OPTIMISATION OF THE TIGRIS RIVER HYDROPOWER SYSTEM OPERATIONS

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ABSTRACT

OPTIMISATION OF THE TIGRIS RIVER HYDROPOWER
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Growing external energy dependence and rising oil prices are encouraging Turkey to turn to renewable energy, especially hydropower. The amended legislation on the transference of the operational rights of existing, under-construction and planned hydropower plants to the private sector and the allocation of water right licenses to develop new projects for electricity production has led to a drastic decrease of the public share in production. Consequently, conflicts related to the operation of reservoirs have intensified because of the increasing number of stakeholders involved. The situation has resulted in a growing need for an integrated and holistic approach to basin planning and management. This study presents a catchment-based optimisation model for the integrated operation of cascade hydropower projects.

Keywords: Nonlinear Programming, Optimisation, Reservoir Operation, ARIMA, Tigris Basin

ÖZ

DİCLE NEHRİ HİDROELEKTRİK SİSTEMİ İŞLETME OPTİMİZASYONU

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Enerjide dışa bağımlılığın artması ve yükselen petrol fiyatları, Türkiye'yi başta hidroelektrik olmak üzere yenilenebilir enerjiye dönmeye zorlamaktadır. Mevcut, inşa halinde ve planlamadaki hidroelektrik santrallerin işletme haklarının özel sektöre devri ile elektrik üretimi için yeni projeler geliştirilmesi amacıyla verilen su kullanım anlaşmaları hakkındaki yasal düzenlemeler, üretimdeki kamu payında önemli bir düşüşe sebep olmuştur. Bunun sonucunda, paydaş sayısının artması sebebiyle rezervuarların işletilmesi ile ilgili ciddi sorunlar ortaya çıkmıştır. Bu durum, havza planlama ve yönetiminde entegre ve tüme dayalı bir yaklaşım ihtiyacını doğurmuştur. Bu çalışma, ardışık hidroelektrik projelerinin entegre olarak işletilmesini sağlayacak havza bazlı bir işletme modeli sunmaktadır.

Anahtar Kelimeler: Doğrusal Olmayan Programlama, Optimizasyon, Rezervuar İşletmesi, ARIMA, Dicle Havzası

To Nisan

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CHAPTER 1

INTRODUCTION

1.1 Problem Definition

Growing external energy dependence and rising oil prices are encouraging Turkey to turn to renewable energy, especially hydropower. In this context, the Electricity Market Law No. 4628 and the revised establishment law of the General Directorate of State Hydraulic Works (DSI) No. 6200 gave rise to a new era in the Turkish energy market by transferring the operational rights of existing, under-construction and planned hydropower plants to the private sector and by allocating water right licenses for the development of new projects for electricity production.

Power generation companies can sell their electricity through bilateral contracts, the renewable energy sources support mechanism or the day-ahead market operated by the Market Financial Settlement Centre (PMUM). Companies have to report their choices of sales method to the Energy Market Regulatory Authority each year. The day-ahead market is the main structure of the energy trade. Producers that prefer to sell electricity on the day-ahead market report their hourly expected production plans to PMUM. Appropriate predictions for the short-term productions of power plants contribute not only to ensuring the system energy balance but also to the profits of the companies.

However, in most cascade hydropower systems in the country, a single-reservoir simulation model is employed in the operation of each of the system reservoirs, with limited knowledge of the short- and long-term operation strategies of upstream schemes. This causes energy imbalances and also widens the range of energy prices. The administration’s influence and control over the market has been loosened as a result of the progressively decreasing public share in production (Demirdizen, 2013). The conflicts related to the operation of reservoirs have become increasingly intense with the commissioning of new power plants and irrigation schemes. The situation has resulted in a growing need for an integrated and holistic approach to basin planning and management.

1.2 Scope of the Study

This study presents a catchment-based optimisation model for the integrated operation of hydropower plants under various sales methods. The key components of the model are database management, inflow modelling and forecasting, optimisation and real-time operation. The assigned system integrates a database with basic hydrological, topographical and technical information to perform the optimisation algorithm. The optimisation model is formulated in terms of nonlinear programming (NLP) due to its superiority in developing guidelines for real-time operations (Rani & Moreira, 2010).

