

$$I_r = I_c / I_p \tag{6.3}$$

Where;

I_r is inflow rate

I_c is the inflow at current time step

I_p is the inflow at previous time step

Finally, state variable is implemented to IF statement and statement is fed by a special rule (Figure 6.17). It advices to release at least 1.5 times of incoming flow, if the statement described in equation (6.4) below occurs:

(Cur_TS ≥ 01Apr && Cur_TS ≤ 31May) && (Pool:Elev_Cur ≥ 167) &&
(Rate_Cur > 1) && && (Inflow_Cur > 12) (6.4)

Where;

&& is AND

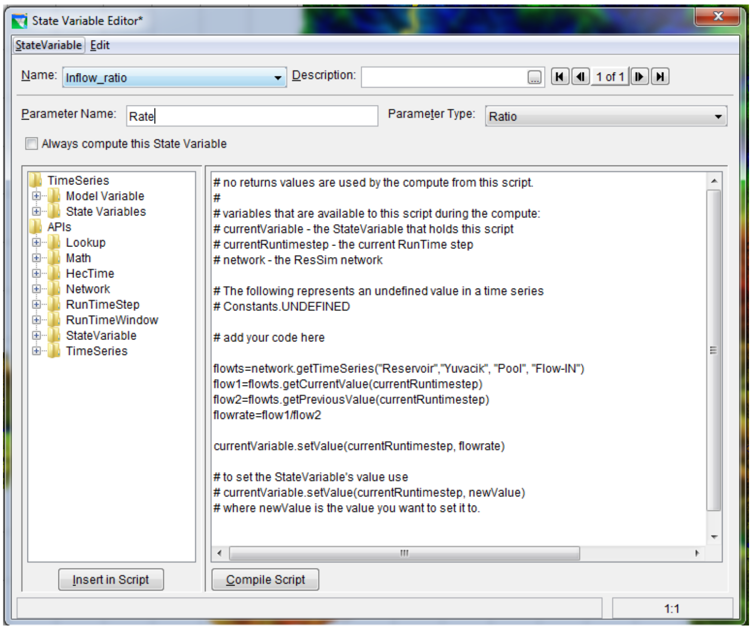
II is OR

Cur_TS is current time step

Pool_Elev_Cur is the pool elevation at current time step

Rate_Cur is the inflow rate at current time step

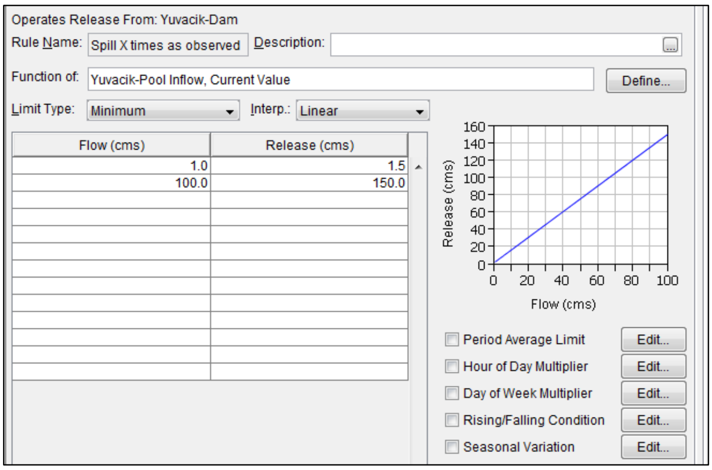
Inflow_Cur is the inflow at current time step



Name: Inflow_ratio
Description:
Parameter Name: Rate
Parameter Type: Ratio
☐ Always compute this State Variable

```
# no returns values are used by the compute from this script.
#
# variables that are available to this script during the compute:
# currentVariable - the StateVariable that holds this script
# currentRuntimestep - the current RunTime step
# network - the ResSim network

# The following represents an undefined value in a time series
# Constants.UNDEFINED

# add your code here

flowts=network.getTimeSeries("Reservoir","Yuvacik", "Pool", "Flow-IN")
flow1=flowts.getCurrentValue(currentRuntimestep)
flow2=flowts.getPreviousValue(currentRuntimestep)
flowrate=flow1/flow2

currentVariable.setValue(currentRuntimestep, flowrate)

# to set the StateVariable's value use
# currentVariable.setValue(currentRuntimestep, newValue)
# where newValue is the value you want to set it to.
```

Figure 6.16 State variable editor



Operates Release From: Yuvacik-Dam
Rule Name: Spill X times as observed
Description:
Function of: Yuvacik-Pool Inflow, Current Value
Limit Type: Minimum
Interp.: Linear

Flow (cms)	Release (cms)
1.0	1.5
100.0	150.0

☐ Period Average Limit
☐ Hour of Day Multiplier
☐ Day of Week Multiplier
☐ Rising/Falling Condition
☐ Seasonal Variation

Figure 6.17 “*Spill as 1.5 much times as observed*” rule screen shot

3) Spillway Crest Zone (159.95 – 112.50 m): This zone is defined between spillway crest elevation and inactive level, it represents that there will be no spillway release within this pool.

4) Inactive Zone (112.50 m): This zone represents the lowest level in which water can be released or stored.

Finally, 2007 – 2011 years are simulated (Figures 6.18 – 23) in the light of these rules according to 1st long term approach, thereby results are presented and discussed below.

The observation of reservoir lake elevation indicates that the reservoir was continually filled during the operation of 2007 water year (Figure 6.18). The reason for this, initial pool elevation was lower than that of other years due to the 2006 drought summer period; therefore simulation rules do force not to spill any amount of water. High inflows of February, March and April were stored, so that there would be enough water for summer months.

Bearing in mind that the low initial pool elevation will cause same storage strategy for all methods, a senario is created manually setting the initial elevation to 150 m at the beginning of January. This scenario is also replaced with observations during other long term approach simulations. Scenario 2007 is used to understand the effects of operational rules (Figure 6.19) and it shows that after mid-March, reservoir elevation is increased due to snow melting. After that period level increases smoothly by continuous spillway flows which are less than 20 m^3/s. It should also be noted that there is no release over spillway on April and May.

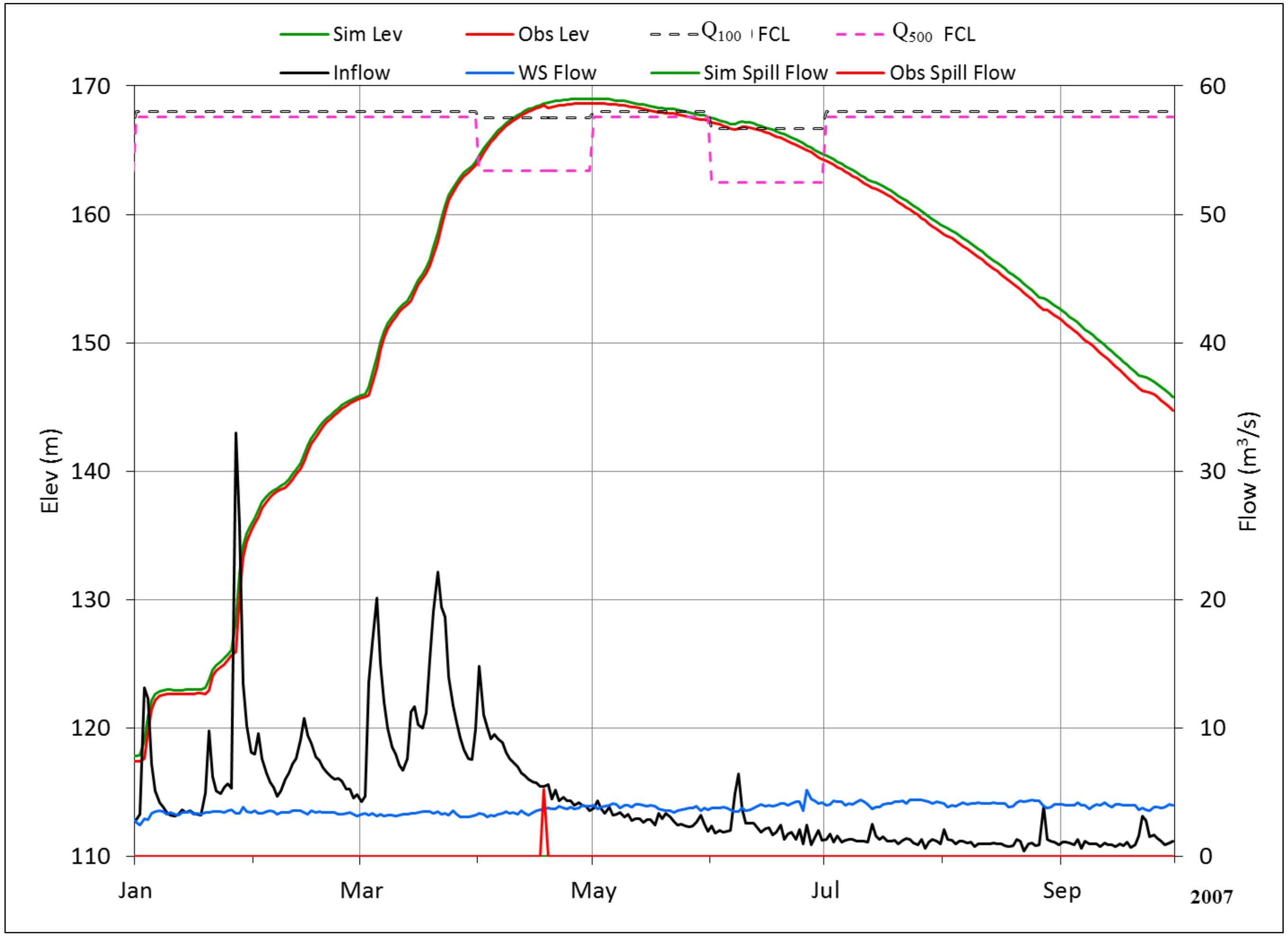


Figure 6.18 Long term water supply simulation results according to first approach (2007)

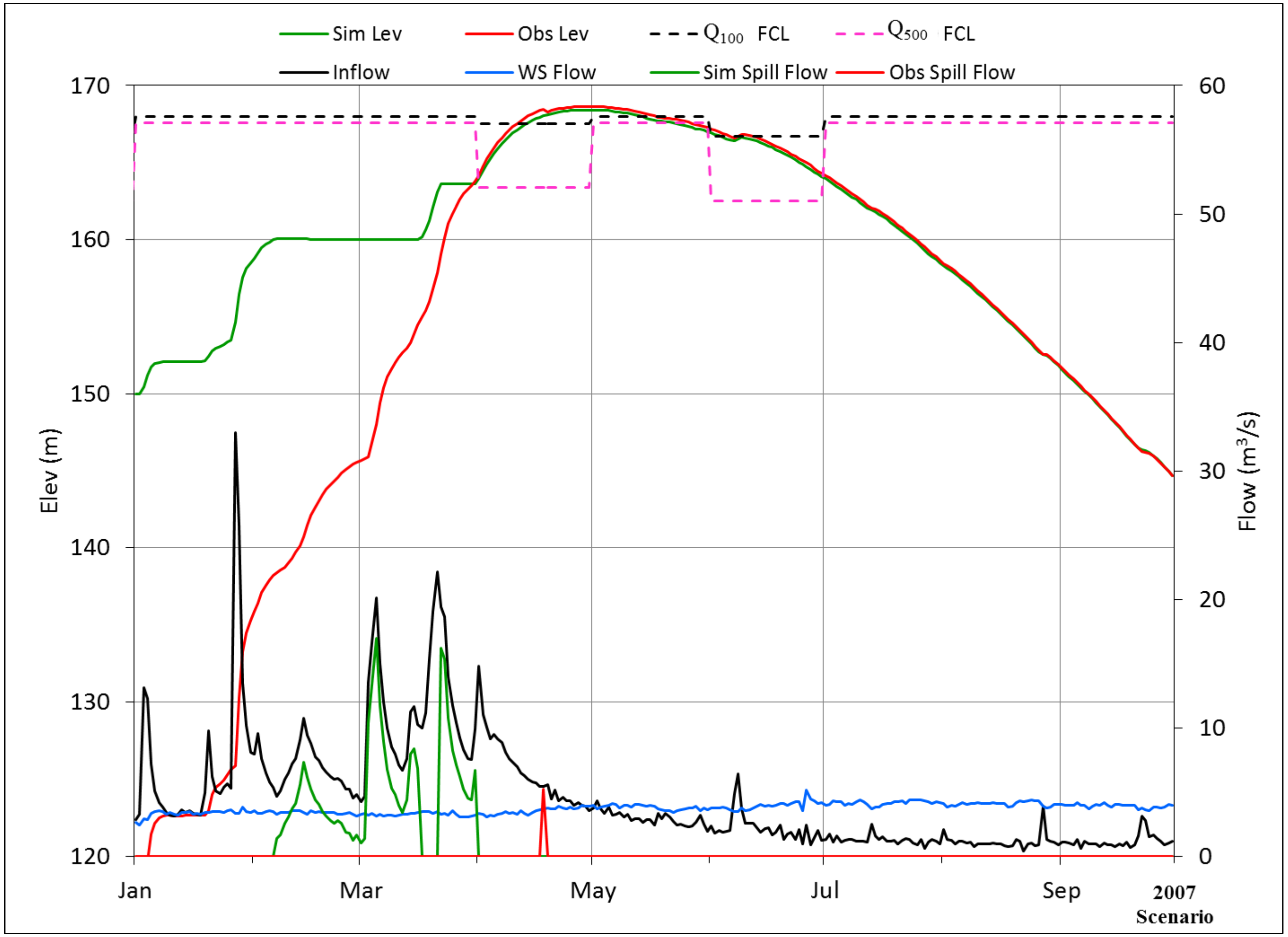


Figure 6.19 Long term water supply simulation results according to first approach (2007 scenario)

Through the year 2008, level in the reservoir reaches spillway crest level on early March (Figure 6.20). Simulation level is lower than observed level until snowmelt period ends, and spillway is operated when reservoir elevation is suddenly increased. Although radial gates are operated both for simulated and observed operation, simulation level exceeds Q_{100} FCL earlier than observation.

The main purpose is to achieve the reservoir elevation as high as possible before recession period takes start that is generally observed on early May for long term water supply. While doing this, flood pool storage should be managed as large as possible; thereby flood risk will be decreased. The key point is that the reservoir should ensure always large volume for flood regulation, but it should be as maximum as possible for further low flow conditions. This is also valid for the year 2009 (Figure 6.21) as well as 2008. Reservoir simulation proposes more constant and continuous spillway flow until May. This approach keeps the reservoir level below 160 m till March, and the elevation smoothly increases with respect to snow condition and inflow. It is analyzed that timing of spillway operation is similar with the observation, but amount of water depends on the gate strategy.

The simulation of 2010 water year especially emphasizes snow accounting rule (during the month March) effect on the results (Figure 6.22). The main difference between the simulation and the observation is observed in March; the simulation takes the advantages of snow condition rule, and hereby late flows could increase the effective volume in an efficient manner.

2011 is also considered to be a low flow but wet year, so that there is no serious reservoir level increase till mid-April water year (Figure 6.23). Simulation reservoir elevation reaches the maximum level slightly earlier than observations. Snow is quickly melted at the end of March, although the melting period ends, as a consequence of the later high inflows in April the reservoir filled earlier. The most instructive importance of this year on reservoir modeling simulation is that once reservoir is filled, later hydrological conditions do not have effects on decisions.

The overall results of different approaches will be compared and discussed in Section 6.5.

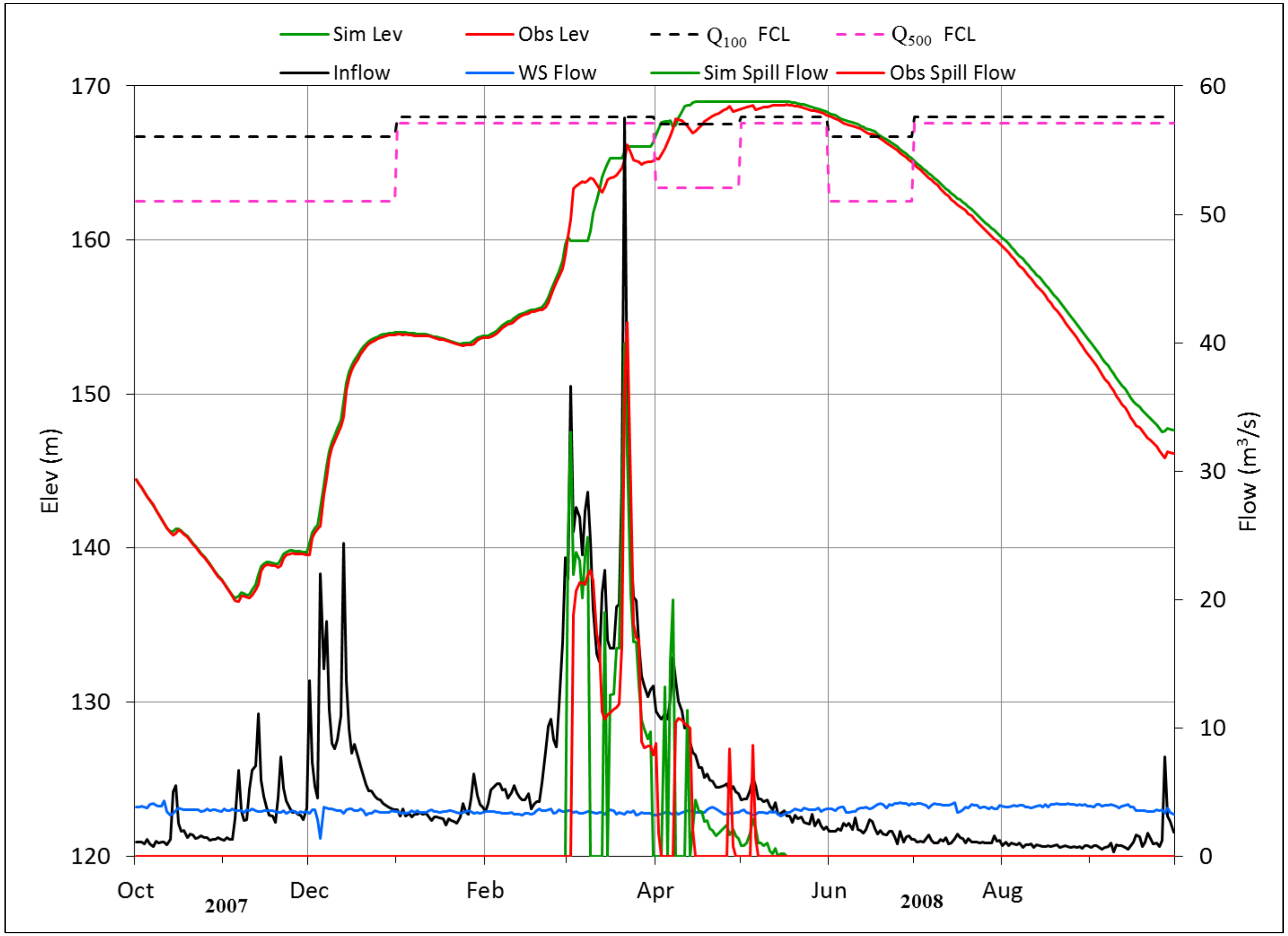


Figure 6.20 Long term water supply simulation results according to first approach (2008)

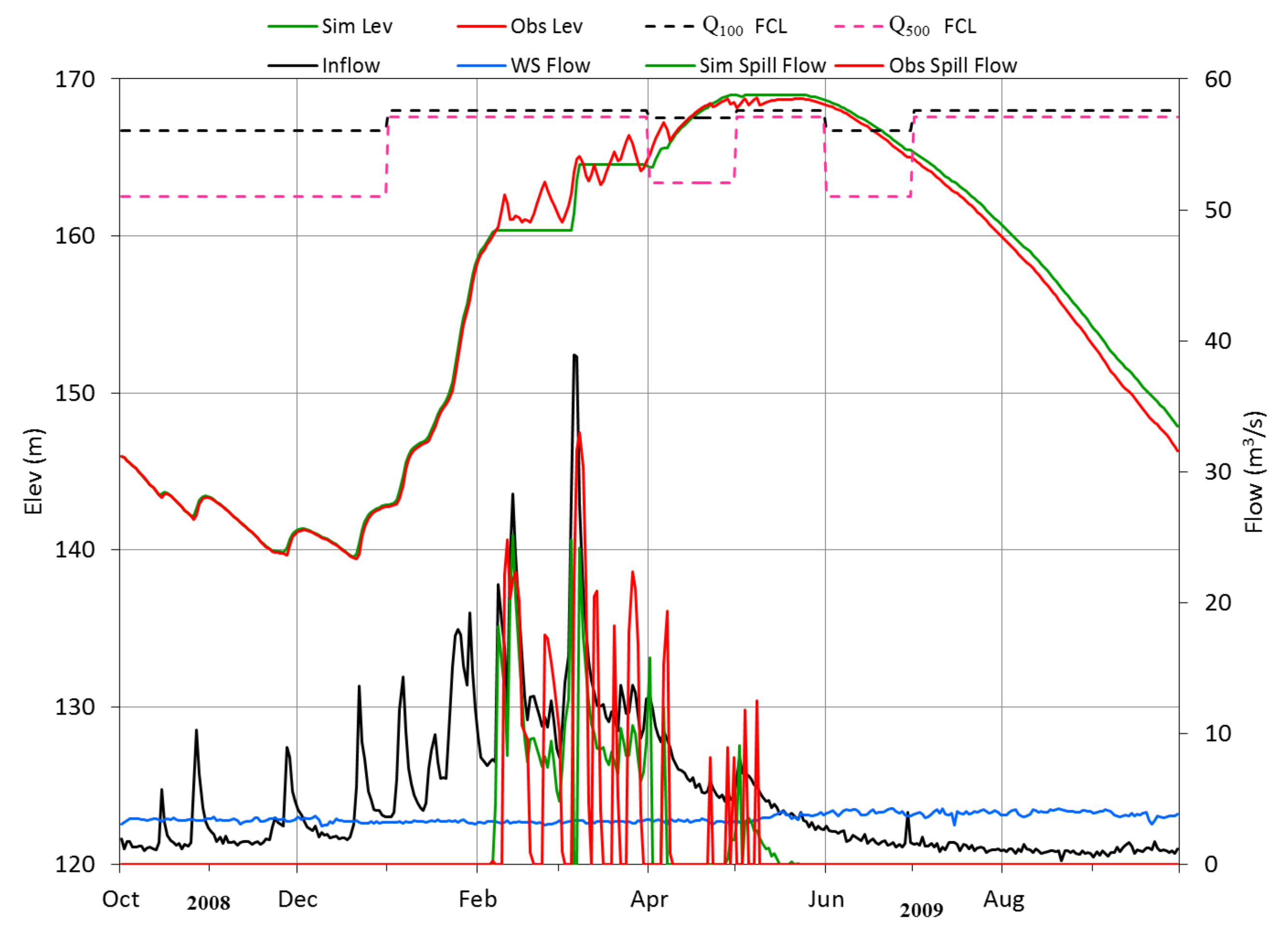


Figure 6.21 Long term water supply simulation results according to first approach (2009)

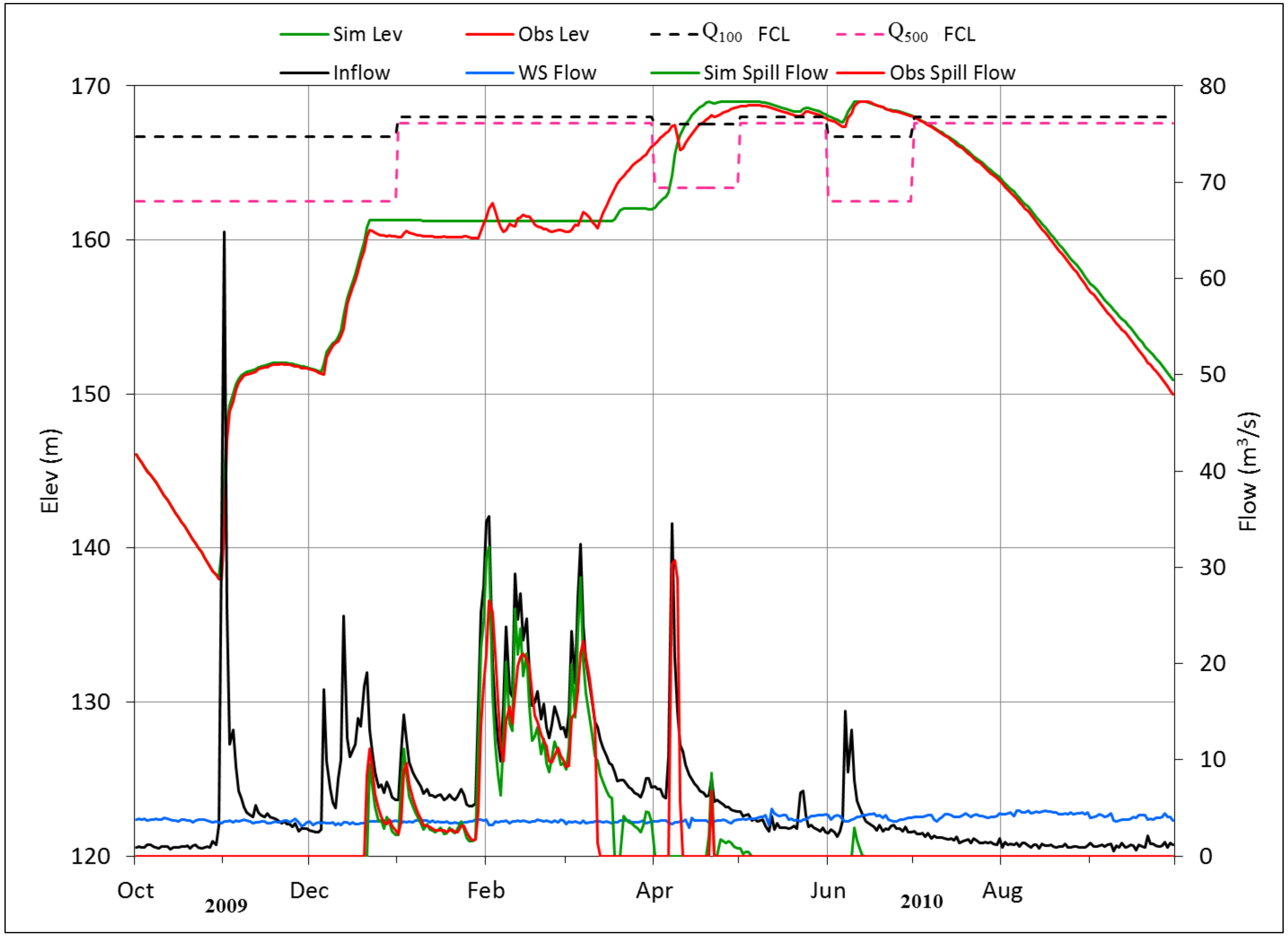


Figure 6.22 Long term water supply simulation results according to first approach (2010)

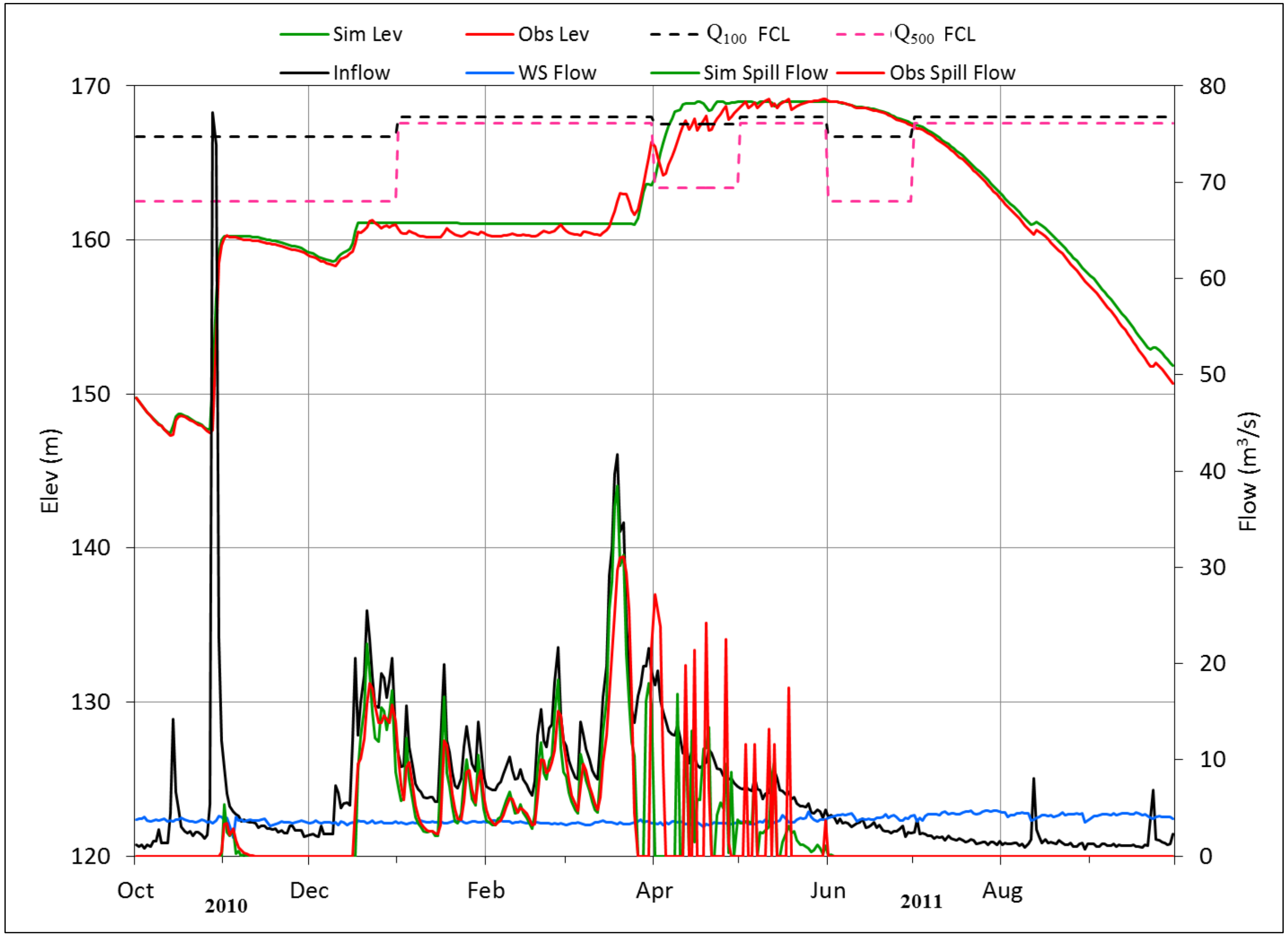


Figure 6.23 Long term water supply simulation results according to first approach (2011)

6.2.2. Variable Guide Curve Approach (Method 2)

The difficulty as expressed in previous sections is to find a constant target elevation for Yuvacık Reservoir. The target (guide) elevation varies with seasons and years and it cannot be directly determined especially for real time applications.

Since, the target elevation is highly correlated with probable inflows for the coming days; there may be a method to use this in the simulation. Hereby; a variable guide curve (VGC) that corporate several basin and flow conditions (season, current inflow and current snow cover) is used in this part of the study; and reservoir elevation is operated by a variable guide curve approach. For this purpose; several runs are done using a Beta version of ResSim that is currently developed by HEC (2011) and results are discussed in this section.

The main difference of this method is that spillway releases are managed by seasonally variable elevations instead of user defined specific rules. Conditions that affect the reservoir elevations are divided into six inter variable classes (Table 6.2) and reservoir elevations (Figure 6.24) corresponding to these conditions are determined by the experience of the reservoir operators.

Table 6.2 Variable conditions for reservoir operation

Reservoir inflow (m^3/s)	**0 - 5**		**5-12**		**>12**	
Snow depth RG-8 >20 (cm)	X	☑	X	☑	X	☑
Condition number	**1**	**2**	**3**	**4**	**5**	**6**

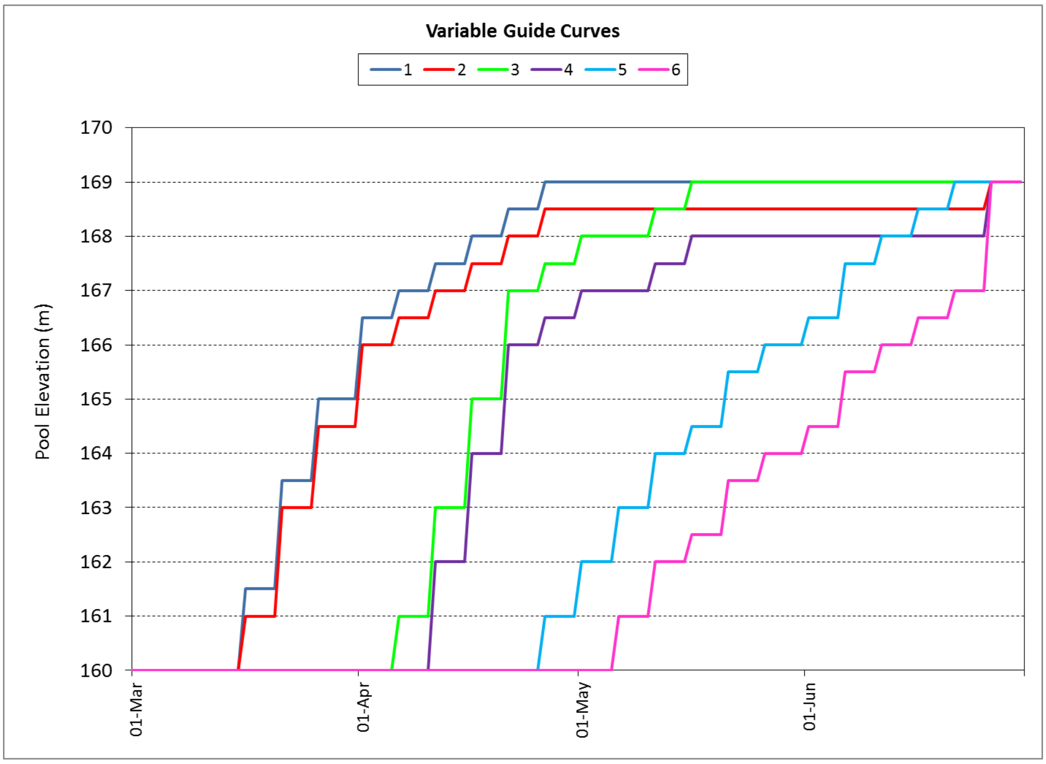


Figure 6.24 Seasonal variable guide curves

This method is evaluated by HEC-ResSim simulations. The curves are described and only two basic rules are defined into the model. These rules are: maximum spillway capacity and municipal water supply rules.

Finally, 2007-2011 years are simulated (Figures 6.25 – 6.29) in the light of these rules according to 2nd long term approach, thereby result are presented and discussed below. Once the curves are carried out into the model, ResSim defines a variable target elevation (that is defined with dash lines in graphs) according to the conditions occurring in each year.

Scenario 2007 simulation (Figure 6.25) is tested by manually setting initial reservoir elevation at 150 m again. Long dash dot lines indicate the variable guide curve which is derived according to variable conditions of this application year. The target elevation varies upon the time. Reservoir level is increasing with respect to season, however a large spillway release is observed due to the sudden change of guide curve. These sudden changes are the weakest point of this method. Although the target elevation later meets with actual operation level, the inflows are not enough to end up with a full filled reservoir.

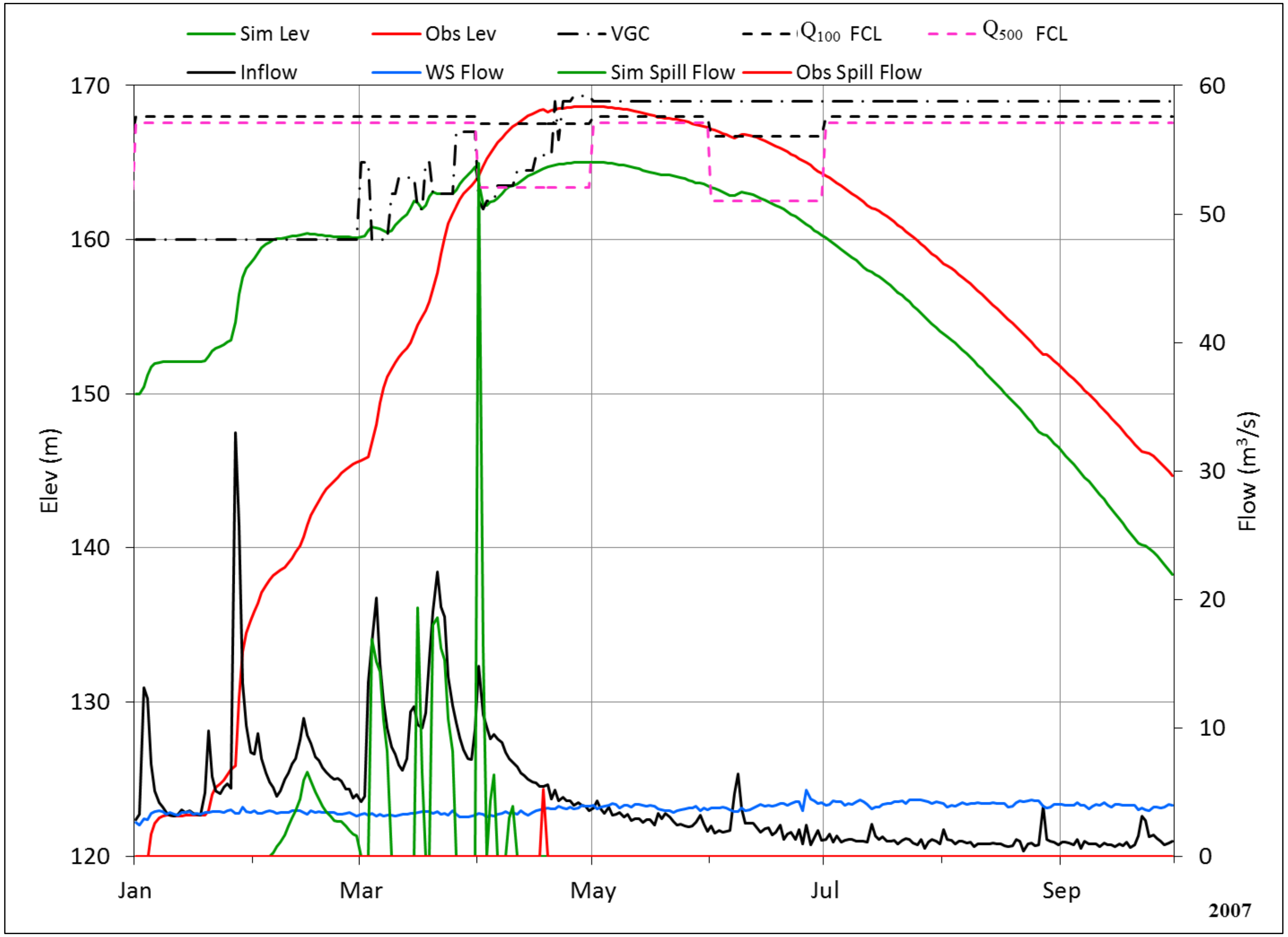


Figure 6.25 Long term water supply simulation results according to second approach (2007 scenario)

VGC reaches maximum elevation on May which is similar to observed one, but April and May inflows are not enough to fill the reservoir in 2008 (Figure 6.26).

Looking through 2009 water year VGC method application (Figure 6.27), better results are observed than previous ones. It is remarkable that simulated and observed levels have similar trends especially in the early period. However, operators increase the level at the beginning of the March, although simulation indicates a later increase. Nevertheless, simulation and observation meet the maximum value at the end of May.

The main difference of 2010 water year (Figure 6.28) is that a high inflow greater than 35 m^3/s is observed during April. This unique circumstance has great impact on April decisions. Although VGC target intersects with observations; April and May inflows do not satisfy the full reservoir storage in advance. Simulation outcomes end up with low elevations compared with observations.

It is remarkable that 2011 water year application (Figure 6.29) of VGC method highly corelated with observations in terms of reservoir elevations. Spillway release strategy is different since simulation spillway flow is less time dependent and continuos. Since there is no sharp decrease on VGC due to the inflow, VGC could provide a more suitable solution for 2011.

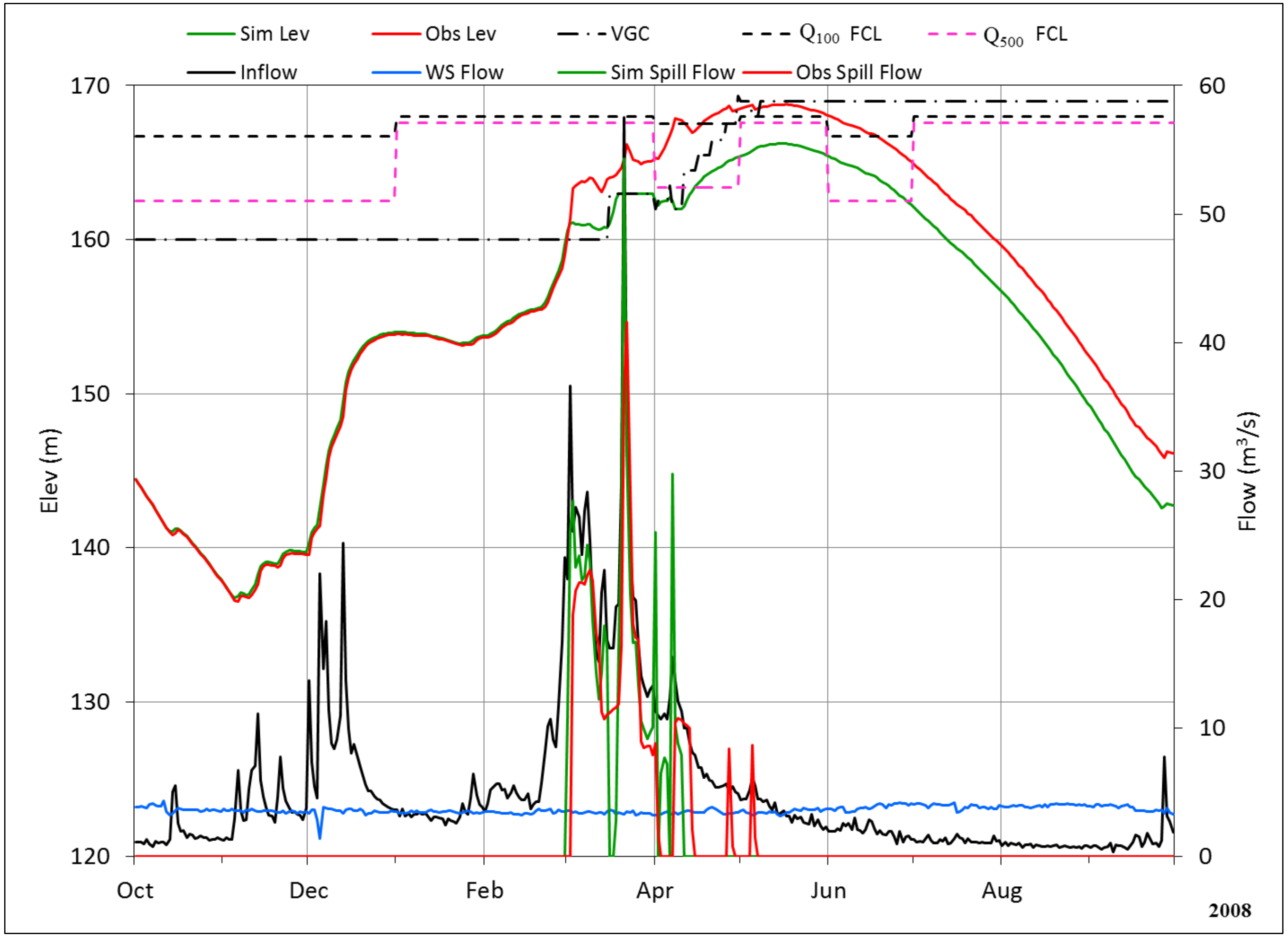


Figure 6.26 Long term water supply simulation results according to second approach (2008)

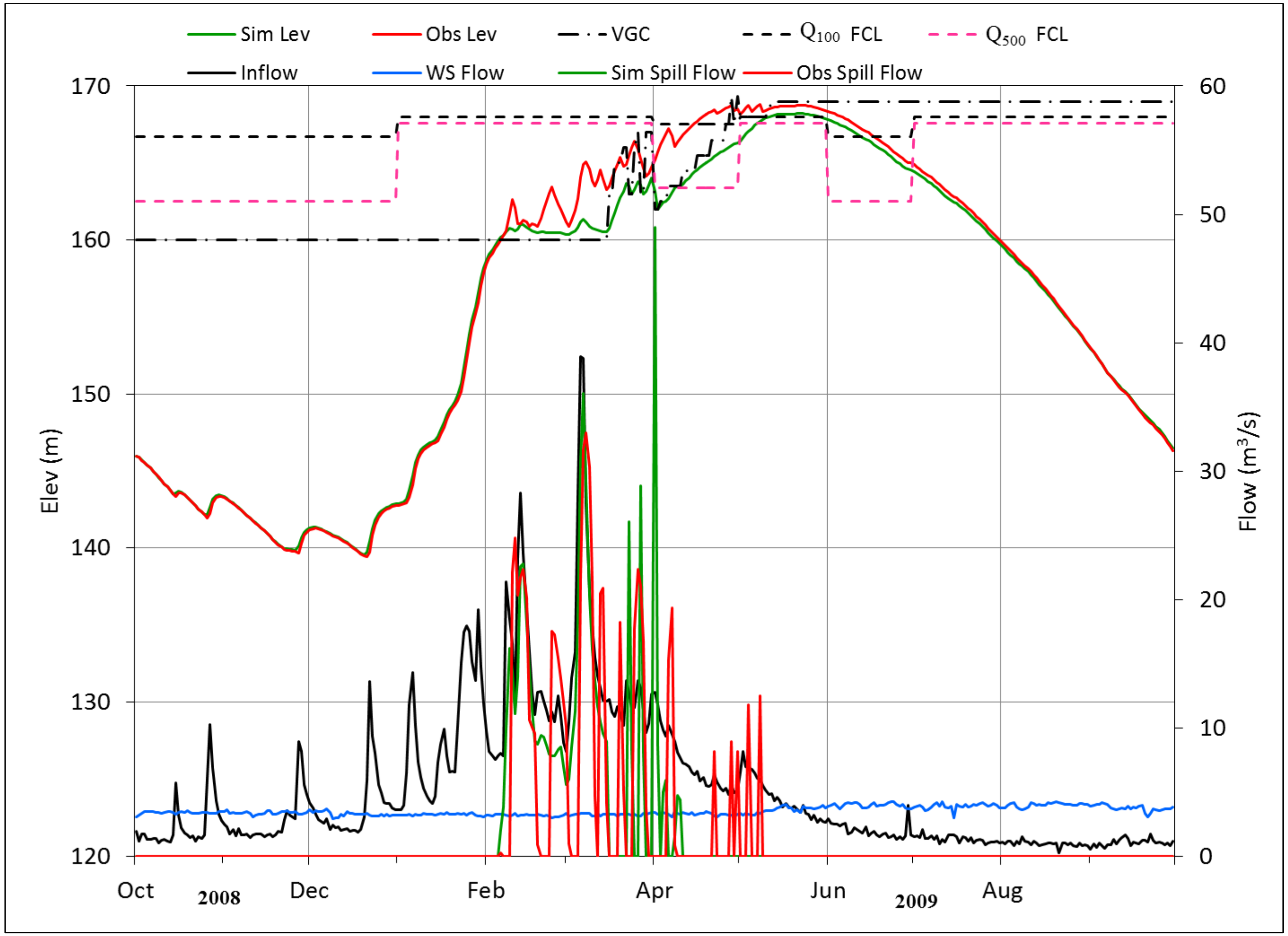


Figure 6.27 Long term water supply simulation results according to second approach (2009)