In Chapter II, initially, the need for a problem-based integrated reservoir operation methodology is explained in terms of the integrated water resources management concept. The adversities facing the implementation of a general integration process are stated, and a reductionist approach to resolving problems in an operational manner is advised. Then, the basic algorithm of the proposed optimisation model that considers the integrated operation of cascade hydropower schemes with domestic, industrial, agricultural and environmental needs is presented, and its nonlinear objective function and constraints are described. In addition, the basis of its application using forecasted inflow time series is depicted as a tool for real-time operations.

Chapter III is dedicated to the optimisation of the operations of the Garzan Hydropower System. The model is tested using historical, mean and forecasted flow values for the dry and rainy seasons to analyse its limits and effectiveness when applied to real-time operations. First, the proposed model is utilised to maximise the revenue that can be gained during a 12-month operation period. Integrated and sequential optimisation studies are conducted using the historical inflow data sets of the rainiest and driest water years during the 1971-2000 period. Then, to provide an estimate of the income that can be achieved in real-time operations, the optimisation of the integrated system operations is performed for each fall season using the successively renewed inflow forecasts and the monthly means of the historical data sets.

Subsequently, in Chapter IV, the basic NLP model developed for the Garzan sub-system is extended to the Tigris Hydropower System, which consists of 15 energy, 9 irrigation and 4 multi-purpose reservoirs, to maximise energy production. The system is optimised for three different cases during a 12-month operation period, and the effects of the system modifications and the demand constraints on energy production are examined. In addition, the state of the Garzan Hydropower System in the integrated Tigris operations plan is analysed to explore the plant utilisation of this sub-system when optimising the operations of the entire hydropower system. In this context, to investigate the maximum energy that can be produced, the operation optimisation of the Garzan sub-system is repeated on a monthly basis for one-year and thirty-year operation periods.

Finally, the conclusions of the performed study are outlined in Chapter V.

CHAPTER 2

INTEGRATED RESERVOIR OPERATIONS

2.1 Integrated Water Resources Management

As water becomes increasingly scarce and its demand management becomes more of a challenge, water-related problems will continue to become increasingly complex and increasingly intertwined with commercial sectors, such as agriculture, energy and industry, and with environmental, social and political considerations (Asian Development Bank, 2007). Until the early 1990s, the solution to these multi-dimensional problems was understood to reside in a 100-year-old concept, which has led to several disappointing implementation results: Integrated Water Resources Management (IWRM) (Biswas, 2008; White, 1998).

Various experts have attempted to explain the spirit of IWRM, but a lack of consensus remains regarding what it actually means and involves. The Global Water Partnership (2000) defines IWRM as “a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems.”

Essentially, the basin-scale management of multi-sectoral water demand for the improvement of social, economic and environmental conditions is the primary objective of this concept. This process can involve stream-flow modifications implemented by means of reservoirs, diversions and intra- and inter-basin water transfers. The key requirement is the analysis of these modifications in an integrated manner. Integration is needed among planning, construction and operational management at the local and national levels and, occasionally, at the regional and international levels.

Conceptually, IWRM appears to be attractive and simple, but many efforts to solve the real water-related problems that are being faced in various parts of the world through this concept have been failures. According to a study conducted by the Third World Centre for Water Management, on a scale of 1 to 100 (1 representing no integration and 100 representing full integration), not even a single macro- or meso-level project anywhere in the world can reach a score of 30 in terms of its application (Biswas, 2008). These disappointing implementation results call into question the value of IWRM in operational terms.

Faniran (1981) explained the widespread failure of IWRM as being attributable to the application of sectoral planning to multi-sectoral circumstances. Unfortunately, coping with interrelated and interdependent issues such as water, energy, agriculture, the environment and rural development under the challenges imposed by bureaucracy, cost, lack of data and institutional weaknesses reduces the implementation possibilities of this approach to a minimum (Le Moigne, Subramanian, Xie, & Giltner, 1994).