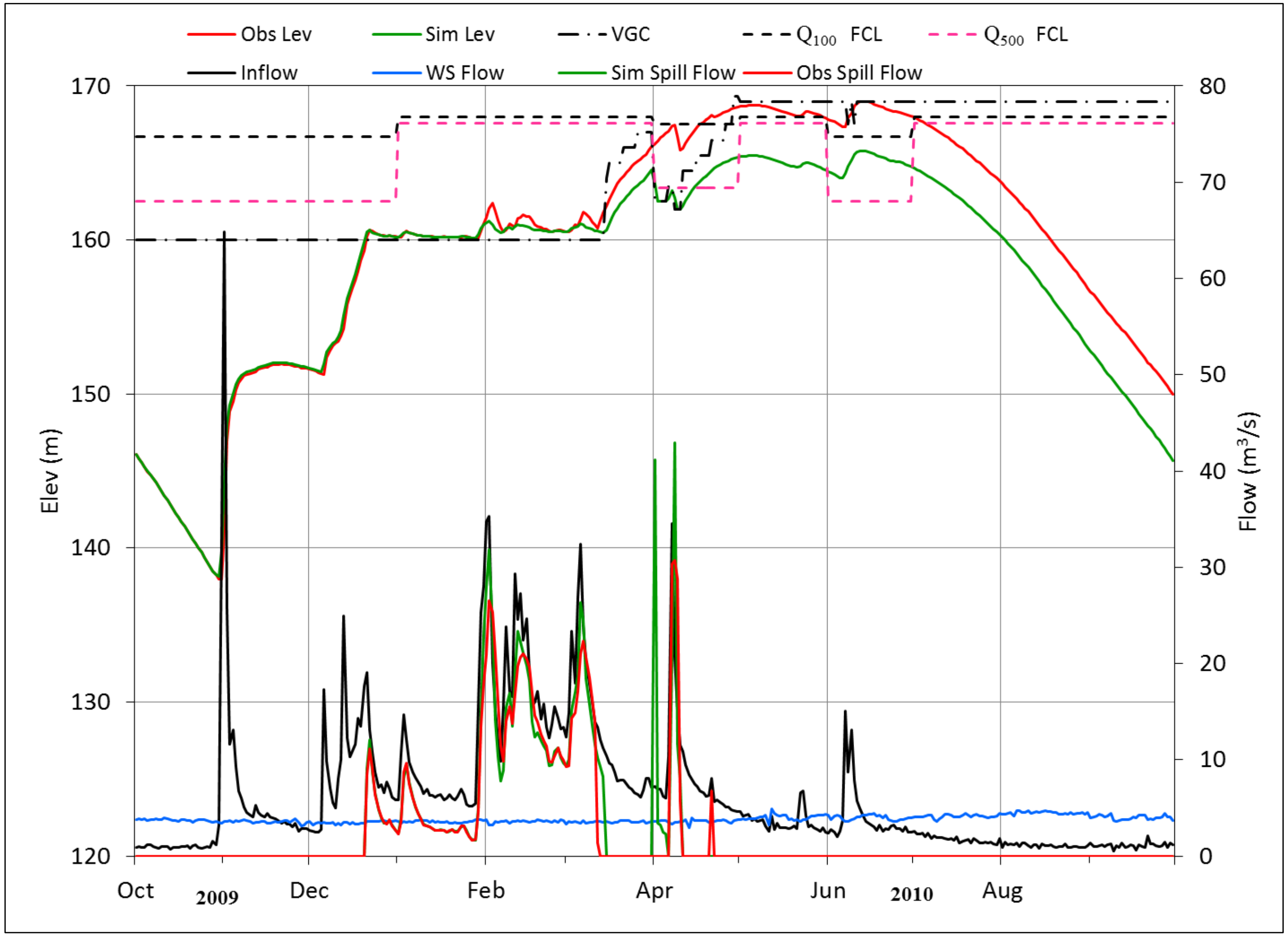


Figure 6.28 Long term water supply simulation results according to second approach (2010)

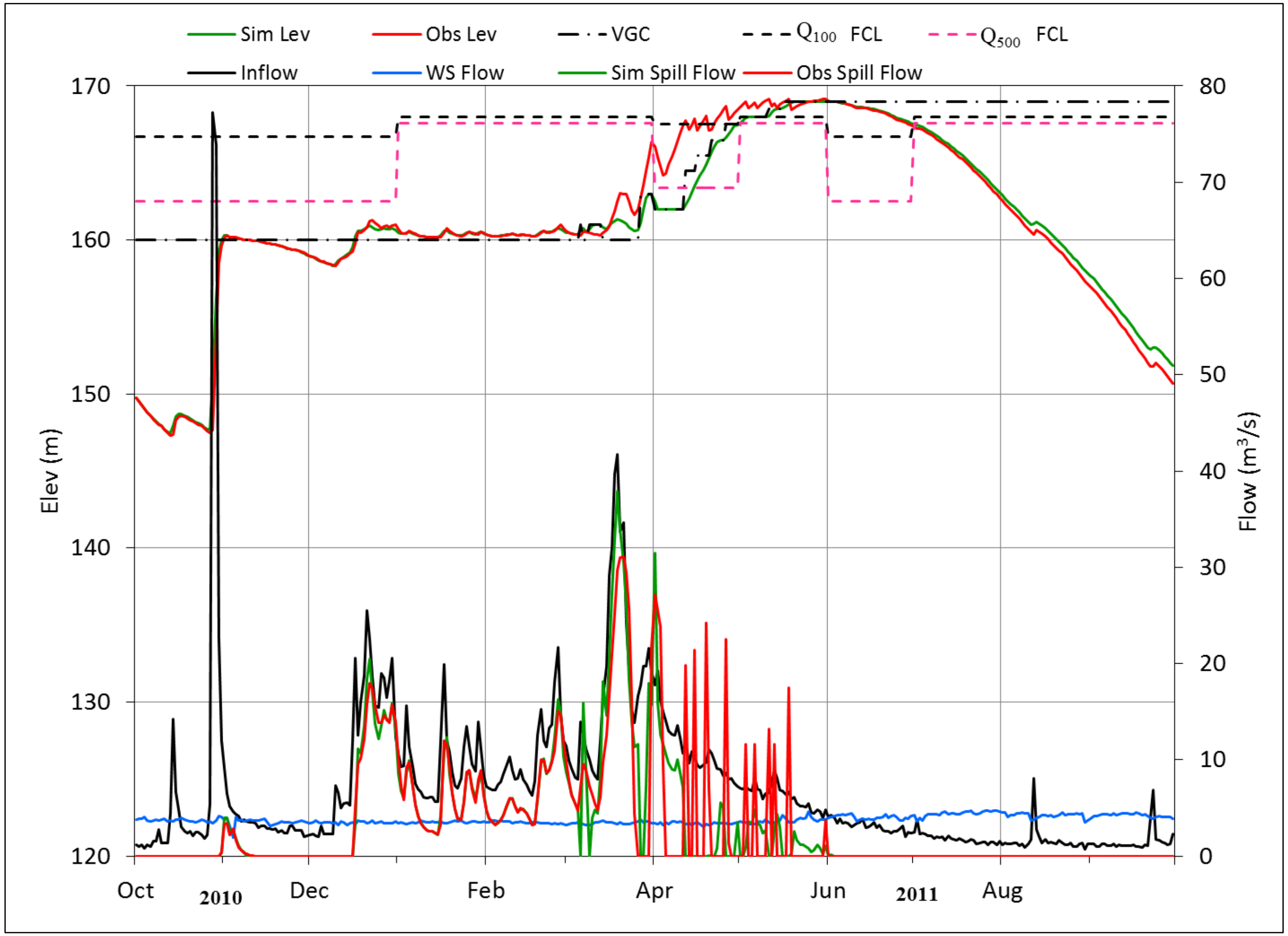


Figure 6.29 Long term water supply simulation results according to second approach (2011)

6.2.3. Recession Curve Release Approach (Method 3)

The important factor in long term planning is that annual volume of inflow is a main uncertainty; on the other hand, strategies are developed daily or weekly according to inflow trends. Although with a numerical weather prediction integrated hydrological model the discharges can be forecasted for one day or two days ahead, it is still unknown how the inflow behaves in the recession part. It would be an effective way to know the lowest possible inflow into the reservoir during April and May periods when the inflow continuously decreases in decision making process.

In this section; the reservoir is operated for long term water supply strategies by a scripted rule that is developed in ResSim. The scripted rule is used to calculate the later possible lowest inflow volume, and decide how much water should be evacuated to provide free volume.

A script rule is an advanced operation rule that provides you the ability to write your own Release Function rule so that you can perform complex calculations or address a complex set of constraints to end up with a desired release. The scripted rule must be written in Jython, a Java implementation of the Python programming language (www.python.org and www.jyton.org).

The possible lowest inflow volume calculation accounts on an assumption of a recession curve that is generated using the lowest inflow observations in 2006 (Figure 6.30). After that, a logarithmic formula is fitted that gives a best match. The ResSim script (Table 6.3) integrates the area under this curve that is volume between the initial value and the estimated maximum demand of 4 m^3/s (fixed). The recession method depends on free volume and probable incoming volume of water calculation at each time step. The inflow hydrograph is assumed as a unique one for all periods.

It should be noted that, target elevation of the reservoir elevation is set to 160 m by rules until 10 March. Therefore; recession curve release control will work after that period when recession of inflows is more possible.

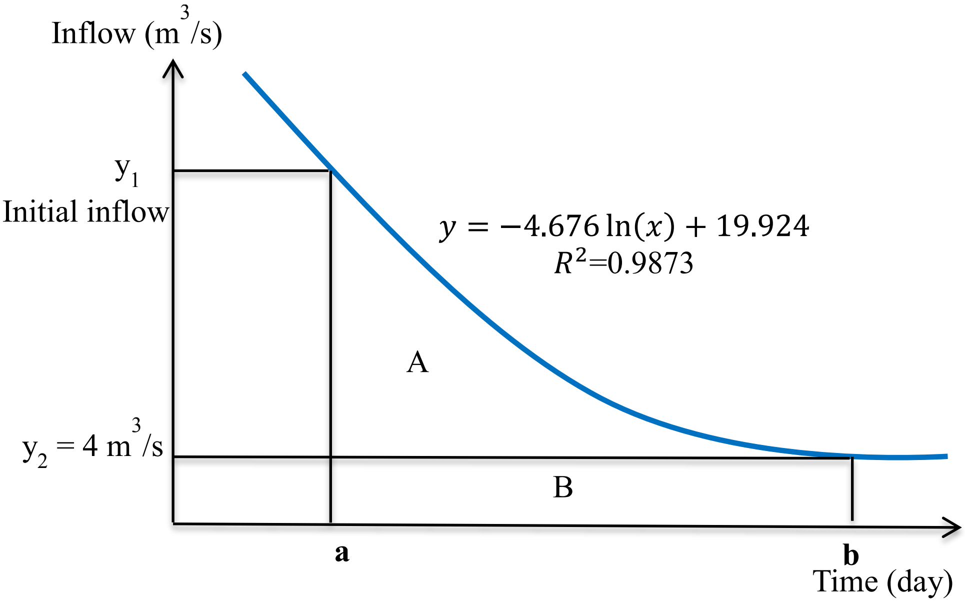


Figure 6.30 Calculation of volume for recession assumption

$$Area\ (A) = \int_a^b (-4.676\ln(x) + 19.924)dx - \int_a^b y_2 dx \qquad (6.5)$$

Since y_2=4 m^3/s (6.6)

$$A = V_{total} = \int_a^b (-4.676\ln(x) + 15.924)dx \qquad (6.7)$$

$$Since\ \int -4.676\ln(x)\,dx = UV - \int VdU \qquad (6.8)$$

And $U = \ln(x)$ (6.5) and $dU = \frac{1}{x}dx$ (6.9)

$so, dV = -4.676\,dx$ (6.7) and $V = -4.676x$ (6.10)

$$\int_a^b -4.676\ln(x)\,dx = \ln(x)\,(-4.676x) - \int -4.676x\left(\frac{1}{x}\right)dx \qquad (6.11)$$

$$= -4.676x\ln(x) + 4.676x \qquad (6.12)$$

$$V_{total} = -4.676x\ln(x) + 4.676x + 15.924x \qquad (6.13)$$

$$V_{total} = (-4.676x\ln(x) + 20.6x)_a^b \qquad (6.14)$$

If $y = -4.676\ln(x) + 19.924$ (6.15)

$so, x = e^{\left(\frac{y_1 - 19.924}{-4.676}\right)}$ (6.16)

a & b terms can be written in terms of y_1 and y_2:

$a = e^{\left(\frac{y_1 - 19.924}{-4.676}\right)}$ & $b = e^{\left(\frac{y_2 - 19.924}{-4.676}\right)}$ (6.17)

Therefore;

$V_{total} = (-4.676 y_2 ln(y_2) + 20.6x) e^{\left(\frac{y_2 - 19.924}{-4.676}\right)} - (-4.676 y_1 ln(y_1) + 20.6x) e^{\left(\frac{y_1 - 19.924}{-4.676}\right)}$ (6.18)

Finally, this formula (6.18) is embedded into the scripted rule.

Therefore; script rule is applied and 2007 – 2011 years are simulated (Figures 6.31 – 35) in the light of this rule, thereby results are presented and discussed below.

Since initial level of 2007 is low, a scenario is carried out by setting it to 150 m again. Two major spillway releases are applied by recession calculations (can be seen in Figure 6.31). It is remarkable that transition periods are well operated by these spillway releases.

Table 6.3 The scripted rule

```
# required imports to create the OpValue return object.
from hec.rss.model import OpValue
from hec.rss.model import OpRule
from hec.script import Constants
from math import *
def initRuleScript(currentRule, network):
    return Constants.TRUE

def runRuleScript(currentRule, network, currentRuntimestep):


    # create new Operation Value (OpValue) to return
    opValue = OpValue()

    # add your code here
    storts=network.getTimeSeries("Reservoir","Yuvacik", "Pool", "Stor")
    stor=storts.getPreviousValue(currentRuntimestep)
    flowts=network.getTimeSeries("Reservoir","Yuvacik", "Pool", "Flow-IN")
    flow=flowts.getCurrentValue(currentRuntimestep)
    d=4
    a1=-4.676
    a2=-19.924
    a3=20.6
    a4=86400
    totalvolume=(((a1*(exp((d+a2)/(a1)))*log(exp((d+a2)/(a1)))+a3*(exp((d+a2)/(a1))))-(a1*(exp((flow+a2)/(a1)))*log(exp((flow+a2)/(a1)))+a3*(exp((flow+a2)/(a1))))))*a4
    freeboard=56027318.954-stor
    spill=(totalvolume-freeboard)/86400
    if freeboard < totalvolume:
        opValue.init(OpRule.RULETYPE_MIN, spill)
    if freeboard > totalvolume:
        opValue.init(OpRule.RULETYPE_MAX, 0)
    return opValue
```

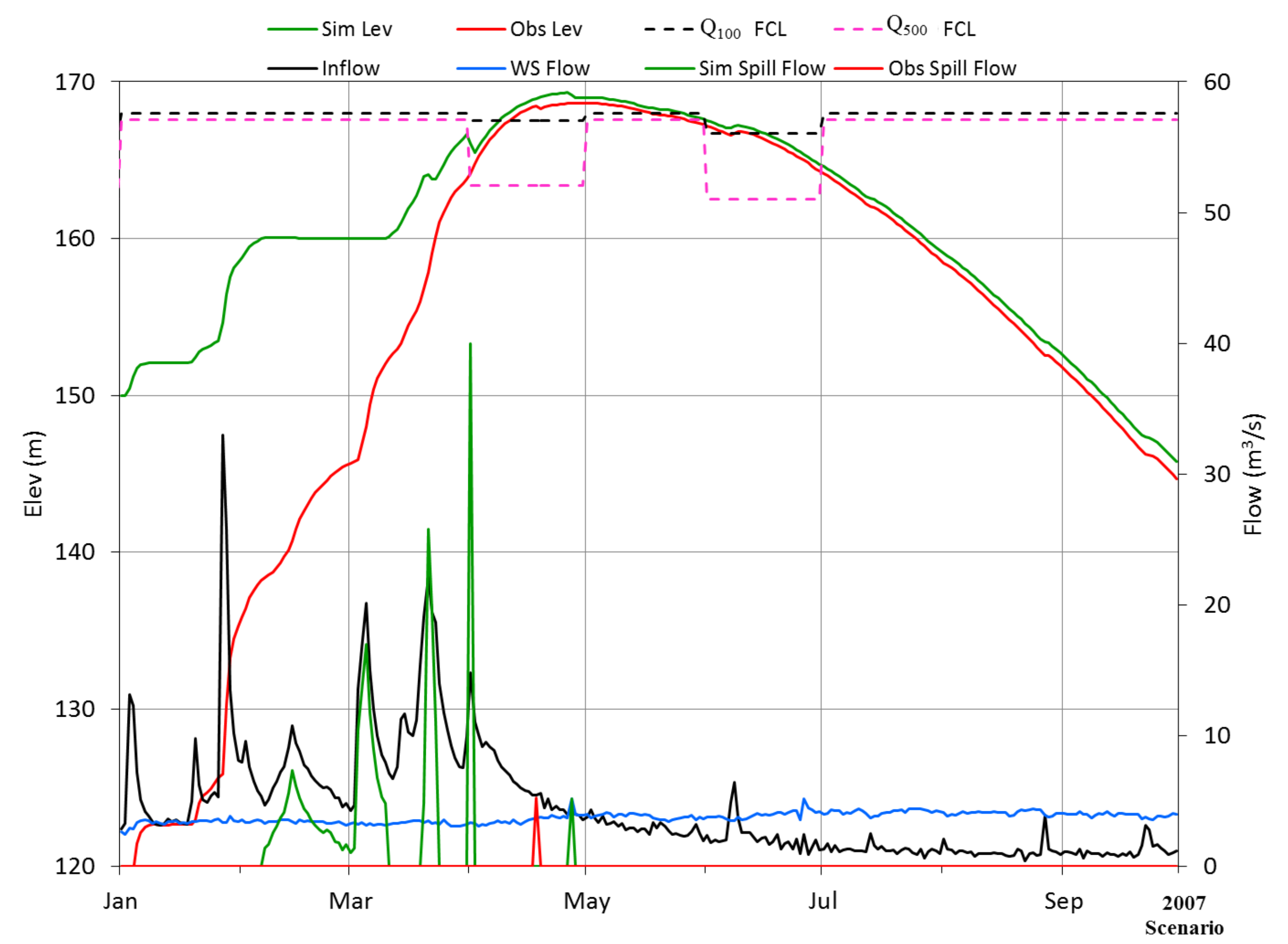


Figure 6.31 Long term water supply simulation results according to third approach (2007 Scenario)

Application of third method gives better results especially for the period of February to May on 2008 (Figure 6.32). It is considerable that spillway releases are similar to observed ones except for the April event. Since the recession method rule is applied for all inflow ranges (it means there is no flow restriction), April event is not evaluated as a new event and recession application calculations is assumed to restart with this event. This situation caused evacuation of more water and decreases the level during the event, afterwards reservoir is operated by storing water until the end of June.

For 2009 water year (Figure 6.33), the simulation and the observation is quite similar to each other after late-March.

The results show that the simulation and observation are similar to each other until the month April for 2010 water year (Figure 6.34). High instantaneous inflows with high rate of increase end up with sudden and huge volume of spillway releases in simulations which is not desirable. Thereby, later inflow cannot provide to store enough volume. The same situation is also observed on June.

This method reflects the operator's point of view especially on 2011 water year (Figure 6.35). When the observed elevation increases, simulation level decreases, and vice versa. The evaluation of this situation is related to operators forecast based pre-release application.

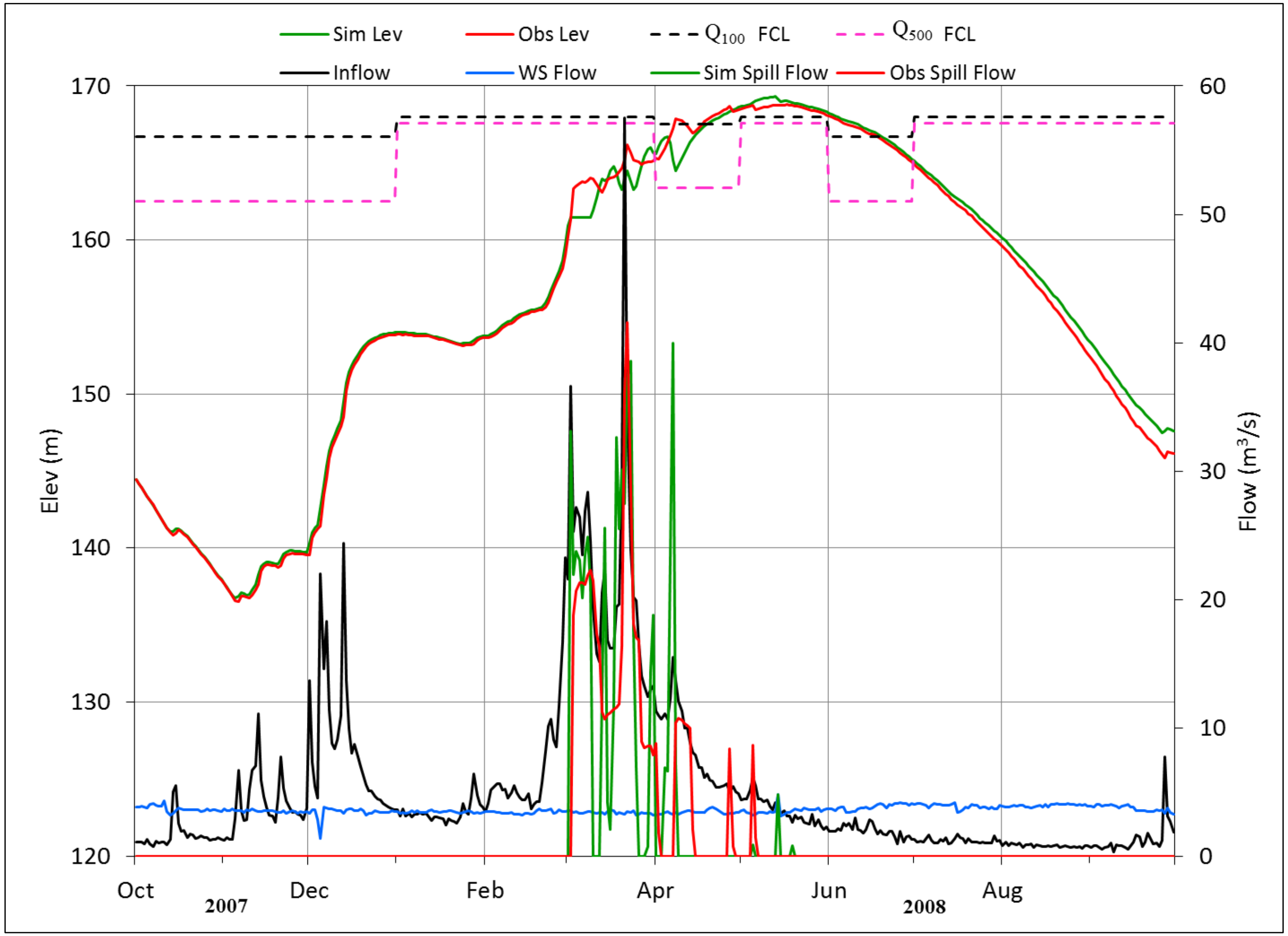


Figure 6.32 Long term water supply simulation results according to third approach (2008)

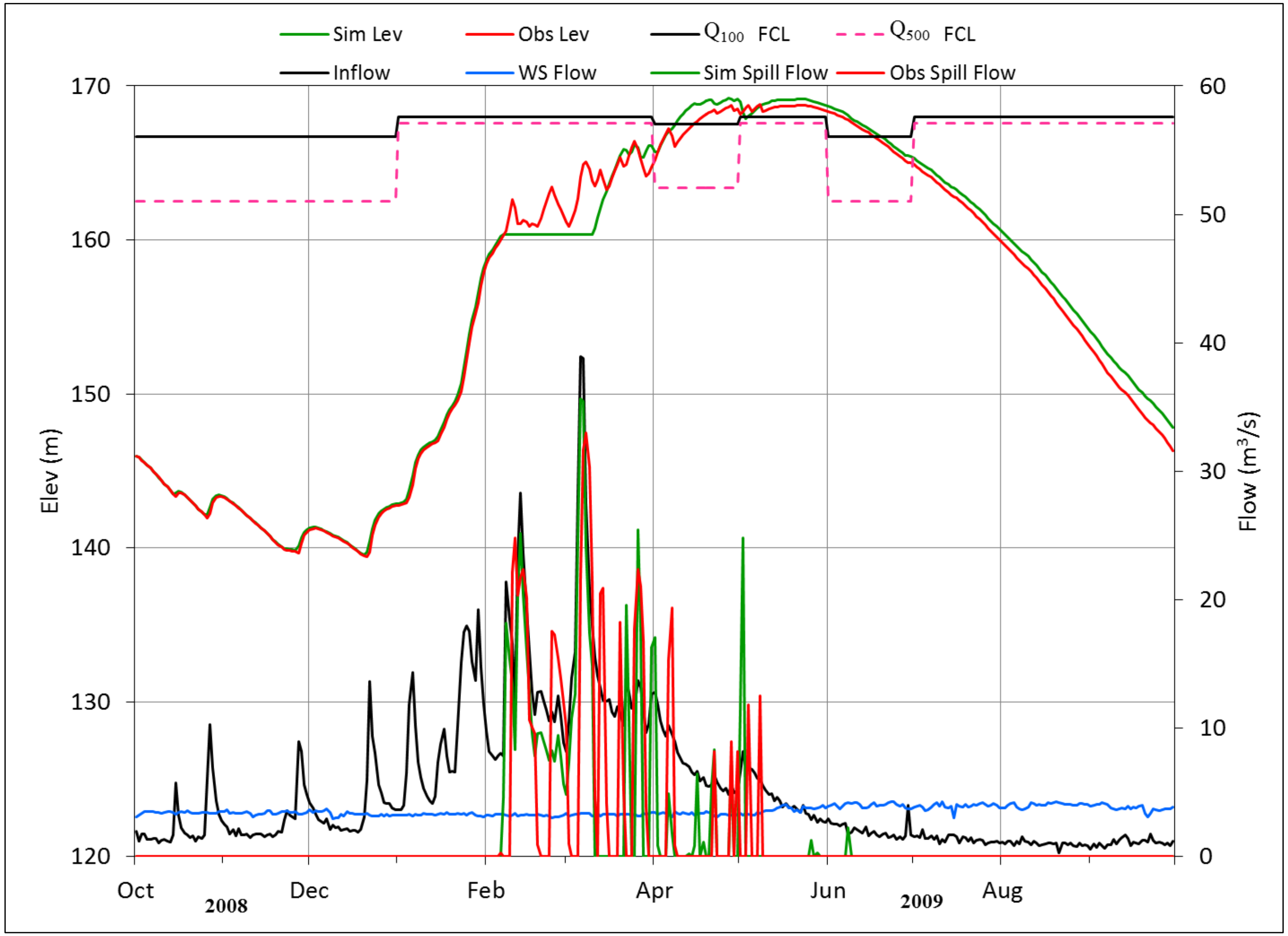


Figure 6.33 Long term water supply simulation results according to third approach (2009)

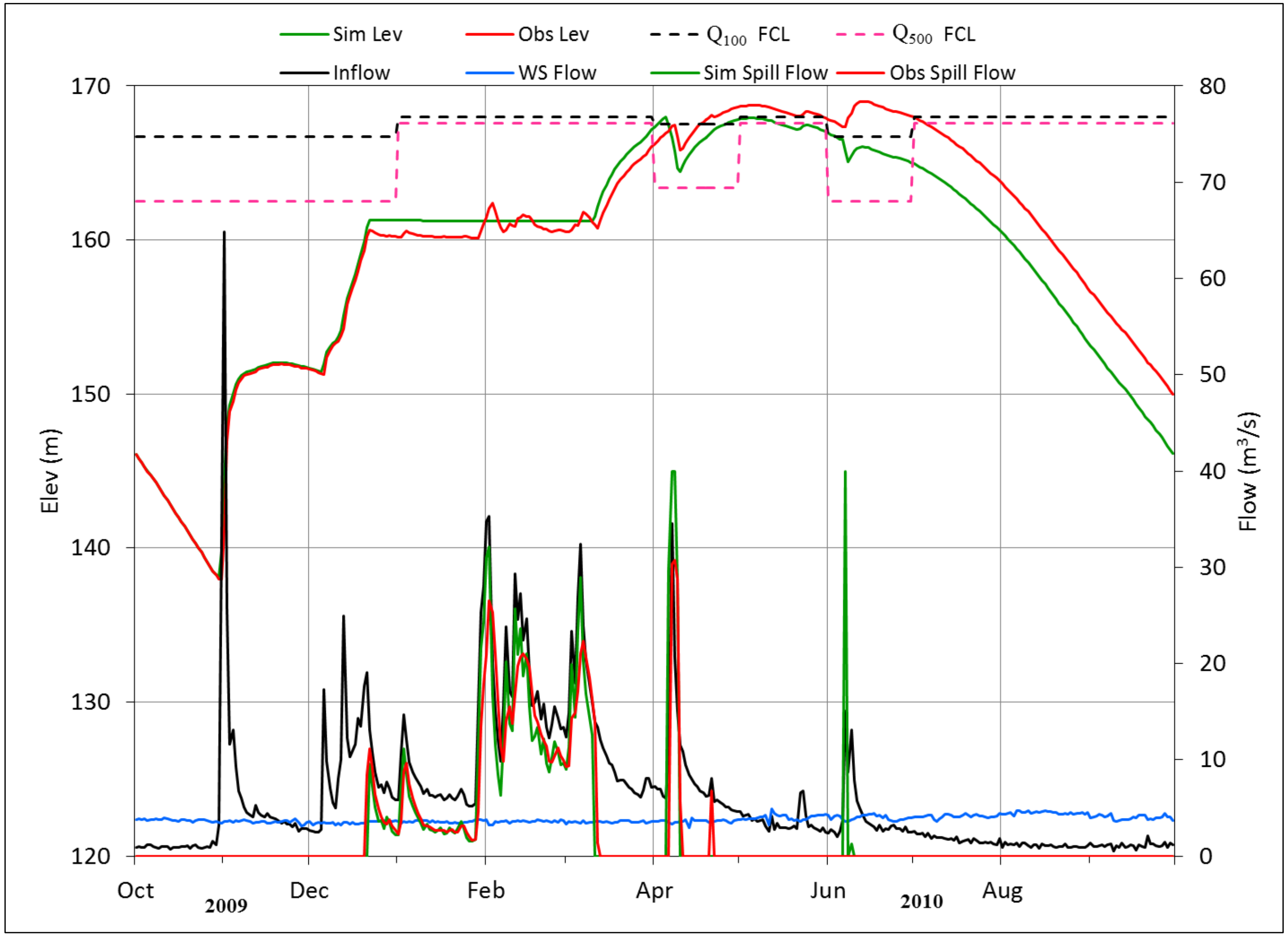


Figure 6.34 Long term water supply simulation results according to third approach (2010)

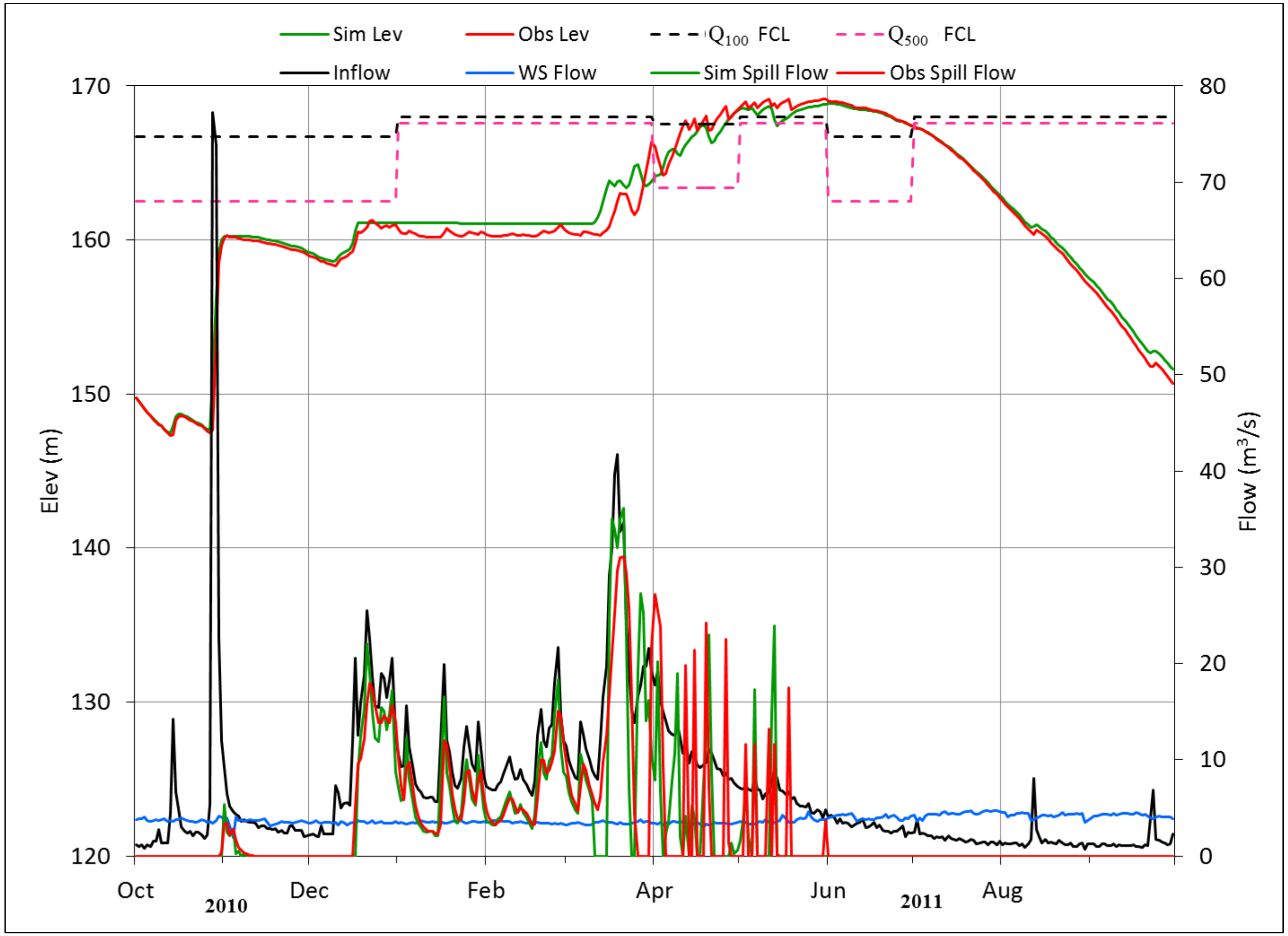


Figure 6.35 Long term water supply simulation results according to third approach (2011)

6.3. Development of New Strategies for Short Term Operation

Flood volume must be as large as possible to use maximum flood control capacity. Hereby, flood regulation is set to achieve the maximum possible flood attenuation by using the full flood-control zone capacity in the reservoir before making releases in excess of the downstream safe-channel capacity. Flood control operation decisions can be organized by long term and short term approaches.

In real time applications, streamflow forecasts provide one or two days ahead daily forecasts. These forecasts will be used in real time operation to take daily decisions. However, in case of a flood risk, it would be necessary to evacuate water before the occurrence of an event. This situation is reflected to DSSS (Figure 6.13) by daily to hourly simulation step. Short term operation strategies are developed using two different scenarios with two different methods and results are discussed.

The flood protection afforded by a reservoir can be enhanced by providing additional reservoir volume for storage of flood water. In case of no information for an upcoming flood event, a short term operation is achieved by operating radial gates with step by step opening. On the other hand an additional volume can be made available on an individual-event basis by responding to NWP MM5 streamflow forecasts. Heeding this forecast information; operators can initiate a preemptive release to evacuate water from the reservoir in advance of the flood. The preemptive release avoids the later high releases.

Two strategies which can quickly be tested, are developed for the short term pre-emptive operation based on MM5 flow forecasts. Pre-release based short term operation strategies are intended for those occasions in which the event is larger than that can be managed by the current flood pool/enlarged outlet combination. The main issue is to deal with pre-releases for an upcoming event.

Since there is no observation that warrants a flood event during the years 2007 – 2011, hypothetical events and flood hydrographs are used in the application of this part.

Maximum channel capacity and water supply rules similar to the rules of long term approach are used; moreover a flow rate of change limit rule is added.

The flow rate of change limit rule specifies allowable change when increasing or decreasing release values. Radial gates are operated step by step procedure.

Two scenarios are tested with two approaches these scenarios are:

Scenario – A

What would be the operation strategy, if 31 October – 08 November 2009 flood event whose peak flow is scaled up to 150 m^3/s *would be observed during 15 – 20 May 2008?*

In this scenario, a real flood event occurred in 31 October – 08 November 2009 is simulated. However; the magnitude and the date of the storm event is changed to end up with a flood risk during the long term operation. While the actual event occurred during October, the scaled new event is assumed to occur in between 15 – 20 May 2008 when the reservoir is almost full.

Scenario – B

What would be the operation strategy, if Q_{100} *flood event whose peak flow is equal to 600* m^3/s *would be observed 15 –17 May 2008?*

Since the short term strategies are necessary especially for critical period when initial pool elevation is higher than available flood control levels, a scenario is carried out to test the effectiveness of approaches by using flood hydrograph of Q_{100}.

In this section, simulation model results are presented for Scenario A with the first approach and for Scenario B with the second approach; overall comparisons and discussion on results are provided in Section 6.4.2.

6.3.1. Changing Guide Curve Approach

When the pool elevation is reset in advance, flood control pool can be enlarged to manage major floods. Therefore, changing guide curve approach provides operators to evacuate water depending on the reservoir elevation.

Scenario-A

Figure 6.36 proves that short term operation strategy with basic rules (maximum channel capacity, water supply and flow rate of change limit rule) is not sufficient to manage this flood event and keep up the initial reservoir elevation value at the end of the event. It should be noted that spillway releases reach up to 270 m^3/s which is greater than the inflow value. Otherwise, the case indicates the risk for dam safety.

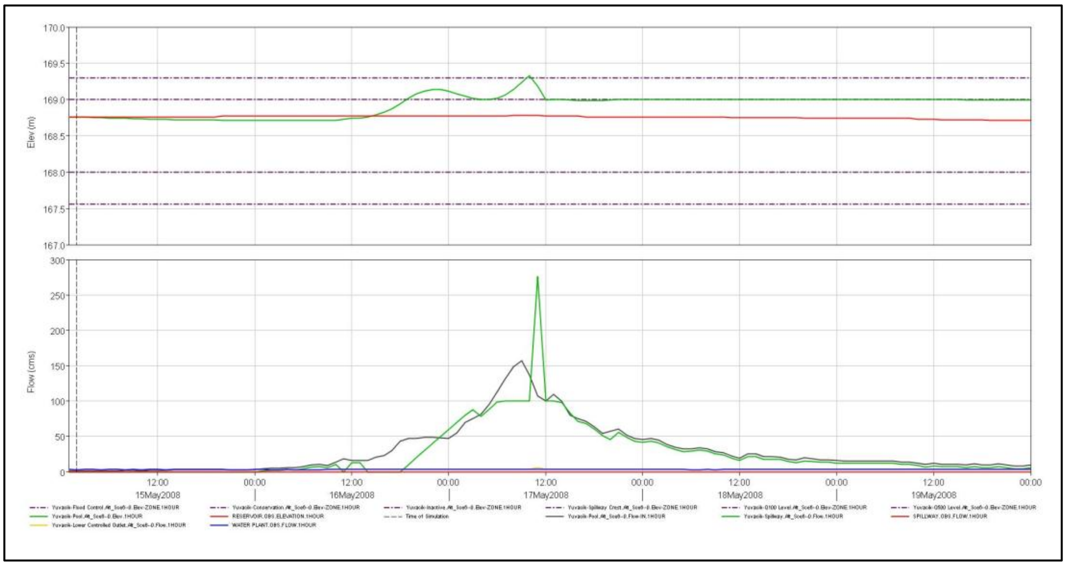


Figure 6.36 Short term operation of scenario-A with basic rules

Afterwards, the guide curve is changed in advance to handle this major flood, and applicability is analyzed (Figure 6.37). A new guide curve is chosen in advance (here, Q_{100} FCL) and pre-releases are taken into consideration. Current reservoir elevation is reset to 167.5 m by this strategy, and maximum channel capacity (100 m^3/s) is not exceeded. As a result, the flood hydrograph is operated in a safe manner by means of pre-releases, but it is considerable that the reservoir elevation at the end of the event would not satisfy the water supply due to the low reservoir level. This is the main disadvantage of the method, since it is as not taking refilling process into account, it is not adaptable for real time applications.

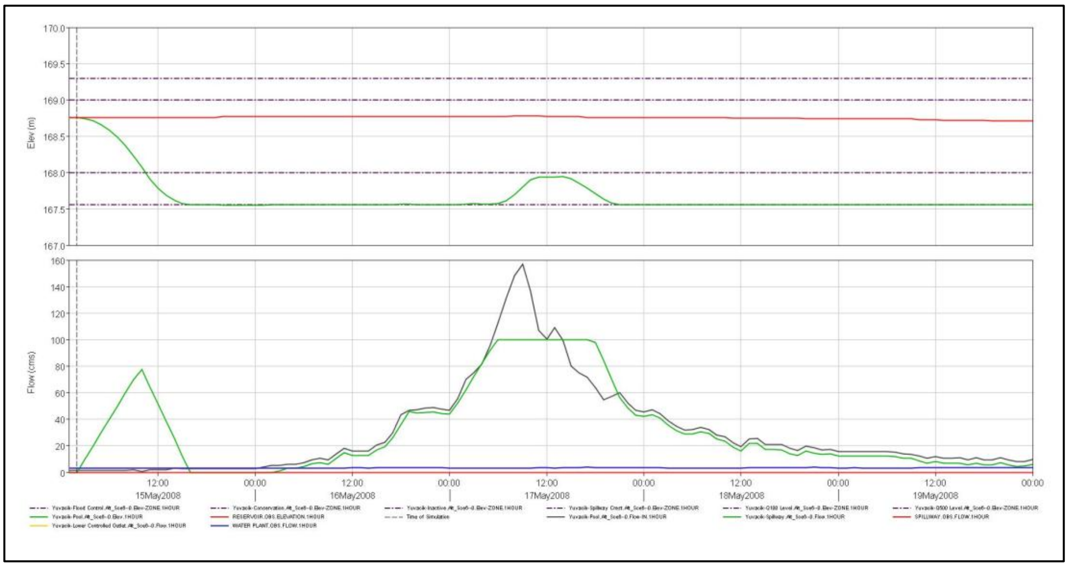


Figure 6.37 Short term operation of Scenario-A with the changing guide curve approach

6.3.2. Scripted Rule based Advance Release Approach

The main application strategy for ResSim is established on a guide curve and user defined rules for conservation and flood control purposes. However, a kind of forecast module that deals with forecasted inflow has not been developed in ResSim by USACE yet. The current rules account on model variables (inflow, elevation, flow etc.); external variables that are not directly used in water budget calculations; and state variables developed to provide user scripted model or state variables. However, there is no generalized rule accounting on upcoming forecasted event (e.g. MM5 based streamflow forecasts) that will initiate water release for pre-emptive purposes.

A scripted rule as expressed in previous sections is a powerful rule type and provides flexibility to write any objective into the program. Therefore, a rule is scripted in ResSim to initiate advance spillway discharges depending on the probable flood volume and be intended for an operator to estimate pre-release time and magnitude of spillway releases in advance. HEC (2002) also used a rigorous method for an advance release strategy by the “uncertainty version” of the Folsom Reservoir Release Forecast Model (RRFM) developed by Utah State University. To that end, several scenarios are generated using peak flood hydrographs and a decision support system is developed to operate short term flood events.

Strategy

The designated strategy is based on the volume of the forecasted event hydrograph. The basic comparison between no advance release and scripted rule based advance release methods is described in Figure 6.38. The main idea is to calculate and find the required amount of release that does not exceed channel capacity. On the other hand, initial reservoir level should be equal to the final reservoir elevation at the end of the short term operation.

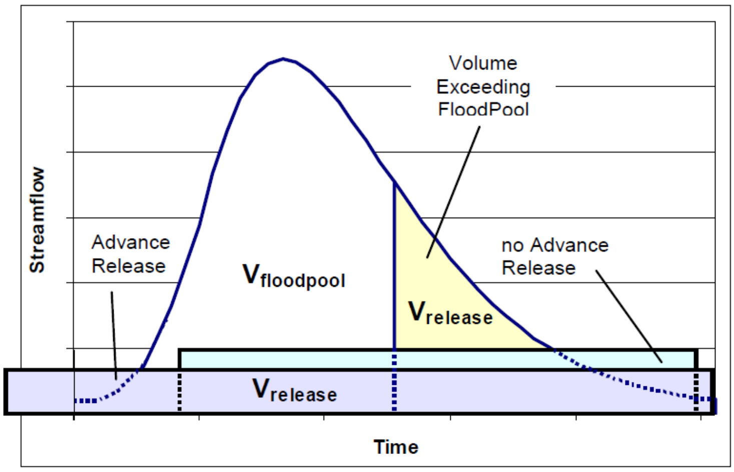


Figure 6.38 Minimum release during a flood event, level of release vs. duration of release

Before describing the calculation steps of the method, general terms used in advance release method are defined below:

Event Volume (m^3); is the total volume of 24 hours peak flow flood hydrograph.