Consequently, to date, river basins have not been managed at all through a general IWRM-based integration concept, and such a scheme is unlikely to be achieved in the near future. A good example in the case of Turkey is the South-eastern Anatolia Project (GAP). The GAP project was initiated as a set of water and land sources development projects in the less developed south-eastern region of the country in the 1970s, but later, in the early 1980s, it was turned into a multi-sectoral and socio-economic integrated development programme, including 22 dams, 19 hydropower plants and the irrigation of about 1.7 million ha of land (Unver, 1997).

The expectation was that this comprehensive development project would improve the living standards of about 7.5 million people living in the borders of the GAP region in terms of income, health, education, and others. To date, although about 80 percent of the energy projects has been completed, this percentage is less than 20 for the irrigation schemes (Kaplan, 2012). In spite of spending over 20 billion US dollars, the GAP Project has basically remained a group of separate hydropower schemes (Guven, 2014). Unfortunately, the commissioning of the irrigation systems will not solely solve the problem because of the private-sector-owned reservoirs. Today, through the rapid development of the Tigris and Euphrates watershed with the projects developed by incorporated companies, a new problem arises on how to operate a cascade reservoir system composed of state- and private- sector-owned reservoirs in terms of the volume and timing of water releases to meet downstream irrigation demands.

2.2 Need for an Implementable Approach

Implementable solutions can be obtained by resolving problems in an operational manner. Different levels and types of integration can be applied to site-specific problems in progressive stages (Barrow, 2001). That is, the objective can be translated into measurable criteria without losing the principle outline of IWRM, and this reductionist approach can be used to improve existing water resources management practices (Biswas, 2008).

Some of the typical recommendations of IWRM, such as the basin approach, the pricing of water and participation in decision-making, can be ignored in this approach (Giordano & Shah, 2014). However, there are firm constraints that cannot be ignored in the maximisation of benefits. Initially, water and energy cannot be managed independently. The energy potential of a basin must be evaluated in an integrated manner, in which all of the basin power plants are planned and operated accordingly. In addition, domestic, industrial, agricultural and environmental needs cannot be separated from the management process. The volume and timing of water releases from reservoirs must be optimised with consideration for upstream and downstream issues. After the implementation of an integrated reservoir operation plan with the existing demand constraints, the management strategy can be improved in progressive stages on the issues of effective usage of water, such as intra- and inter-basin water transfers, plant modifications and selection of crop type, according to flow regimes, storages in the reservoirs and energy prices in following seasons.

The planning and management of integrated operations should be based on well-defined objectives that are mutually beneficial to all involved. Resource availability, demand constraints and all feasible options should be analysed with consideration for both short- and long-term strategy formulations. The proposed solutions should be sensitive and adaptive to future, and presently unanticipated, conditions. Adequate monitoring and, thus, maintenance of a good database ensure appropriate assumptions regarding future scenarios. This also requires a satisfactory administration that regulates the mechanisms and enforcement of the management strategy by means of trained staff (Le Moigne et al., 1994; Westcoat, 1991). Tools such as geographical information systems, forecasting simulations and computer-aided decision-support techniques can assistance in the processes of data evaluation, decision-making, implementation and management.

2.3 Problem-Based Integrated Reservoir Operation

A number of classical optimisation and computational intelligence techniques, such as linear programming, dynamic programming, nonlinear programming, evolutionary computations, fuzzy set theory and artificial neural networks, have been developed and applied for the management and operations of reservoir systems over the last three decades. Labadie (2004), Rani and Moreira (2010), Wurbs (1993) and Yeh (1985) provided comprehensive literature reviews of the theories and applications of these algorithms in the context of reservoir operation models.