Release Time (hour); defines how early the pre-release must be started. Since streamflow forecast is available one day ahead in current conditions, release time is defined as user oriented (6 or 12 hours). It should be manually selected according to the operators initiative.

Release Duration(hours); is the duration of release and must be defined simultaneously with *Required Release Amount*.

Freeboard (m^3); is the available volume during *Release Time* step.

Required Release Amount (m^3); the minimum volume of release necessary to avoid the flood; the inflow volume in excess of $V_{freeboard}$.

Guide Curve Elevation; the target value is set to the initial reservoir level which is necessary to meet the final reservoir elevation especially for the recession part of the inflows. The main disadvantage that encountered while simulating the 1st Short Term Approach, is not achieving the initial reservoir elevation at the end of the simulation. This could be achieved by means of guide curve and advance release calculations.

The calculation procedure is:

(1) Firstly, a trigger test simulation is done to check whether a flood event is expected or not.

(2) If the trigger test simulation results prove that it is not possible to operate flood volume without exceeding channel capacity, an advance release operation must be done.

(3) *Release Time* and *Release Duration* must be selected by the model user. Alternatives can be tested to decrease Advance Release magnitude and timing; and provide flexibility on decisions.

(4) Required Advance Release amount is calculated by the equation (6.19):

$$\textit{Advance Release}\ (m^3/s) = \textit{Required Release Volume} \,/\, \textit{Release Duration} \qquad (6.19)$$

Although overall procedure is similar for all scripted flood rules, some terms can change depending on user defined release time and duration. Therefore, a scripted flood regulation rule for 12 hours *Release Time* and 24 hours *Release Duration* is given in Table 6.4.

Table 6.4 Scripted advance release rule

```
# required imports to create the OpValue return object.
from hec.rss.model import OpValue
from hec.rss.model import OpRule
from hec.script import Constants
from math import *
def initRuleScript(currentRule, network):
        return Constants.TRUE
def runRuleScript(currentRule, network, currentRuntimestep):

        opValue = OpValue()
storts=network.getTimeSeries("Reservoir","Yuvacik Reservoir", "Pool", "Stor")
stor1=storts.getValue(0)
freeboard=56027318.954-stor1
flowts=network.getTimeSeries("Reservoir","Yuvacik Reservoir", "Pool", "Flow-IN")
flow14=flowts.getValue(++14)
flow15=flowts.getValue(++15)
flow16=flowts.getValue(++16)
flow17=flowts.getValue(++17)
flow18=flowts.getValue(++18)
flow19=flowts.getValue(++19)
flow20=flowts.getValue(++20)
flow21=flowts.getValue(++21)
flow22=flowts.getValue(++22)
flow23=flowts.getValue(++23)
flow24=flowts.getValue(++24)
flow25=flowts.getValue(++25)
flow26=flowts.getValue(++26)
flow27=flowts.getValue(++27)
flow28=flowts.getValue(++28)
flow29=flowts.getValue(++29)
flow30=flowts.getValue(++30)
flow31=flowts.getValue(++31)
flow32=flowts.getValue(++32)
flow33=flowts.getValue(++33)
flow34=flowts.getValue(++34)
flow35=flowts.getValue(++35)
flow36=flowts.getValue(++36)
flow37=flowts.getValue(++37)
flow38=flowts.getValue(++38)
totalvolume=(flow14+flow15+flow16+flow17+flow18+flow19+flow20+flow21+flow22+flow23+flow24+flow25+flow26+flow27+flow28+flow29+flow30+flow31+flow32+flow33+flow34+flow35+flow36+flow37+flow38)*3600
release=(totalvolume-freeboard)/86400
time=currentRuntimestep.getStep()
if (freeboard < totalvolume) & (time < 26):
        opValue.init(OpRule.RULETYPE_MIN, release)
return opValue
```

Scenario – B

The summary of the scenario is described as:

Simulation period **:** 15 – 17 May 2008
Initial water level **:** 168.76 m
Flood hydrograph **:** Q_{100}
$\mathbf{t_p}$ = 6 hours, $\mathbf{t}_b$ = 24 hours

Step – 1 Trigger Test Simulation:

A trigger test simulation is done (Figure 6.39) and according to the simulation results, spillway releases exceed channel capacity. Therefore, it is decided that the pre-emptive decisions must be taken to regulate flood volume without increasing the flood risk.

Step 2 – Pre-release with 6 hrs Release Time

A scripted rule based advance release is simulated by taking *Release Time* as 6 hours and *Release Duration* as 18 hours (Figure 6.40). The real time operation of radial gates requires controlling the gates by the flow change increment. Moreover, the release discharges should be increased by 30 m^3/s during the start and end of the spillway operation.

At the end of the simulation, the spillway releases reach to approximately 250 m^3/s, although radial gates opened directly.

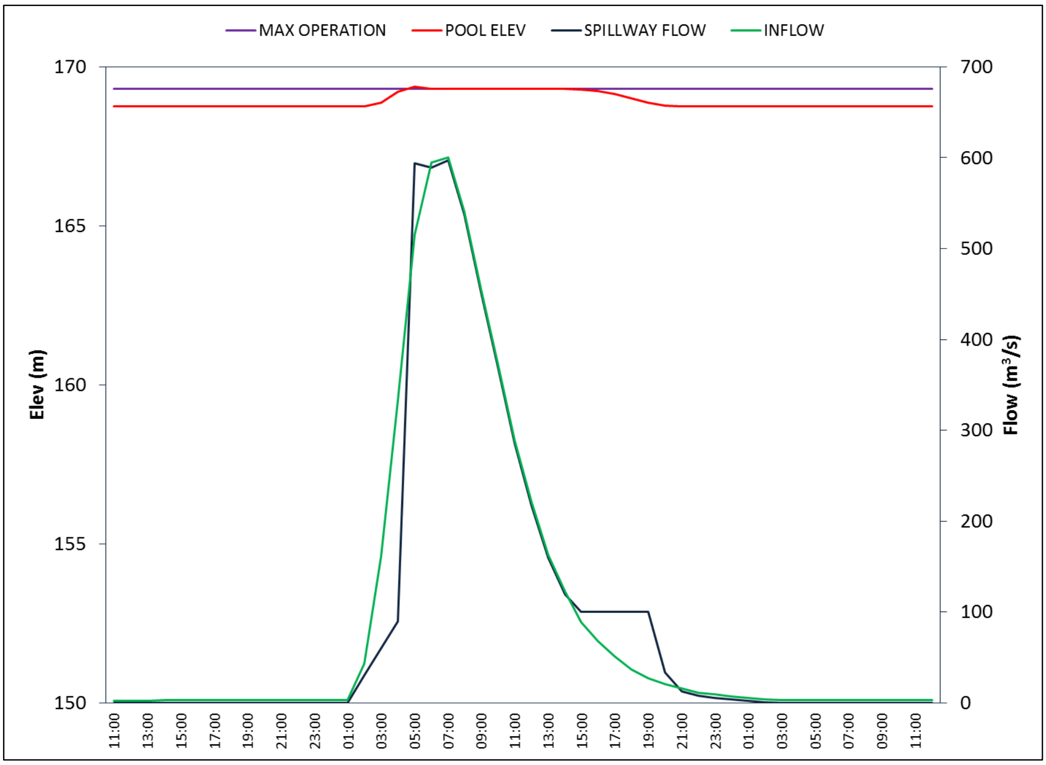


Figure 6.39 Scenario – B Trigger test simulation result

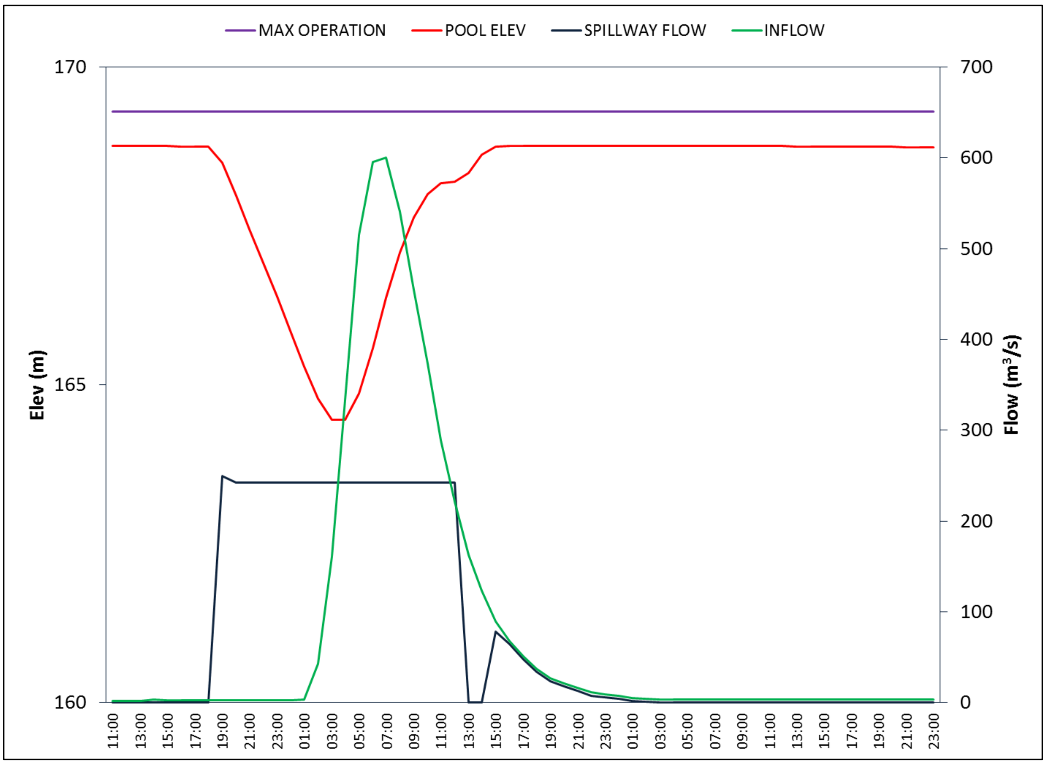


Figure 6.40 Step 2 result of Scenario – B

Step 2 – Pre-release with 12 hrs Release Time:

Finally, an advance release is simulated by taking *Release Time* as 12 hours and *Release Duration* as 24 hours (Figure 6.41). The spillway flow is increased up to 187 m^3/s by pre-release flood regulation policy. Hereby, spillway flows are controlled by increments while operating gates.

It is remarkable that neither the spillway flows exceed channel capacity of emergency case limit (200 m^3/s) nor the reservoir elevation after operation is significantly different from the initial value. Thus, the initial elevation value is provided at the end of the short term operation to ensure water sustainability. The results are promising for real time application in terms of Release Time, Release Duration, Maximum Spillway Release.

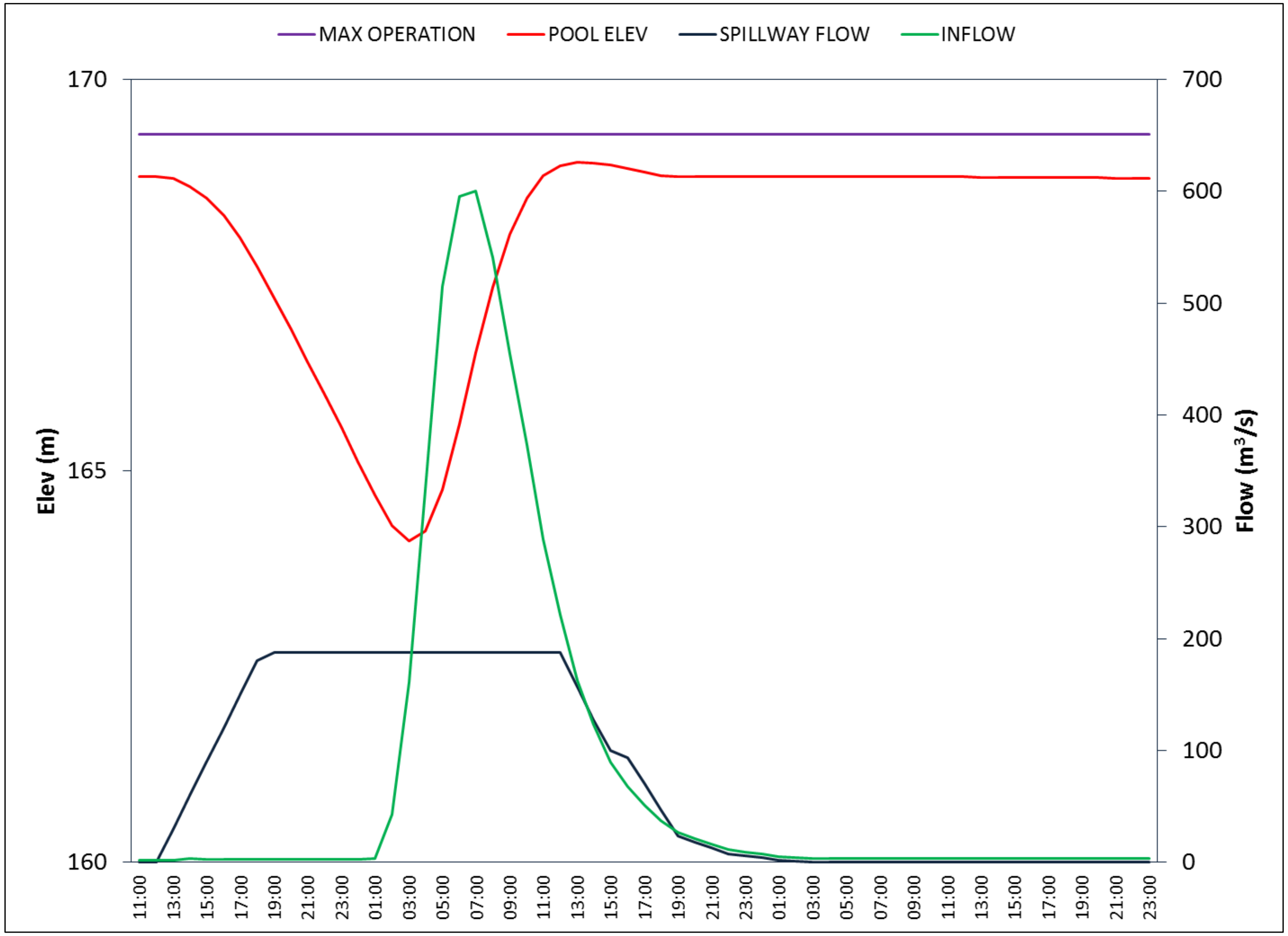


Figure 6.41 Scenario – B Pre-release before 12 hours simulation result

6.4. Discussion of Simulation Model Results

Reservoir operation is divided into two basic approaches in the development part. Long term daily decisions depend on how much water should be stored or released considering current water potential, and water need in advance without unduly increasing flood risk. Short term hourly decisions require the evaluation of MM5 based streamflow forecast with a flood risk, and pre-release operation to manage these kinds of events.

After the application of model simulations, results should be evaluated and goodness of performance should be defined. Since there is no direct measure to test the efficiency of the results, some indicators come into account to evaluate the performance of the different simulation approaches. These indicators can be considered as water supply sufficiency, maximum water level considered together with alarm zones, FCL exceeded days, spilled amount of water, mechanical efficiency of radial gate operations, etc.

First of all, long term simulation approaches are compared with each other. To that end, simulation results are compared with each other and also with drought zones. However, it should be noted that although the reservoir level drops to a drought zone, it may still serve demanded amount of water.

Short term results are presented by several scenarios and their applicability and efficiency are discussed by comparisons, accuracy of the target rules and consistency of resultant reservoir levels with the long term simulations.

6.4.1. Discussion on Long Term Operations

Daily operation of Yuvacık Reservoir considering both flood control and water supply strategies necessitates taking complex decisions. While developing a simulation model, the basic challenge is to define a guide curve. Since it is difficult to define a target elevation for this specific reservoir, several approaches are developed and long term water supply strategies are simulated using these approaches.

Since each method has some advantages and disadvantages, a combined method taking the advantages of all methods is proposed in this section and simulation results of this method are evaluated at the end.

Combined Method

Methods (approaches) are developed depending on several assumptions and experiences of operators. Each method has advantages and disadvantages that depend on season, inflow characteristic and snow conditions. For example; since it is one of the challenging issue to decide the date on which the radial gates are closed during snow melting season, it is considered that Method 1 “snow rule” is well applicable. However, recession release rule is powerful to achieve better simulation results concerning the amount of water released or stored especially in times of low flow conditions. While applying the recession release rule, convective precipitation (falls over a certain area for a relatively short time) can cause a sudden increase of inflow (generally April and May). This increase will not be a part of a general recession curve. Thereby, it is not suitable to apply recession release rule for a new storm event during the recession period. Then, it is proposed to apply rate of increase rule of Method 1 for inflows greater than 12 m^3/s. The simulation results also indicate that operating the reservoir using a target variable guide curve approach (Method 2) is not efficient.

Combined method is developed and simulated through 2007 – 2011 (Figure 6.42 – 6.46) water years. The final combination of the rules in the method is described in Table 6.5:

Finally, comparison tables (Table 6.6 – 6.18) are prepared to understand the performance of the methods. The results of 2007 are not reflected to summary table due to the special characteristics of this year.

Table 6.5 Combined method rules

Name	**Description**	**Reference**
YUVACIK DAM		
FLOOD CONTROL	169.30 m	Max Ope. Elev.
These rules are same with conservation pool		
CONSERVATION	169.00 m	Long Term Water Supply Strategies
Municipal Water (Lower Controlled Outlet Rule)	Function of external variable time series – used to set “water supply” as specified demand.	City demand
October-February If, Level > 159.95 m And, Season btw. Oct – Feb **Max Spill** (Spillway Rule) **Spill as observed** (Spillway Rule)	**If,** Pool elevation ≥ 159.95 m **&&** (01 Jan ≤ Current time step ≤ 01 Mar) | | (01 Oct ≤ Current time step ≤ 31 Dec) Max release set to be 40 m^3/s Function of model variable time series. Minimum release set to inflow,	Experinces based on long term operations
Snow rule If, Season is April And, (RG-8 Snow depth >= 0.2 m and, Snow depth is increasing) Or, (RG-8 Snow depth < 0.2 m And, RG-9 Snow depth >= 1m And, Pool Elev >= 164 m) Or, (RG-9 Snow depth <0.2 m And, Pool Elev >= 167 m) **Max Spill** (Spillway Rule) **Spill as observed** (Dam Rule)	**If,** (Current time step >= 01Mar && Current time step <=20 Apr) && ((RG-8:SD >=0.2) II (RG-8:SD$_{\text{current}}$>=RG-8:SD$_{\text{previous}}$)) II (RG-8:SD$_{\text{current}}$ <0.2) && (RG-9:SD>=1&&Pool:Elev>=164) II (RG9_SD<0.2 && Pool:Elev_Cur>=167)) Max. release set to be 100 m^3/s Function of model variable time series. Minimum release set to inflow – thus, the spill will be at least the inflow value	Experince rule, based on snow period
Rate of increase rule If, Season btw. April – May And, Level > =167 m And, Inflow is increasing And, Inflow >12 m^3/s **Max Spill** (Spillway Rule) **Spill as 1.5 times of observed** (Dam Rule)	**If,** Pool elevation ≥ 167 m && (01 Mar ≤ Current time step ≤ 31 May) && (Inflow$_{\text{current}}$ > Inflow$_{\text{previous}}$[increasing]) Max. release set to be 100 m^3/s Function of model variable time series – used to set spill as observed inflow.	Experince rule, based on maximum pool operations
Recession rule If, Season btw. March – May And, Pool Elev >=159.95 m And, Inflow >= 12m^3/s **Max Spill** (Spillway Rule) **Scripted Rule** (Spillway Rule)	**If,** Pool elevation ≥ 159.95 m && (Inflow ≥ 12m^3/s) Max. release set to be 100 m^3/s Scripte spillway release rule	Calculation based on optimal recession operation
SPILL CREST ZONE	159.95 m	No spillway flow
Municipal Water (Lower Controlled Outlet Rule)	Function of external variable time series – used to set water supply as specified demand.	City demand
No Spill	Minimum relase set to zero	
INACTIVE ZONE	112.50 m	

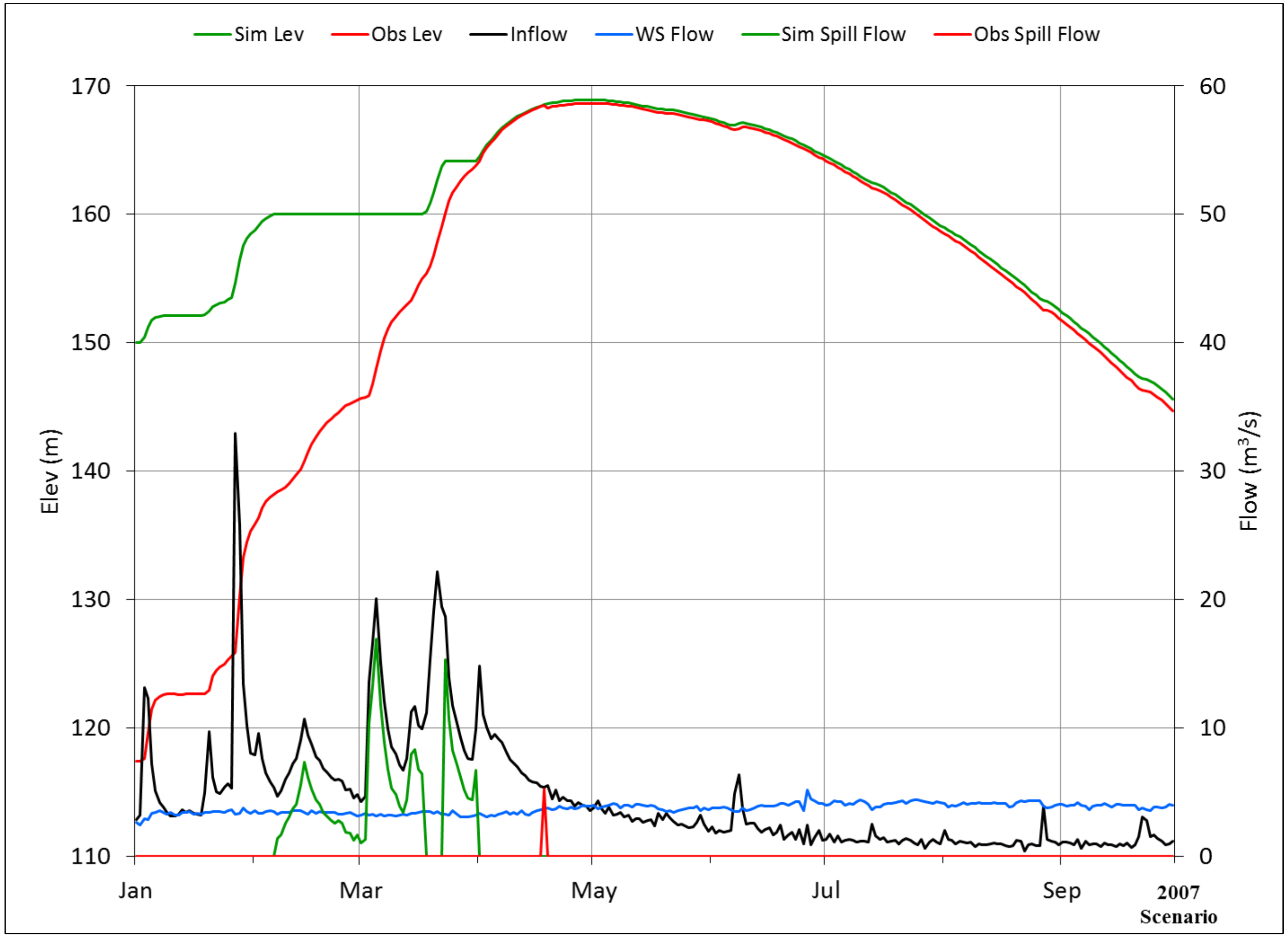


Figure 6.42 Long term water supply simulation results according to combined method (2007 scenario)