In recent years, a number of basin-wide water resources management tools have been developed for the simulation and optimisation of reservoir operations, such as IRAS (Interactive River-Aquifer Simulation), TERRA (Tennessee Valley

Authority Environment and River Resource Aid), CTIWM (Cooling Technology Institute Water Management) and RiverWare (Ito, Xu, Jinno, Kojiri, & Kawamura, 2001). However, these general packages which have been commonly developed employing linear and dynamic programming optimisation are not appropriate for determining the optimal operation policies for most site-specific systems (Karamouz, Zahraie, & Araghinejad, 2005). Hence, there is a need to develop more intelligent tools to generate decisions in real-time operations (Rani & Moreira, 2010).

Huysentruyt, Olason, Bridgeman, and Allen (1996), Karamouz and Zahraie (1996) and Shim, Fontane, Lee, and Koh (1996) developed decision support systems for power systems in New England, Iran and South Korea, respectively. Peng (1998) developed a mathematical model for the real-time operation optimisation of the West Branch Penobscot river system in the State of Maine of the United States. Barros, Tsai, Yang, Lopes, and Yeh (2003) formulated a monthly optimisation model, called SISOPT, for the management and operations of the Brazilian hydropower system. Karamouz et al. (2005) presented a system for the monthly operational planning of multipurpose reservoirs in the Dez and Karoon river system in Iran.

In this study, the optimisation model is formulated in terms of nonlinear programming. To date, there have been few applications of this technique to hydropower generation because of its extreme computational requirements (Ahmed & Lansey, 2001). Although reaching the global optimum is a challenge in NLP, it offers the most general formulation of the nonlinear and complex relationships between physical and hydrological variables (Rani & Moreira, 2010; Yeh, 1985).

2.3.1 Objective Function

The proposed NLP model uses the maximisation of income, which is the product of the produced energy and the energy price, as its objective:

$$max\sum_{t}\left[p_t\left(\sum_{i}E_{i,t}-E_t^c\right)\right] \quad (1)$$

where p_t = estimated energy price on the day-ahead market for a time period t in US dollar cent/kWh, $E_{i,t}$ = energy production of the i^{th} plant during time period t in kWh and E_t^c = contractual energy demand of the system for time period t in kWh.

Energy production is a function of the net head, the power releases and the system efficiencies and can be formulated as follows:

$$E_{i,t} = \xi_T\,\xi_G\,\varphi_t\,P_{i,t} \quad (2)$$

$$P_{i,t} = g\,H_{i,t}^n\sum_{j}\left(\varepsilon_{i,j,t}\,\phi_t\,R_{i,j,t}^p\right) \quad (3)$$

where ξ_T = transformer efficiency, ξ_G = generator efficiency, φ_t = conversion factor from time period t to hours, $P_{i,t}$ = power of the i^{th} plant during time period t in kW, g = acceleration of gravity (9.81) in m/s^2, $H_{i,t}^n$ = net head in the i^{th} reservoir during time period t in m, $\varepsilon_{i,j,t}$ = efficiency of turbine j of the i^{th} reservoir during time period t, ϕ_t = conversion factor from m^3 to m^3/s and $R_{i,j,t}^p$ = power release through the j^{th} turbine of the i^{th} reservoir during time period t in m^3.

Typical values adopted as default for transformer and generator efficiencies are 98.5% and 97.5%, respectively (IFC, 2015). The efficiency of a turbine is directly related to the ratio of power release to capacity:

$$\varepsilon_{i,j,t} = f_1\left(\frac{R_{i,j,t}^p}{R_{i_{max}}^p}\right) \quad (4)$$

where $R_{i_{max}}^p$ = maximum power release through a turbine of the i^{th} reservoir in m^3.

Net head is characterised as follows:

$$H_{i,t}^{n} = \lambda \left(H_{i,t}^{a} - tw_i\right) - \kappa_i \left(\phi_t \sum_j R_{i,j,t}^{p}\right)^2 \tag{5}$$

where λ = gross head reduction for local losses (95% as default), $H_{i,t}^{a}$ = average water level in the i^{th} reservoir during time period *t* in m, tw_i = tail water level of the i^{th} reservoir and κ_i = friction loss constant for the penstocks and/or energy tunnels of the i^{th} reservoir in $m/(m^3/s)^2$.