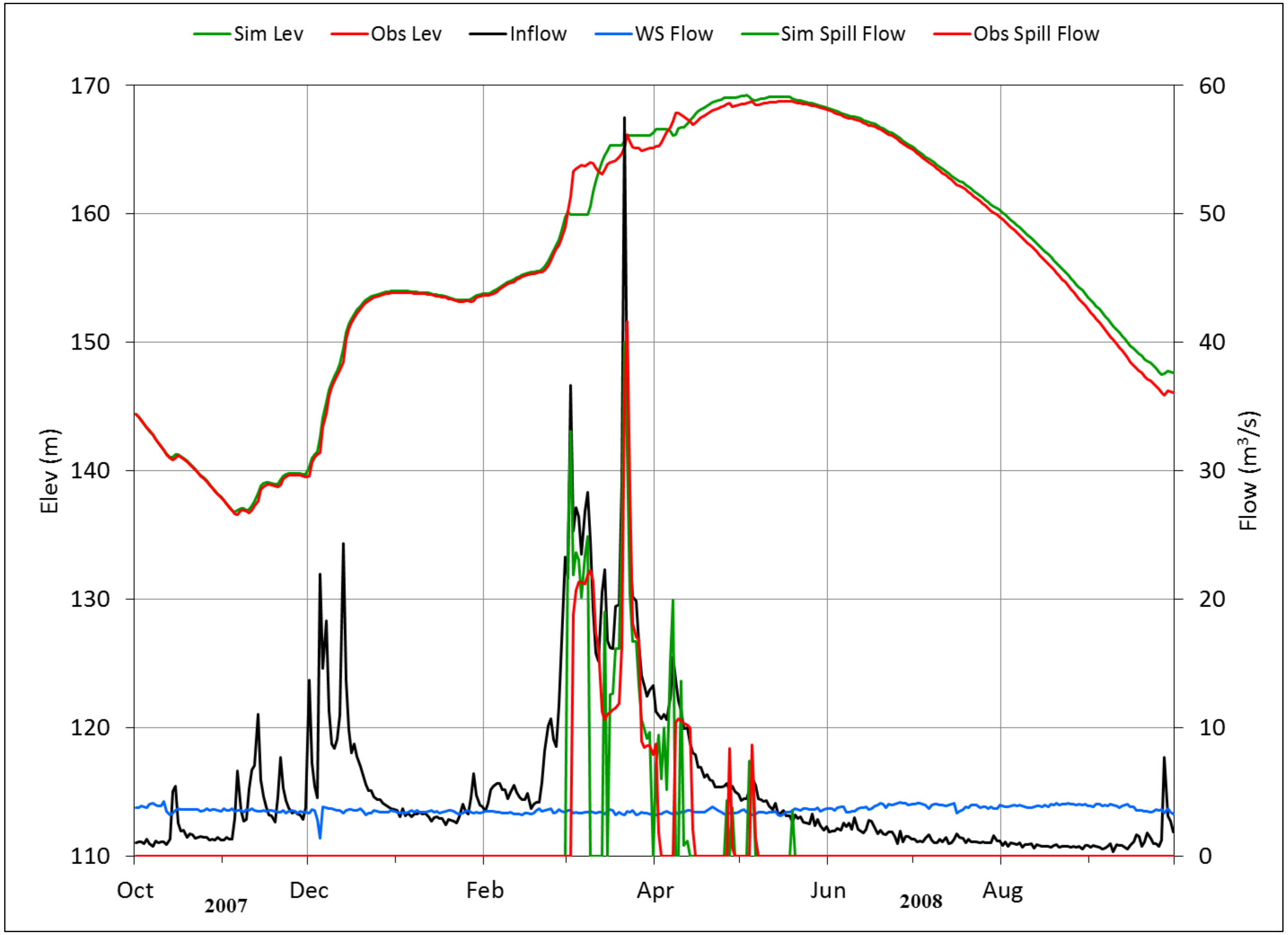


Figure 6.43 Long term water supply simulation results according to combined method (2008)

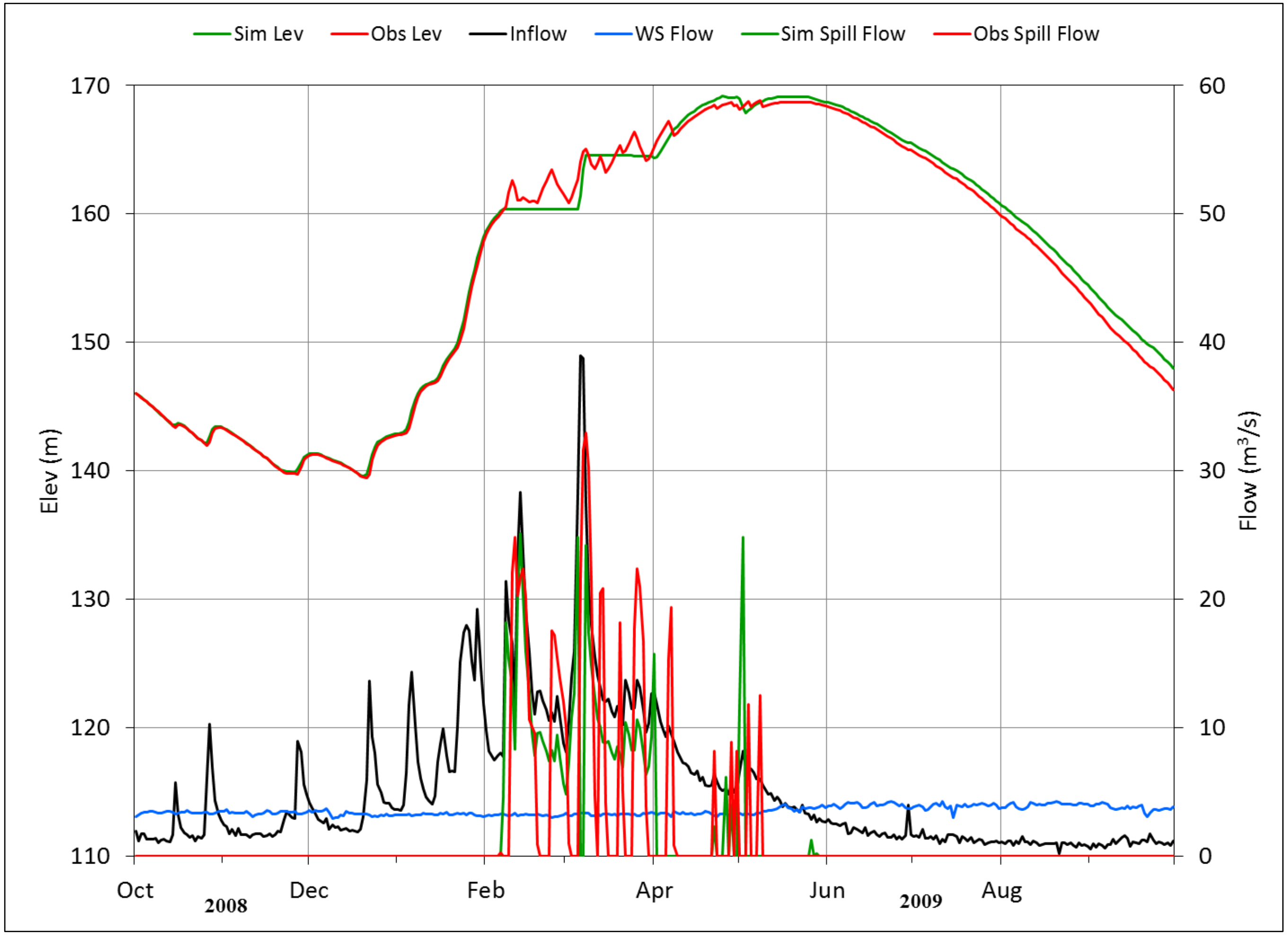


Figure 6.44 Long term water supply simulation results according to combined method (2009)

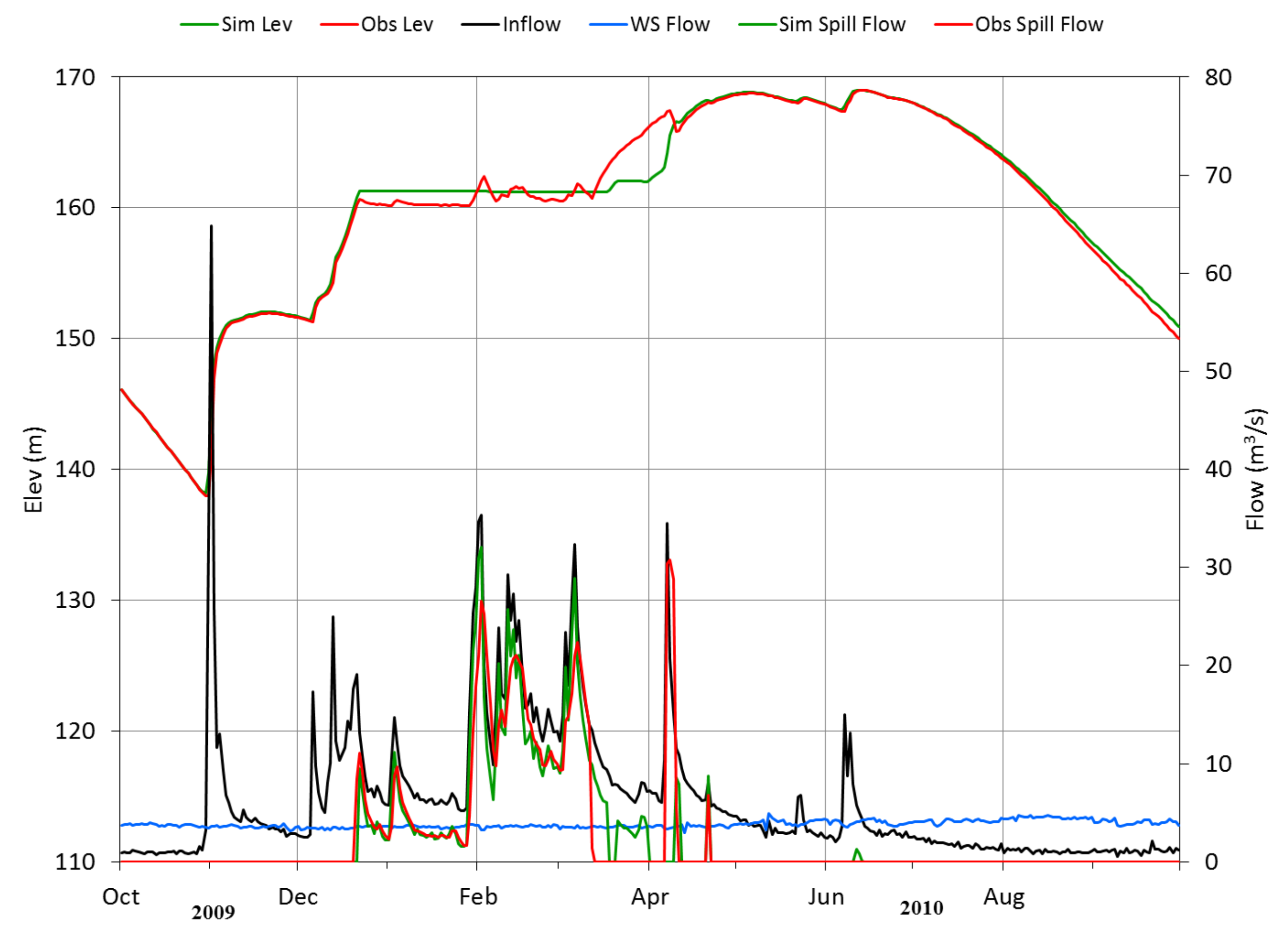


Figure 6.45 Long term water supply simulation results according to combined method (2010)

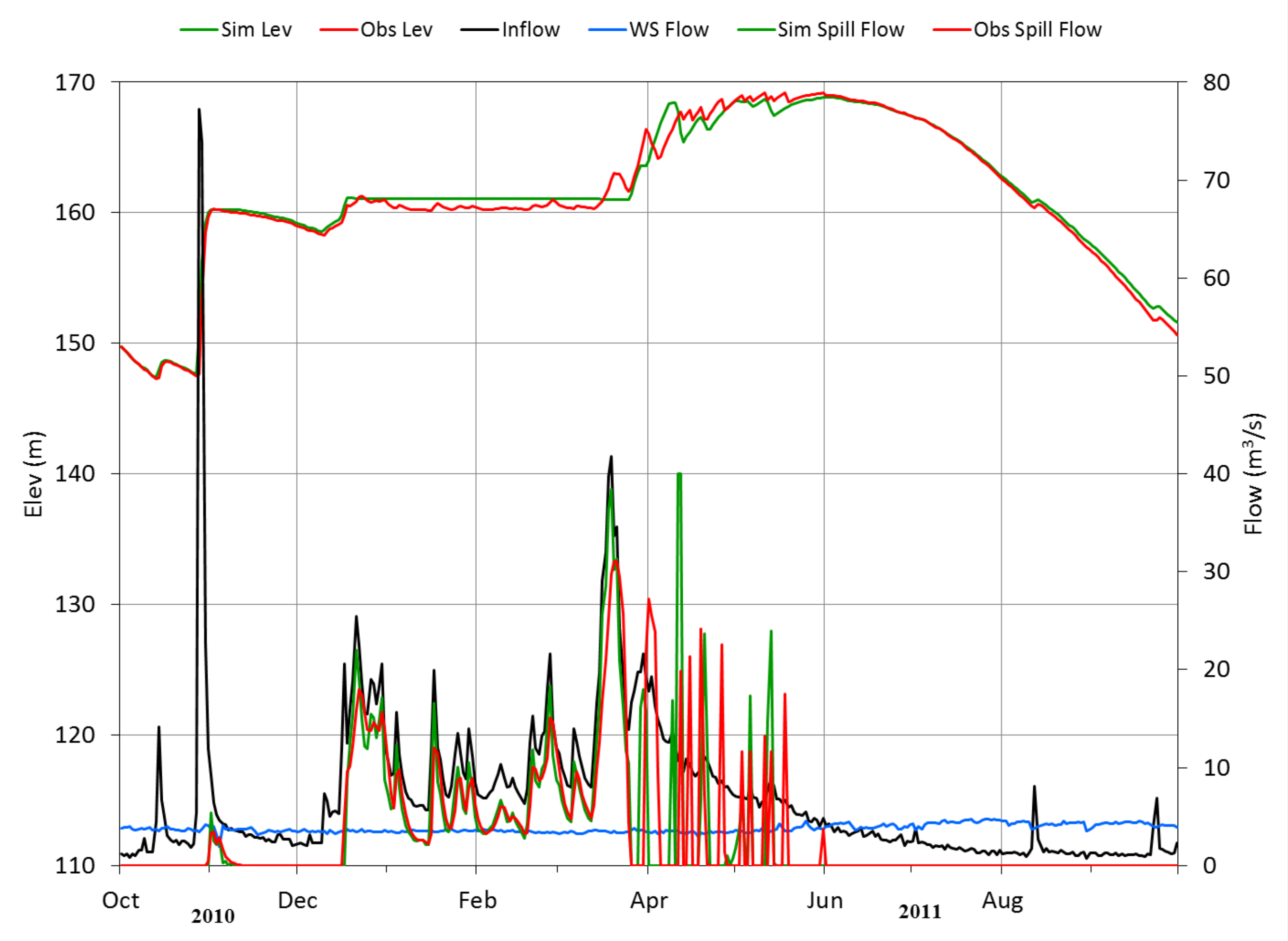


Figure 6.46 Long term water supply simulation results according to combined method (2011)

Maximum pool elevation results (Table 6.6) indicates that all methods except method 2 and observations reach the maximum elevation. Total volume of spillway flows are compared in Figure 6.47 and it is observed that volumes are similar in amount and Method 2 yields more release as expected.

Table 6.6 Maximum reservoir elevations (2008 – 2011)

Pool elevation (m)	2008	2009	2010	2011
Method 1	169.00	169.00	169.00	169.00
Method 2	166.24	168.20	165.79	169.00
Method 3	169.30	169.21	167.79	168.84
Combined Method	169.25	169.16	169.00	168.84
Observation	168.78	168.82	169.00	169.18

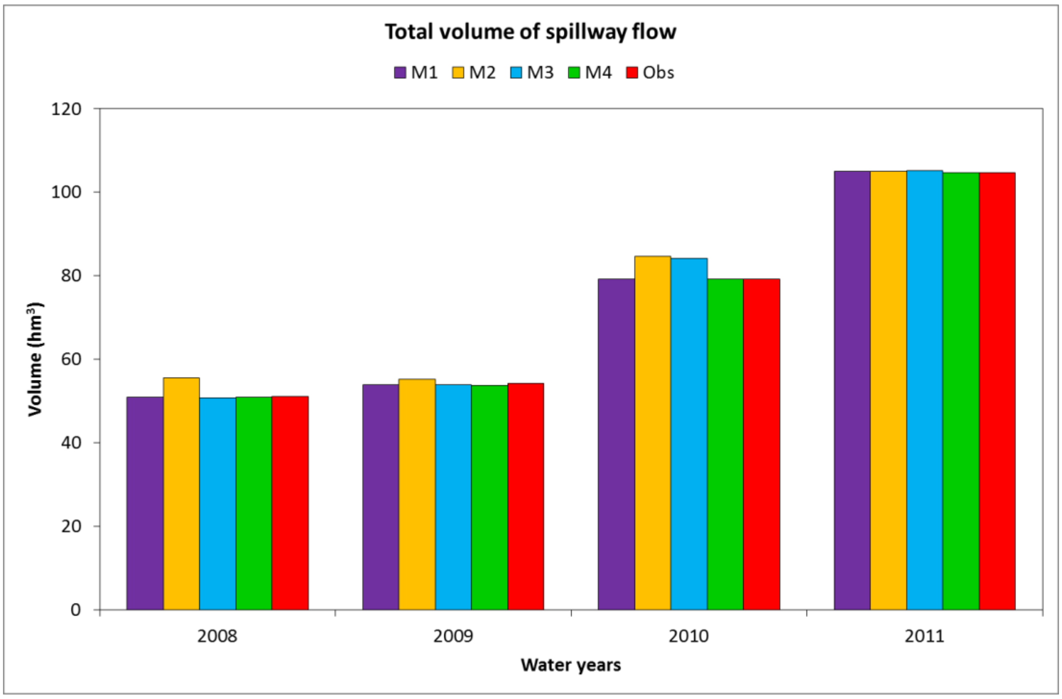


Figure 6.47 Total volume of spillway flows

Although the downstream channel capacity is taken as 100 m^3/s, it is an important criterion to operate the reservoir with lower spillway flows. Therefore, the maximum spillway flows are presented in Table 6.7. Long term simulations are subjected to maximum channel capacity constraint (40 – 50 m^3/s); however methods can advise less than this amount. It is observed that, all methods propose that spillway flows are in between 25 – 55 m^3/s during daily operations.

Table 6.7 Max value of spillway flow (2008 – 2011)

Max Spill (m^3/s)	M-1*	M-2*	M-3*	C-M*	Observed
2008	40.00	54.28	40.00	40.00	41.60
2009	25.13	48.98	35.63	25.13	32.97
2010	32.08	42.94	40.00	32.08	32.08
2011	38.44	37.93	36.09	40.00	31.09

*M-1 is method1, M-2 is method2, M-3 is method3 and C-M is combined method

On the other hand, flood control levels (FCLs) (Table 6.1) propose that reservoir elevation must be decreased in times of a flood risk. Although, it is not possible to operate the reservoir without exceeding the FCLs for water supply purposes, it is still an important criterion to supply water with a minimum risk. So, FCL (Q_{100} and Q_{500}) exceeded days are calculated to check the performance of the methods (Table 6.8 – 6.11).

Table 6.8 FCL exceeded days for March and April (2008)

2008	M-1	M-2	M-3	M-4	Observed
Q_{100}	21	0	7	14	10
Q_{500}	46	13	31	36	45

Table 6.9 FCL exceeded days for March and April (2009)

2009	M-1	M-2	M-3	M-4	Observed
Q_{100}	11	0	20	16	13
Q_{500}	39	11	39	42	41

Table 6.10 FCL exceeded days March and April (2010)

2010	M-1	M-2	M-3	C-M	Observed
Q_{100}	17	0	2	12	9
Q_{500}	18	10	25	15	28

Table 6.11 FCL exceeded days March to April (2011)

2011	M-1	M-2	M-3	C-M	Observed
Q_{100}	23	0	3	6	6
Q_{500}	27	2	21	13	20

Since the reservoir reaches its peak value in May, FCL exceed days for May are shown in separate tables Table 6.12 – 15.

Table 6.12 FCL exceeded days for May (2008)

2008	M-1	M-2	M-3	M-4	Observed
Q_{100}	31	0	31	31	31
Q_{500}	31	0	31	31	31

Table 6.13 FCL exceeded days for May (2009)

2009	M-1	M-2	M-3	M-4	Observed
Q_{100}	31	18	30	30	31
Q_{500}	31	25	31	31	31

Table 6.14 FCL exceeded days for May (2010)

2010	M-1	M-2	M-3	M-4	Observed
Q_{100}	31	0	0	30	29
Q_{500}	31	0	14	31	31

Table 6.15 FCL exceeded days for May (2011)

2011	M-1	M-2	M-3	M-4	Observed
Q_{100}	31	21	26	26	31
Q_{500}	31	31	30	30	31

One the other hand; it is not mechanically efficient to open and close the radial gates a number of times mechanically during a long term operation. There are two options to operate the radial gates; one of them is to open the gates continuously during snowmelt period and the other is to open and close once in a week during April and May. Hereby; “number of gate openings” (see Table 6.16) are presented to compare the simulations in terms of mechanical efficiency.

Table 6.16 The number of gate opening during long term operation

Years	M-1	M-2	M-3	M-4	Observed
2008	7	4	5	8	4
2009	4	6	11	6	12
2010	5	3	4	5	5
2011	7	9	10	12	12

Furthermore; alarm levels during the summer period (August - September) and reservoir elevations at the end of simulation period (30 September of each year) are presented (see Table 6.17 and 6.18).