The average water level is the mean value of the water levels at the beginning and end of time period *t*:

$$H_{i,t}^{a} = \frac{H_{i,t-1} + H_{i,t}}{2} \tag{6}$$

where $H_{i,t-1}$ = water level in the i^{th} reservoir at the beginning of time period *t* in m and $H_{i,t}$ = water level in the i^{th} reservoir at the end of time period *t* in m.

The water level is expressed as a function of the reservoir storage:

$$H_{i,t} = f_2(S_{i,t}) \tag{7}$$

where $S_{i,t}$ = ending storage in the i^{th} reservoir at the end of time period *t* in m^3.

2.3.2 Constraints

The constraint set includes flow continuity, turbine capacity, spillway capacity, minimum release, minimum energy production, minimum storage and reservoir capacity.

Flow continuity:

$$S_{i,t} = S_{i,t-1} + I_{i,t} + \sum_j R^p_{i-1,j,t} + R^s_{i-1,t} + R^{de}_{i-1,t} + r_{i-1} R^{di}_{i-1,t} - e_{i,t} A_{i,t-1} - \sum_j R^p_{i,j,t} - R^s_{i,t} - R^{de}_{i,t} - R^{di}_{i,t} - R^{dw}_{i,t} \quad (8)$$

where $S_{i,t-1}$ = beginning storage in the i^{th} reservoir at the beginning of time period t in m^3, $I_{i,t}$ = forecasted inflow into the i^{th} reservoir during time period t in m^3, $R^p_{i-1,j,t}$ = power release through the j^{th} turbine of the i-1^{th} reservoir during time period t in m^3, $R^s_{i-1,t}$ = non-power release through the spillway from the i-1^{th} reservoir during time period t in m^3, $R^{de}_{i-1,t}$ = non-power release as environmental water for the maintenance of natural ecosystems from the i-1^{th} reservoir during time period t in m^3, r_{i-1} = rate of return for the irrigation scheme of the i-1^{th} reservoir, $R^{di}_{i-1,t}$ = irrigation water supplied by the i-1^{th} reservoir during time period t in m^3, $e_{i,t}$ = net evaporation rate per unit area of the i^{th} reservoir during time period t in m, $A_{i,t-1}$ = reservoir area of the i^{th} reservoir at the beginning of time period t in m^2, $R^s_{i,t}$ = non-power release through the spillway from the i^{th} reservoir during time period t in m^3, $R^{de}_{i,t}$ = non-power release as environmental water from the i^{th} reservoir during time period t in m^3, $R^{di}_{i,t}$ = irrigation water supplied by the i^{th} reservoir during time period t in m^3 and $R^{dw}_{i,t}$ = domestic water supplied by the i^{th} reservoir during time period t in m^3.

The reservoir area is expressed as a function of the reservoir storage:

$$A_{i,t-1} = f_3(S_{i,t-1}) \quad (9)$$

Turbine capacity:

$$R^p_{i,j,t} \leq R^p_{i_{max}} \quad (10)$$

Spillway capacity:

$$R_{i,t}^{s} \leq R_{i_{max}}^{s} \tag{11}$$

where $R_{i_{max}}^{s}$ = spillway capacity of the i^{th} reservoir in m^3.

Minimum release:

$$\sum_{j} R_{i,j,t}^{p} + R_{i,t}^{s} + R_{i,t}^{de} \geq R_{i_{min},t}^{d} \tag{12}$$

where $R_{i_{min},t}^{d}$ = minimum release to supply water demand from the i^{th} reservoir during time period t in m^3.

Minimum energy production:

$$\sum_{i} E_{i,t} \geq E_{t}^{c} \tag{13}$$

Minimum and maximum storage values:

$$S_{i_{min}} \leq S_{i,t} \leq S_{i_{max}} \tag{14}$$

where $S_{i_{min}}$ = minimum storage in the i^{th} reservoir in m^3 and $S_{i_{max}}$ = maximum storage in the i^{th} reservoir in m^3.