Table 6.17 Long term operation methods which goes drought level (August – September)

Years	M-1	M-2	M-3	M-4	Observed
2008	Alarm-1	Alarm-1	Alarm-1	Alarm-1	Alarm-1
2009	Alarm-1	Alarm -1	Alarm-1	Alarm-1	Alarm-1
2010	X	Alarm -2	Alarm-2	X	X
2011	X	X	X	X	X

Table 6.18 Reservoir elevation on 30 September (2008 – 2011)

Years	M-1 (m)	M-2 (m)	M-3 (m)	C-M (m)	Observed (m)
2008	147.63	142.73	147.60	147.60	146.12
2009	147.90	146.49	147.82	148.01	146.32
2010	150.94	145.70	146.13	150.94	146.98
2011	151.83	151.84	151.59	151.59	150.67

Long term simulations of reservoir elevations are compared both with each other, observations and also with drought zones. The initial elevation of 2007 is lower than other years, and reservoir is filled during real time operation. So, a fictitious initial reservoir elevation value is assigned as 150 m for all simulations. Although simulation results are independent from observations, the reservoir elevation is presented in order to compare the operation trends. It is obvious that VGC approach gives the worse results for 2007 critical period (Figure 6.48) and VGC simulation result goes through 2nd drought alarm level. Although there is no drastic change in between other methods, Method 2 and 3 causes storing water earlier than other methods. Since this is an undesirable situation due to increasing flood risk, Method 1 gives better results. On the other hand combined method takes both late storage advantage of method 1 and shows higher water elevation when it is compared with others. By this way, combined is evaluated as the best one for the application of the year.

Method 1 stores water earlier than others in 2008 (Figure 6.49 and Table 6.8). Method 2 is not useful for this year since it represents low reservoir level by entering 2nd drought alarm level (Figure 6.49). Method 3 and combined method are powerful by optimizing the reservoir level due to step by step calculation. According to Table 6.7, 6.12, 6.17 and 6.18, results are very similar to each other. However Table 6.8 and 6.16 show the advantage of method 3.

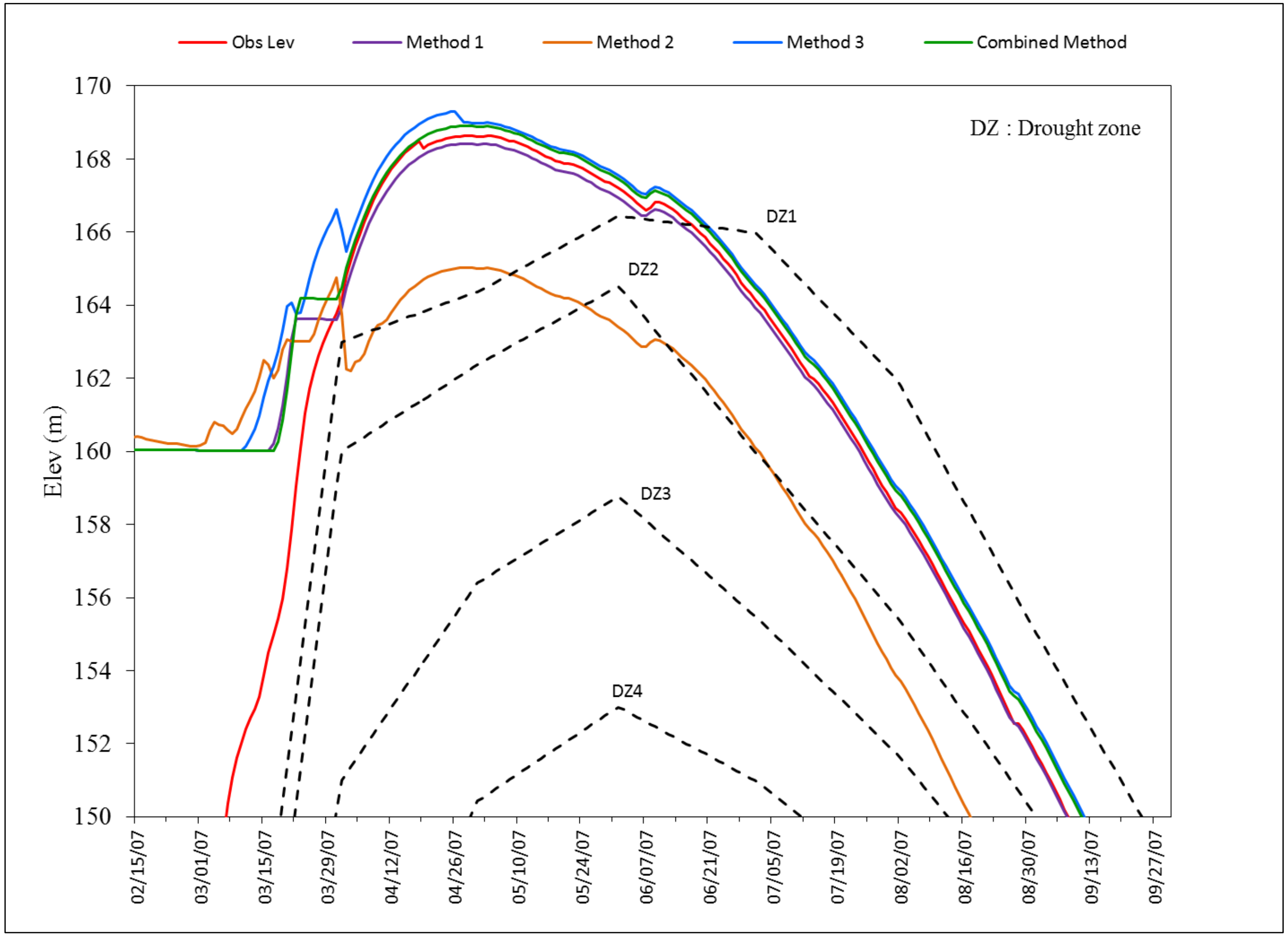


Figure 6.48 Long term water supply simulation results comparisons (2007 Scenario)

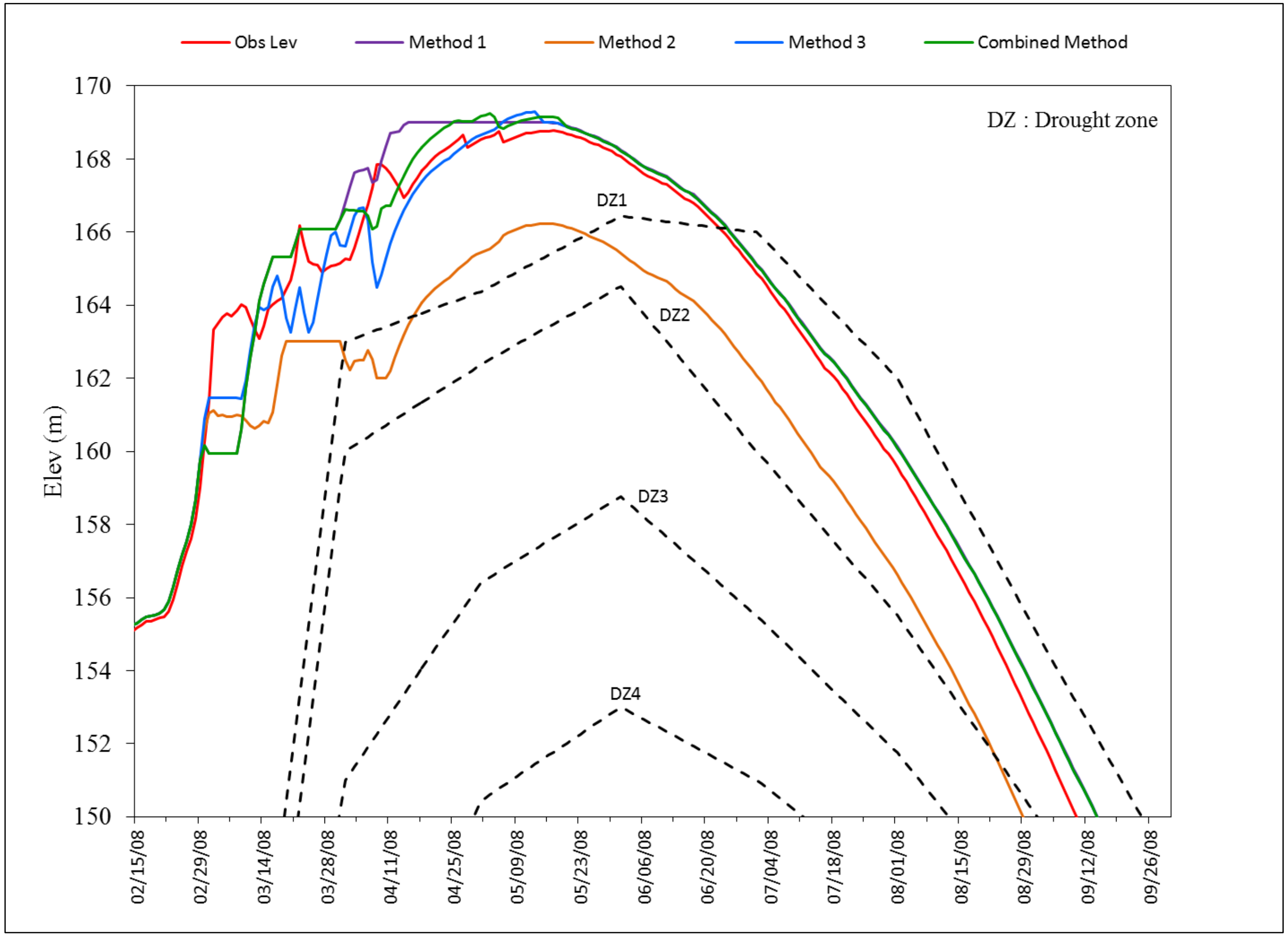


Figure 6.49 Long term water supply simulation results comparisons (2008)

Method 1 and combined method almost indicate same operation (Table 6.7, 6.9, 6.13) in 2009 (Figure 6.50). Method 2 and method 3 evacuate more than expected water especially in sudden inflow increase is observed (Table 6.7). All methods are ahead of the 1st drought zone (Table 6.17).

While all methods and observation suggest to empty reservoir early in April, method 1 is seriously raising the elevation for the year 2010 application (Figure 6.51). Method 3 initiates fast response to the event, and evacuates more amount of water than expected (Table 6.7). On the other hand, combined method provides to store water later and spill water with respect to rate of increase and recession rules so propose a better solution for long term water supply strategy (Table 6.16). Later storage is provided by snow rule, water level is raised by high guide curve and releases are controlled with respect to transition rules in combined method. While Method 1 and combined method are not going through drought zones, Method 2 and 3 directly end up with 2nd drought zone. Therefore, combined method is the best for this simulation.

Looking through 2011 water year (Figure 6.52), it is remarkable that all methods ensure reservoir elevation to be above all drought zones until September. While operators and method 3 prefer to store water on late-April, Method-1 and combined method propose to early storage depending on snow condition (Table 6.11). Large amount of water is evacuated from spillways on early April in combined method which creates basic differentiation. Although Method 2 presents lower elevation almost until the end of critical period (Table 6.17), further it enables to fill the reservoir. The reason for that can be explained by the wet year condition of 2011 which have high flows through the water year.

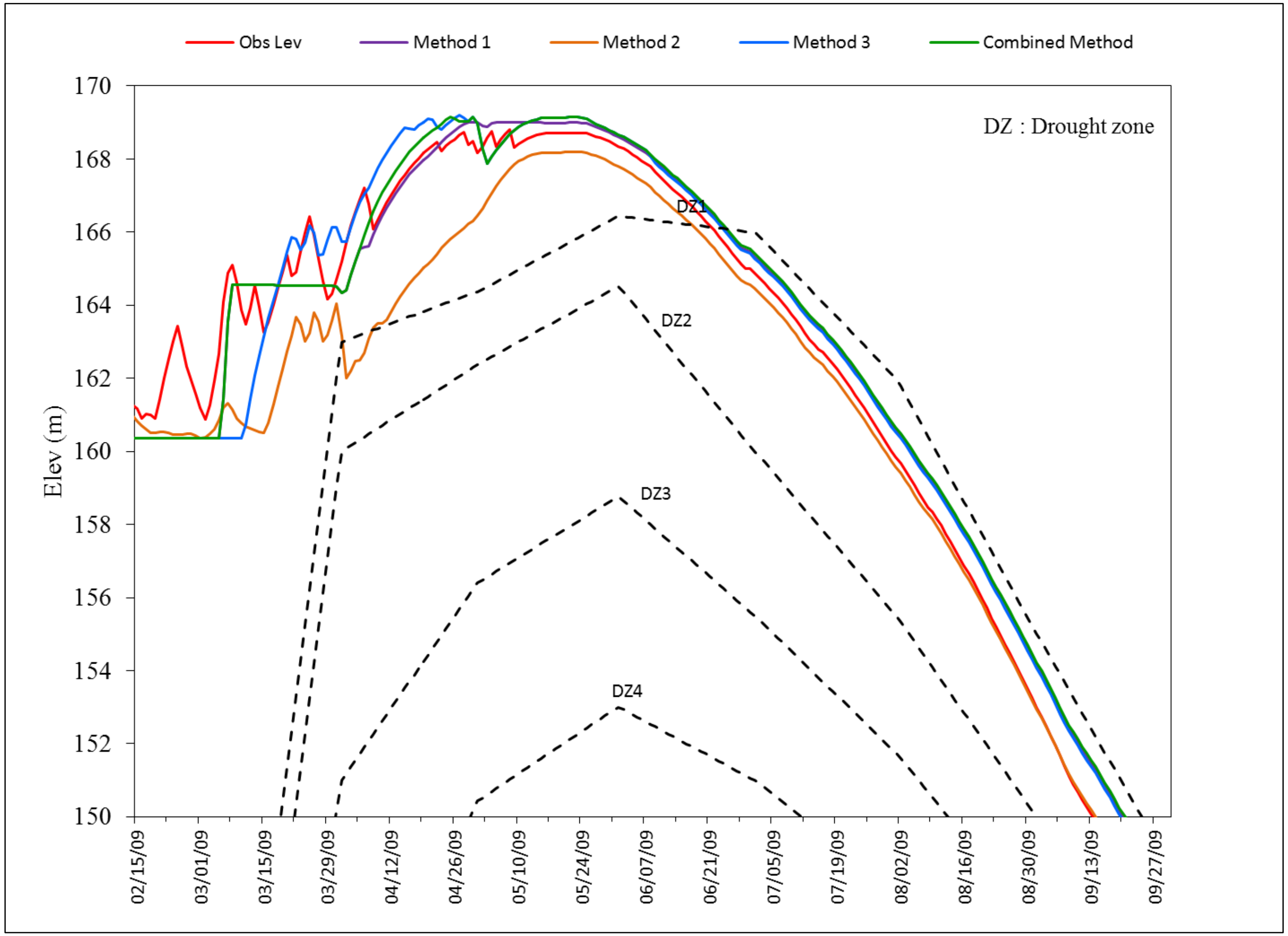


Figure 6.50 Long term water supply simulation results comparisons (2009)

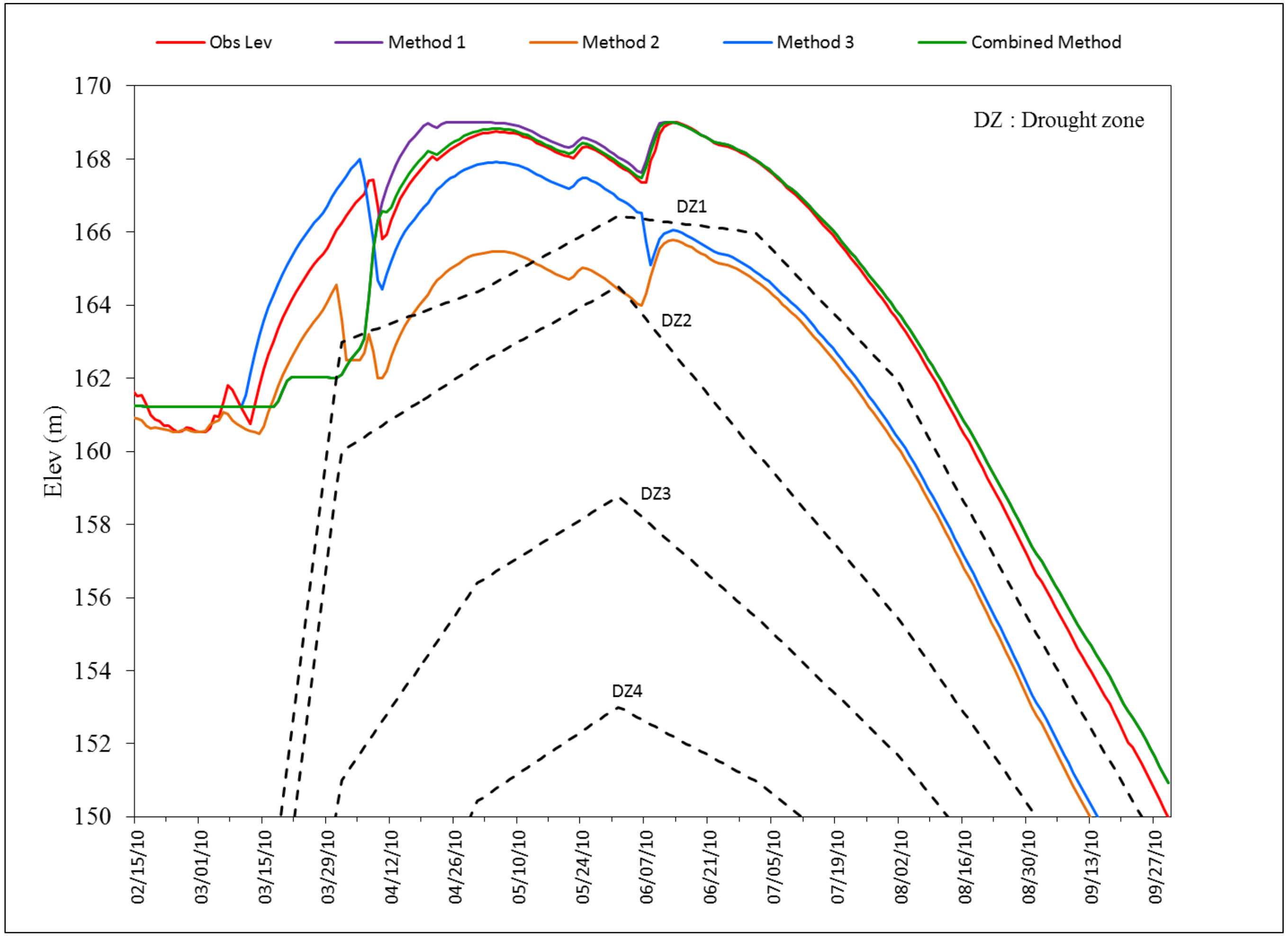


Figure 6.51 Long term water supply simulation results comparisons (2010)

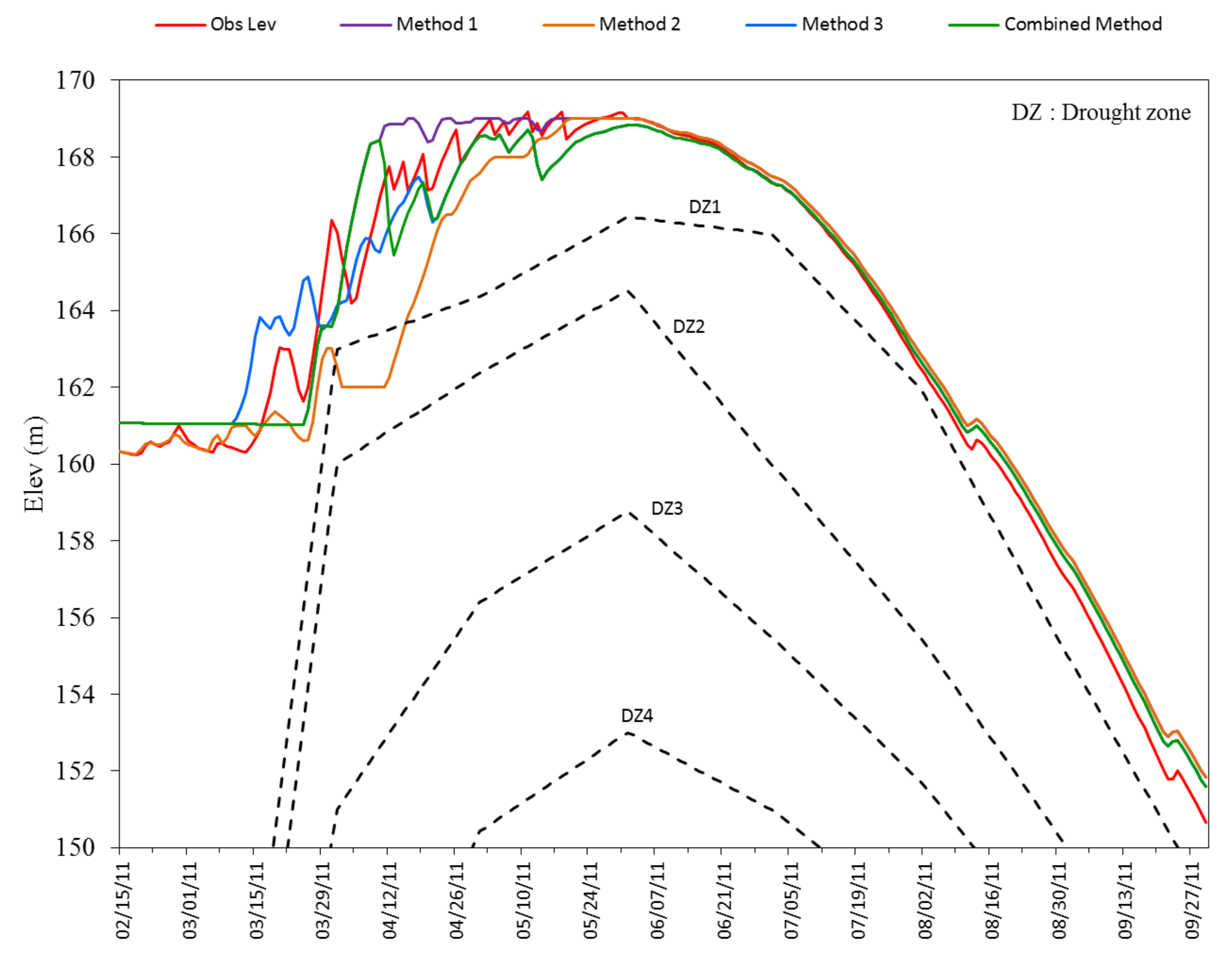


Figure 6.52 Long term water supply simulation results comparisons (2011)

The main purpose of this part is to develop a simulation model which is applicable for taking daily decisions. Since each water year represents different behavior in terms of precipitation and runoff (e.g. 2007 is dry, 2011 is wet years), it is one of the important criterion to find suitable simulation rules and model that are applicable for all conditions. Since the simulation models are derived from 2007 – 2011 decisions and observations, the results are obtained from these methods are highly correlated with observations. Finally, an objective method is developed instead of subjective decisions in terms of long term purposes, gate management strategy, flood risk and finally water supply targets and reported as appropriate simulation model to be used in real time applications.

6.4.2. Short Term Operation Discussion

In this part of the study, flood events are controlled with pre-emptive policies through the instrument of scenario inflows that will further form the basis for real time simulation of the reservoir using MM5 based streamflow forecasts. Two methods are developed and tested using a flood hydrograph and hypothetical inflows for decision support system of short term strategies.

First of all, the flood event must be operated with pre-release approach while spillway releases do not exceed downstream channel capacity. Pre-release activity could not be considered successful unless it avoided the following outcomes:

i) Release of a higher flow in advance of the event that would have been released during the event with no pre-emptive action.

ii) Failure to refill the reservoir’s conservation pool at the end of the event which will cause short term operation to interfere with water supply.

To make it comparable with each other, scenarios (A & B) are simulated with the two short term methods developed in section 6.3. The results are compared in Figure 6.53 and Figure 6.54 for Scenario A and B, respectively. Method 2 is applied with release time of 36 hours and 12 hours, respectively in these simulations).

Both methods achieve to attenuate the flood event. The main difference in the results of these two applications is the refilling part of the simulations. Advance release method is more successful to catch the initial pool elevation at the end of the event. So, advance release strategy would be more helpful for real time simulation studies and provides better results in terms of the final reservoir levels.

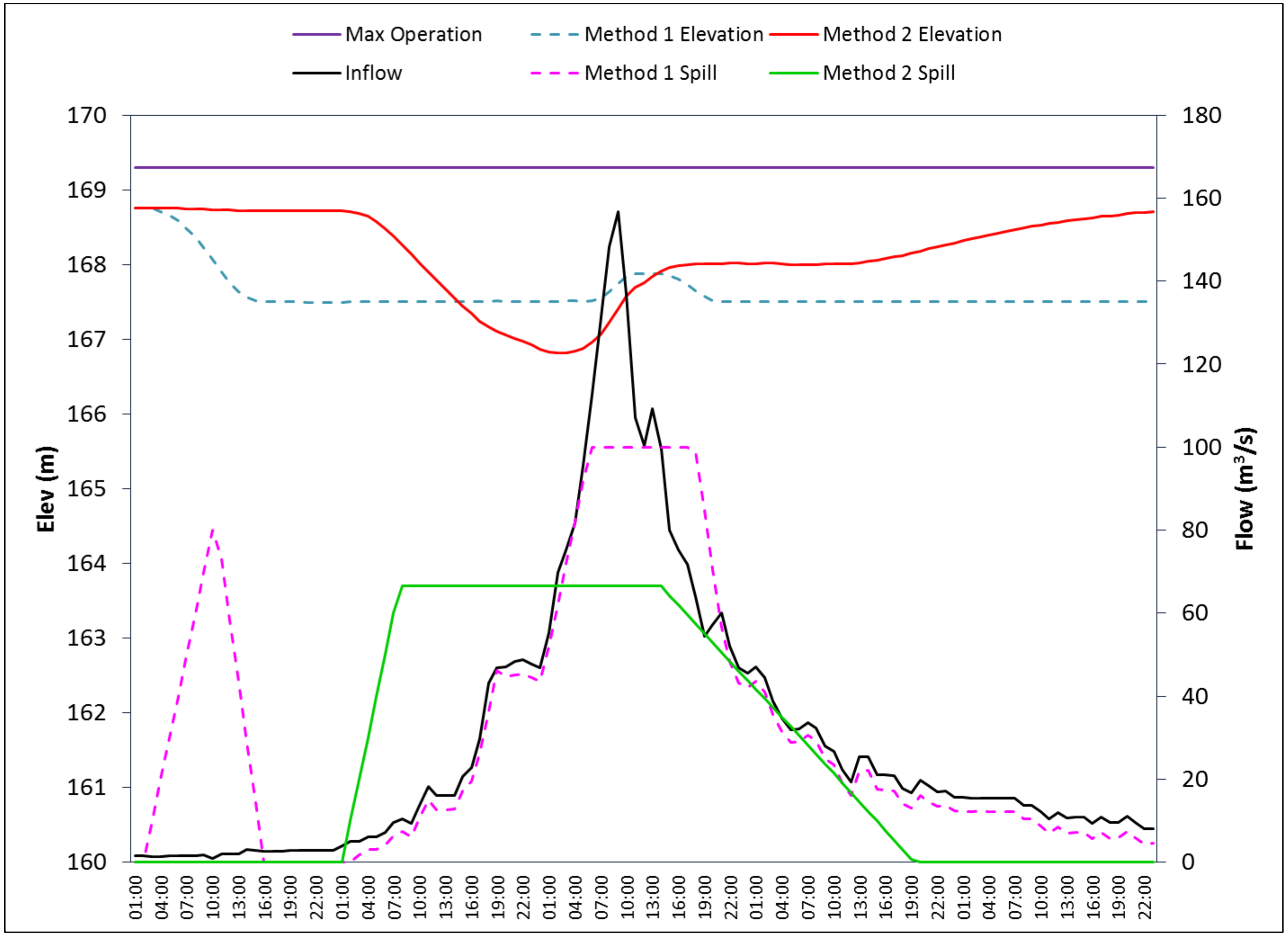


Figure 6.53 Short term flood control simulation results comparisons (Scenario A)

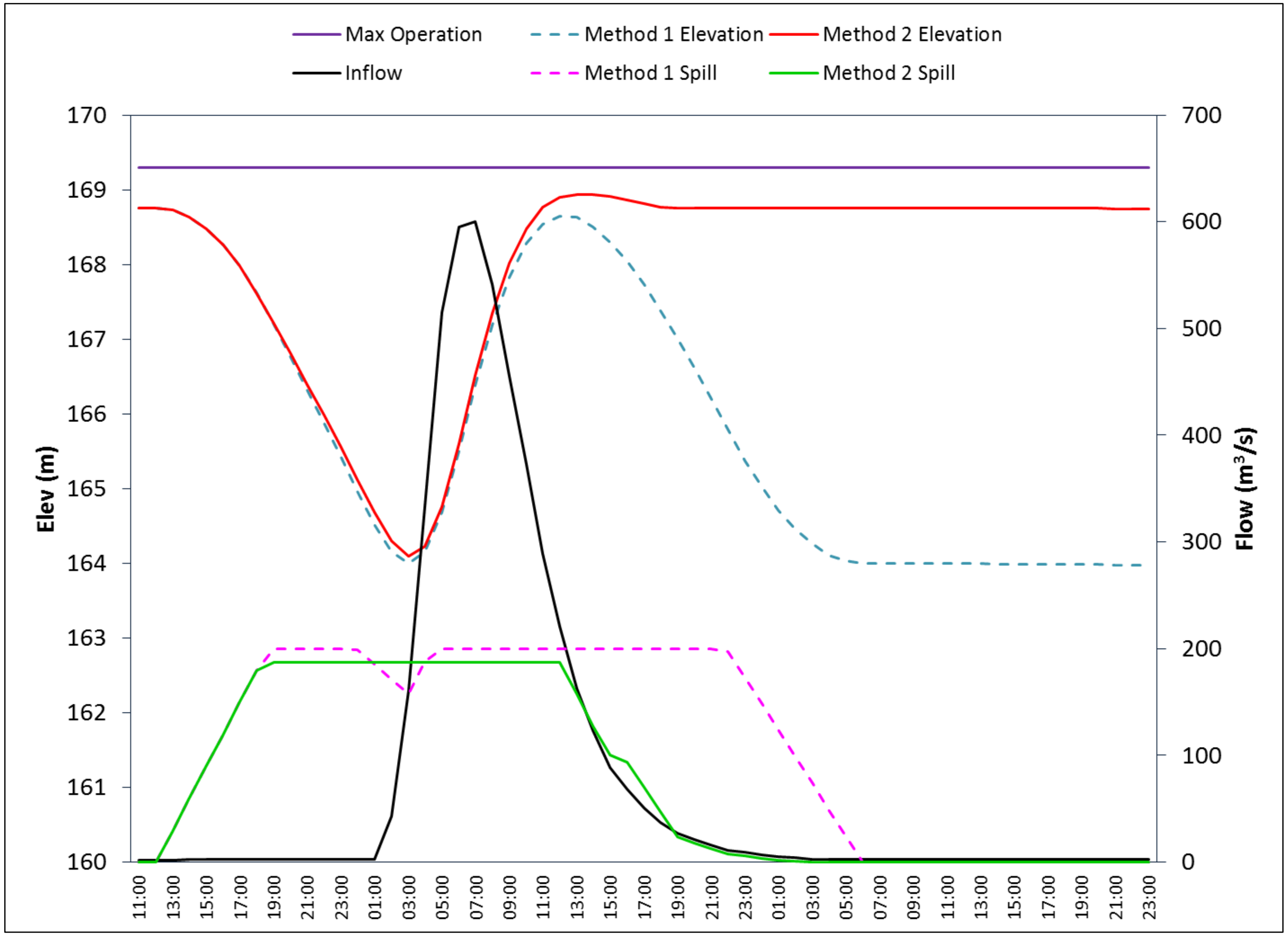


Figure 6.54 Short term flood control simulation results comparisons (Scenario B)

7. REAL TIME RESERVOIR OPERATION

Real time operation of a reservoir necessitates the assessment of all the data and conditions in a limited time period. These are; current hydro-meteorological data (inflow into reservoir by mass-balance equations, average precipitation by rain gauges, current storage by reservoir level readings, snow potential by snow depth observation stations etc.), climate reports, radar and numerical weather predictions, forecasted streamflows and scenarios. A decision support tool is developed in this study integrating these kinds of data and conditions with a hydrogical and a reservoir model for the operation of Yuvacık Dam Reservoir.

The details of the application methodologies are provided in Chapter 6. The valuable merit of this study is the integration of these strategies with real time applications. At the end, ongoing 2012 year is chosen as a real time operation and application year. The results and improvements are presented in this chapter.

7.1. Long Term Reservoir Operation for Daily Decisions

Early decisions for reservoir operation are taken a day or hours ago according to daily streamflow forecasts. First, the long term water supply simulations are done for 2012 critical period (March – June) with observed data. In the second step, MM5 based streamflow forecasts are provided as main input.

7.1.1. Daily Simulation Using Observed Data

Since the high snow depth values were observed at RG-8 and RG-9 (Figure 7.1) during 2012 winter period, the inflows gave a fast response during and after snowmelt period. Two minor and three major peaks are observed on hydrograph in March – April months.

Combined method is selected as the best methodology for decision support tool for long term water supply oriented simulations during 2012 critical period.

According to simulation results of the year 2012 (Figure 7.2), radial gates are open for an extended period due to the snow conditions on the basin, a considerable increase in the inflow is observed at the beginning of the April.

The results are promising in terms of storage timing, increase of reservoir level policy and water supply sustainability. According to results, operated and simulated levels are quite similar.

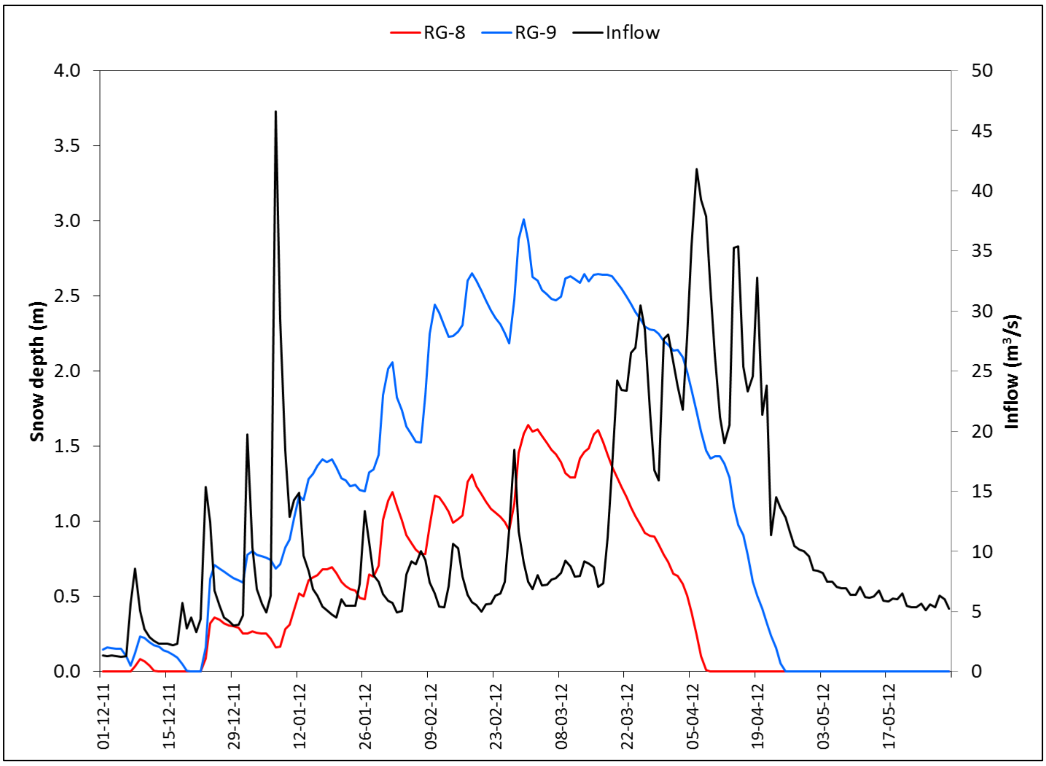


Figure 7.1 Snow depth and inflow (2011 – 2012 snow season)

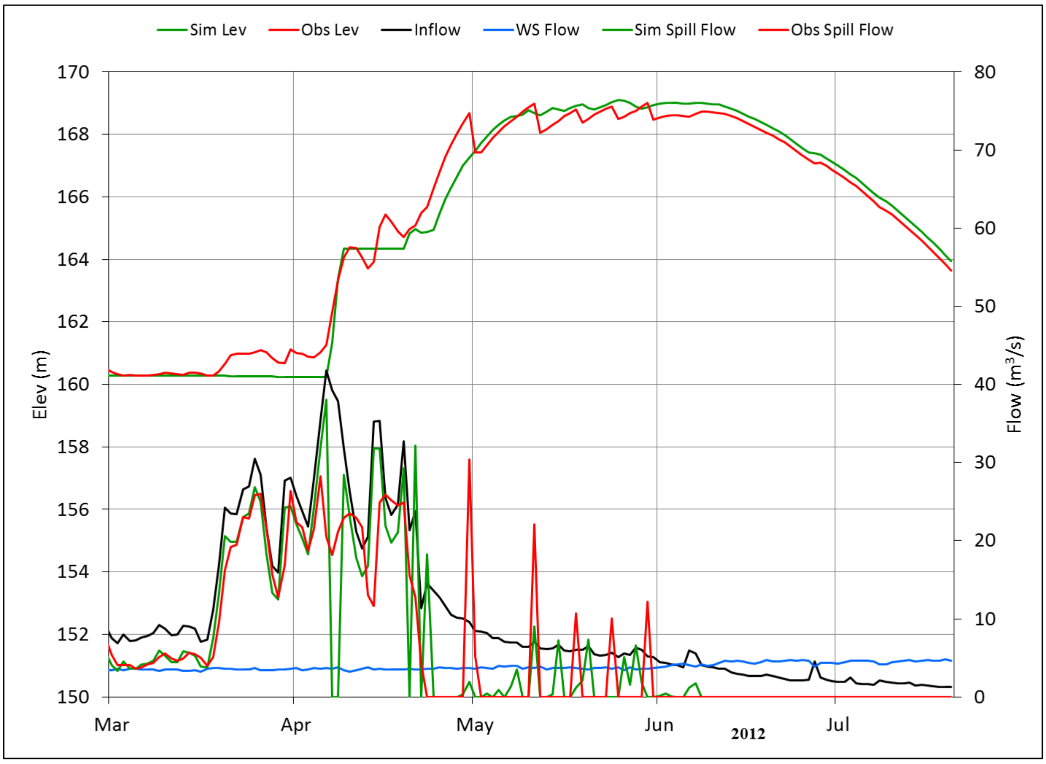


Figure 7.2 Daily real time simulation results by combined method (2012)

7.1.2. Daily Simulation Using NWP Data

Numerical weather prediction based streamflow forecasts are provided as a main input to ResSim during 2012 real time operation. Since MM5 gives a day and two days ahead forecasts, simulations are done day by day. On the other hand, a simulation is carried out by providing forecasted streamflows continuously without any update to present consistent results with previous applications. The results are evaluated using the results of;

1. Observed operation,
2. Simulation using observed inflows, and
3. Simulation using MM5 inflows.

Reservoir elevation and releases from spillway are shown in Figure 7.3. According to Figure 7.3, forecast based simulation gives consistent results in terms of both flow conditions and reservoir storage. If the simulation is done by updated reservoir levels as initial conditions, more convenient results would be obtained. As a conclusion, it seems that, the simulation model is applicable for real time operations, especially when the streamflow forecasts are consistent with the observed ones.

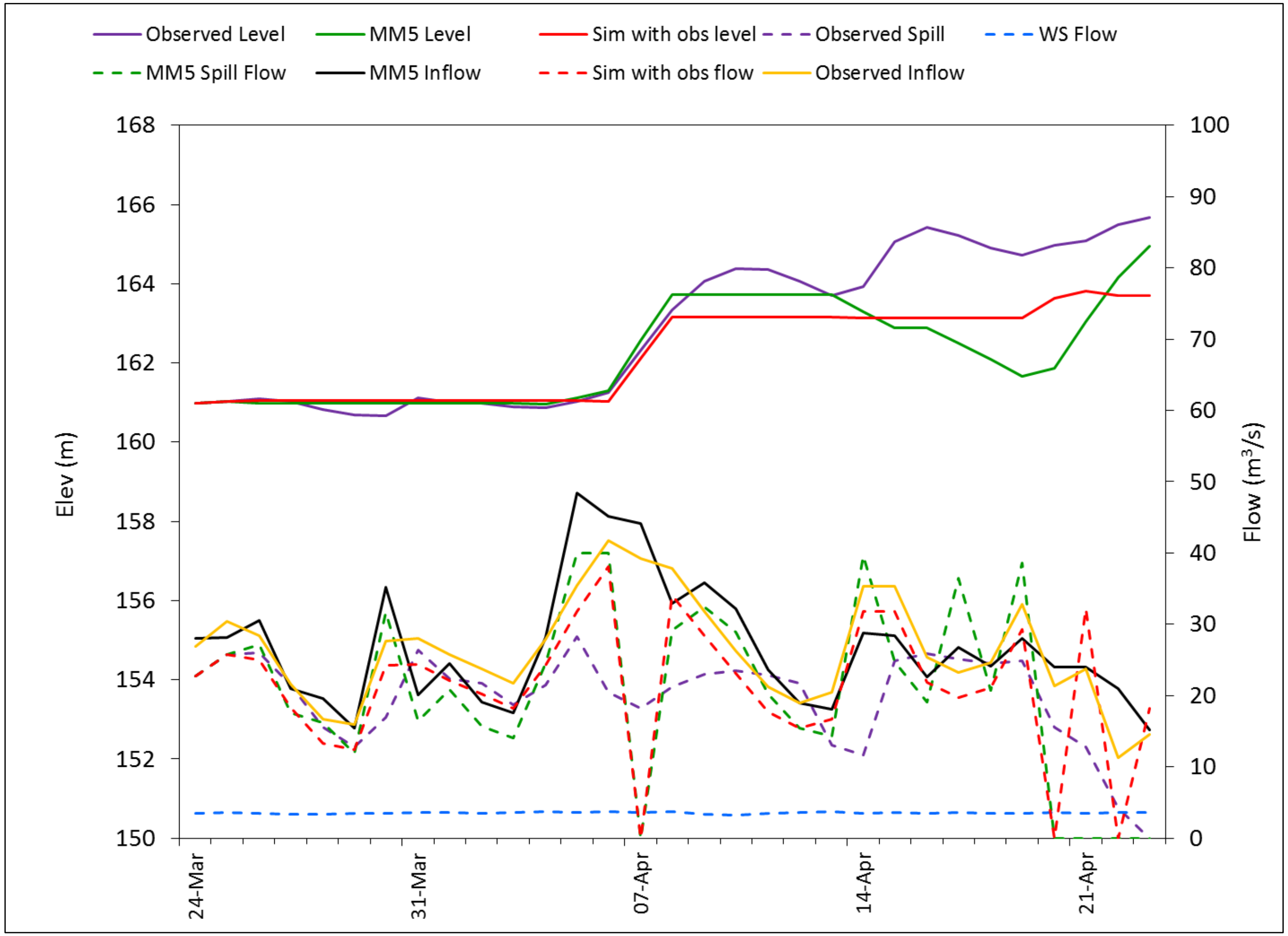


Figure 7.3 Real time simulation results (2012)

7.2. Short Term Reservoir Operation for Hourly Decisions

Short term strategies are developed to overcome flood risks especially during critical season (April and May). However, there was no remarkable flood risk provided from one or two days ahead MM5 based streamflows during the application periods. Therefore, no result would be presented in terms of real time short term operation during the year 2012.

8. CONCLUSIONS and RECOMMENDATIONS

Yuvacık Reservoir is essential for the city of Kocaeli and operation of it is a challenging task due to its multi-purpose characteristic. Several studies as described in literature are conducted to find out an optimal operation level either using optimization algorithms or simulation models. The main problem is to find a guide curve between endless battle of water supply and flood regulation targets. While optimization techniques are more complex to apply considering operating policies which are prepared as tables or graphs, a simulation model that reflect real situation is more realistic and adaptable for a decision maker.

Therefore, HEC-ResSim reservoir system simulation program is selected to develop a support tool for operators' decisions. The reservoir operation is divided into two basic approaches as long term for water supply and short term for flood control. The daily decisions are affected by seasonal variables and main aim during the operation period is to achieve maximum reservoir level (nearly 98~99 % filled) when the inflow is in the recession period. Hereby, the flood pool is eventually operated as empty as possible to decrease flood risk during March – May period. During the daily operations, several scenarios are conducted to this end using 2007 – 2011 data. Three different approaches are tested and the combined method that takes the advantages of all approaches is selected as the most remarkable method. It should be also noted that snow is classified as vital variable for the operational long term decisions.

On the other hand; since flood hydrographs are not regulated within the operational long term decisions, pre-release short term operation strategies are developed using different approaches. The basic idea is to put pre-releases into practice using numerical weather prediction based streamflow forecasts. Thereby, enough volume is provided to attenuate the flood whereas the reservoir level should reach the initial high level at the end of the event.

As a result, Yuvacık Reservoir is real timely operated during 2012. The simulations are integrated simultaneously with another hydrological modeling study which provides MM5 based streamflow forecasts. The results are promising to be directly used in real time operation. Although no flood event was experienced during the risky season, improved scripted rules are prepared in advance to be used in operation.

The importance of this study is that valuable decision support tool is developed using reservoir simulation and flood forecasting. The development is supervised with direct communication with real time decision makers. All challenges are tried to be simplified by flexible rules during the operation. Furthermore, this study is pioneer in terms of collaboration between scientific researchers and practitioners especially in water resources field.

The main merit of this study is that there is a combination of hydrological modeling using numerical weather prediction data and reservoir simulations in real time. In spite of the single water supply reservoir in the system, the operation is subjected to many constraints (e.g. drainage discharge capacity, sustainable water supply). Finally, it is also a pioneer study for similar complex reservoirs which are operated by governmental offices in Turkey.

This study further leads some recommendations on the following important activities for the future studies. The recommendations are generalized as:

1. The reservoir simulation is applied to 2007 – 2012 period for long term water supply operation. The simulation alternatives can be tested by enriched data using other years.

2. The short term studies conducted in this thesis operated by HEC-ResSim scripted rules. Although pre-releases provide remarkable results with calculation based scripted rules, similar studies may be carried out by simulation-optimization based hybrid programs.

3. Since the decisions are strongly based on the streamflow into the reservoir, accuracy of forecasted inflows are important. Therefore, besides MM5 other type of forecast data could be utilized.

4. Downstream channel capacity should be increased with rehabilitation to minimize the flood risk.

5. Real time simulation of reservoir operation can be combined with flood inundation mapping studies which provide visualization of the downstream flooding areas.

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