2.3.3 Model Application

The model is established on a monthly basis for a one-year period to assess the production strategies of the reservoir systems for that year. To simulate real-time operations, inflow forecasts are utilised and are frequently updated. Integrated system operation optimisations are performed with these forecasted inflow values for each month of the operation period. The state of the system reservoirs is updated at the beginning of each month based on the observed inflow values of the previous month, as schematically illustrated in Figure 1.

If the observed inflow value for a reservoir is lower than its forecasted amount, the spillway release, if any, is decreased at first with the difference of the forecasted and observed flow amounts. In this case, if the changed storage level remains below its minimum value, the optimised power release is decreased until the minimum storage constraint is satisfied. Conversely, if the observed inflow value is higher than its forecasted amount, the storage level is increased with the difference of the observed and forecasted flow amounts. If the increased storage level remains above its maximum value, the optimised power release is increased up to the design discharge, and the remaining storage amount is added to the spillway release. Subsequently, the inflow value of the downstream reservoir is updated based on these adjustments, and forecasting error modifications are continued for each system reservoir sequentially. The operation optimisation for the next month starts with the updated storage levels of the system reservoirs. This procedure can be extended to daily and hourly optimisations by virtue of the floating energy prices on the day-ahead market (PMUM, 2014).

Furthermore, the concept of firm energy can be used to maximise reliable energy production capacity obtainable on a long-term basis, even during the most adverse hydrological seasons (Ouarda, Labadie, & Fontane, 1997). In this context, the objective function can be modified to maximise total energy production, and the power-release terms in the constraints are expressed in terms of the sum of the firm and secondary power releases, as defined in Equation (15) and Equation (16), respectively.

$$max \sum_{t} \sum_{i} E_{i,t} \tag{15}$$

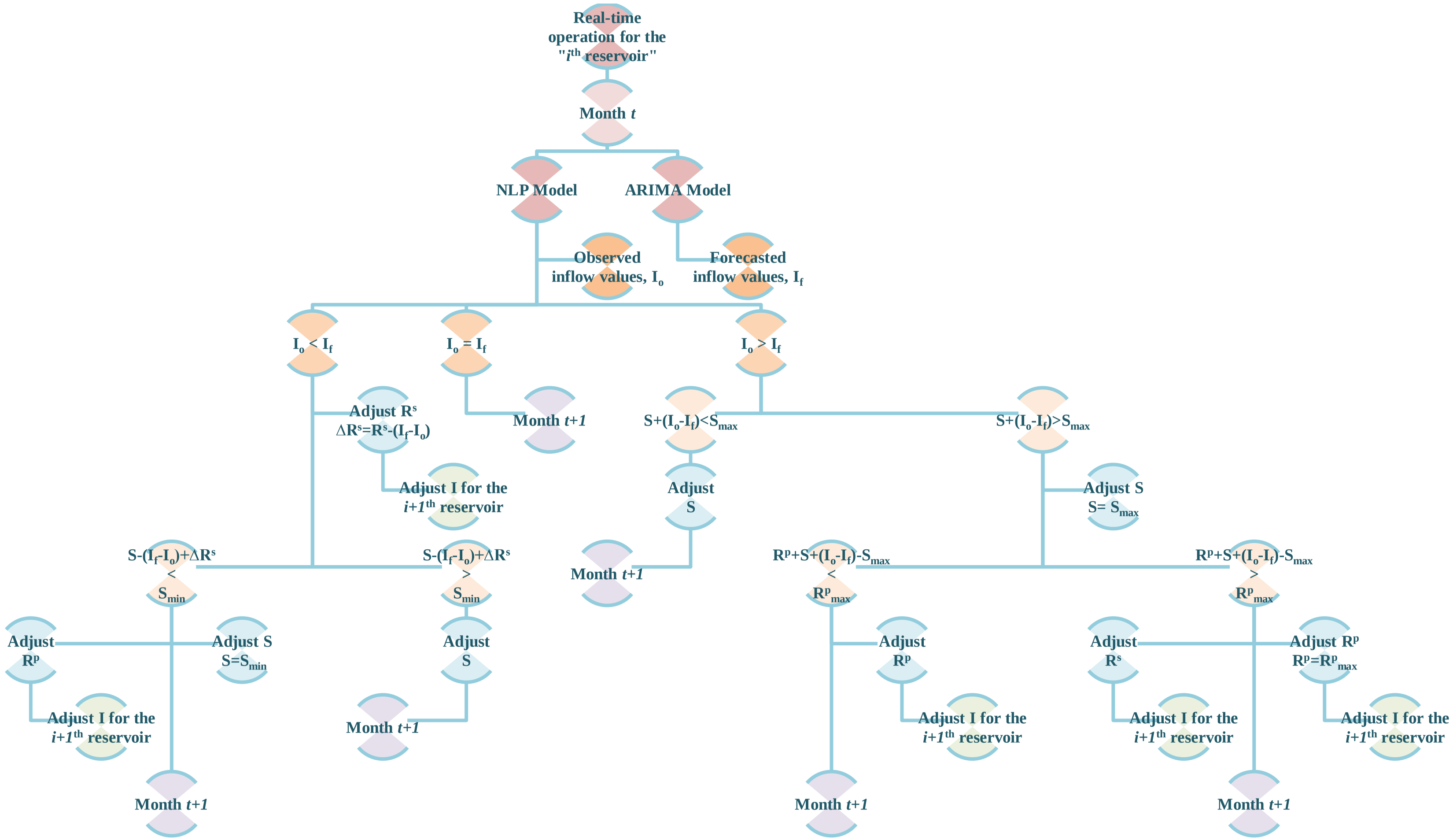


Figure 1 Real-Time Operations

$$R_{i,j,t}^{p} = R_{i,j}^{P^f} + R_{i,j,t}^{P^s} \quad (16)$$

where $R_{i,j}^{P^f}$ = firm power release through the j^{th} turbine of the i^{th} reservoir and $R_{i,j,t}^{P^s}$ = secondary power release through the j^{th} turbine of the i^{th} reservoir during time period t in m^3.

System firm energy is an important issue in planning stage and future success to assess the energy potential of especially large-scale hydropower systems. The results of such an examination can be utilised to establish energy contracts, and significantly higher revenues can be obtained than with the day-ahead market.

CHAPTER 3

THE GARZAN HYDROPOWER SYSTEM

The proposed model is applied on the Garzan Hydropower System as a case study. Garzan Creek is a branch of the Tigris River and flows through the south-eastern Anatolia Region of Turkey. The hydropower system consists of the Aysehatun Dam and HEPP Project with Mutki Derivation, the Kor Dam and HEPP Project, the Garzan Dam and HEPP Project and the Garzan irrigation scheme, which covers an area of 60000 ha, as depicted in Figure 2 (Aksa, 2004; DSI, 1987; Enersu, 2008; Jemas-Su, 2001).

Net evaporation rates, monthly mean inflow values, environmental and irrigation water demands, reservoir area and water level functions expressed as high-order polynomials of storage, turbine efficiency curves and energy prices are the inputs to the proposed model, together with the topographical and technical features of the projects listed in Table 1 (Appendix A).

The MINOS solver that employs a projected Lagrangian algorithm on a sequence of linearly constrained sub-problems is used to solve this optimisation problem with nonlinear constraints and objective function within the General Algebraic Modelling System (GAMS) package (Murtagh, Saunders, Murray, & Gill, 2014). The steps of the procedure followed for this purpose are schematically illustrated in Figure 3. Moreover, to verify the efficiency of the integrated operations, the same process is applied to the system reservoirs sequentially.

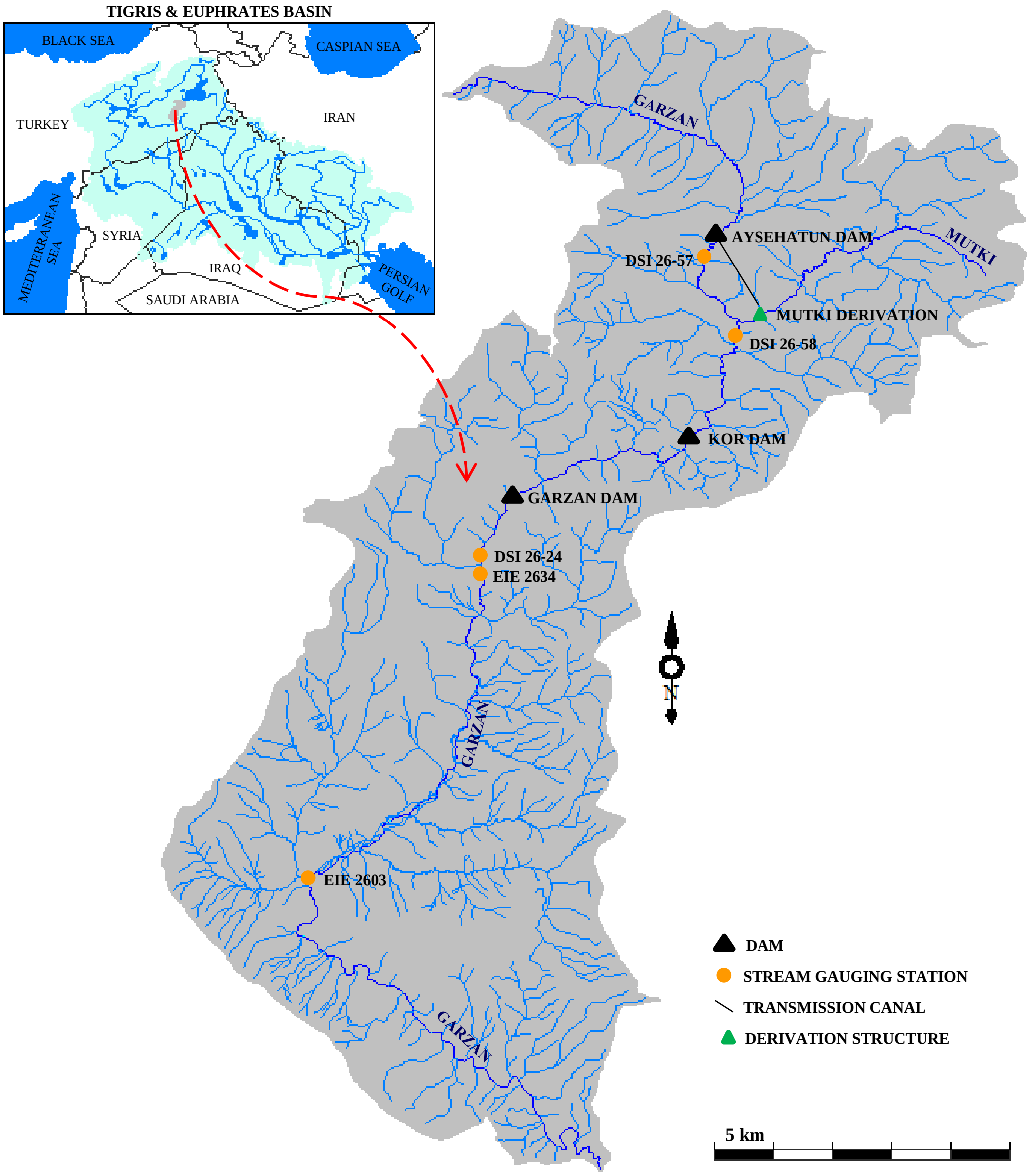


Figure 2 Location Map of the Study Area

3.1 Evaporation Rates

The net evaporation rates of the system reservoirs are based on records from meteorological stations operated by the General Directorate of State Meteorological Works (DMI). For the Aysehatun and Kor Projects, the monthly total evaporation and monthly mean temperature data from the Bitlis

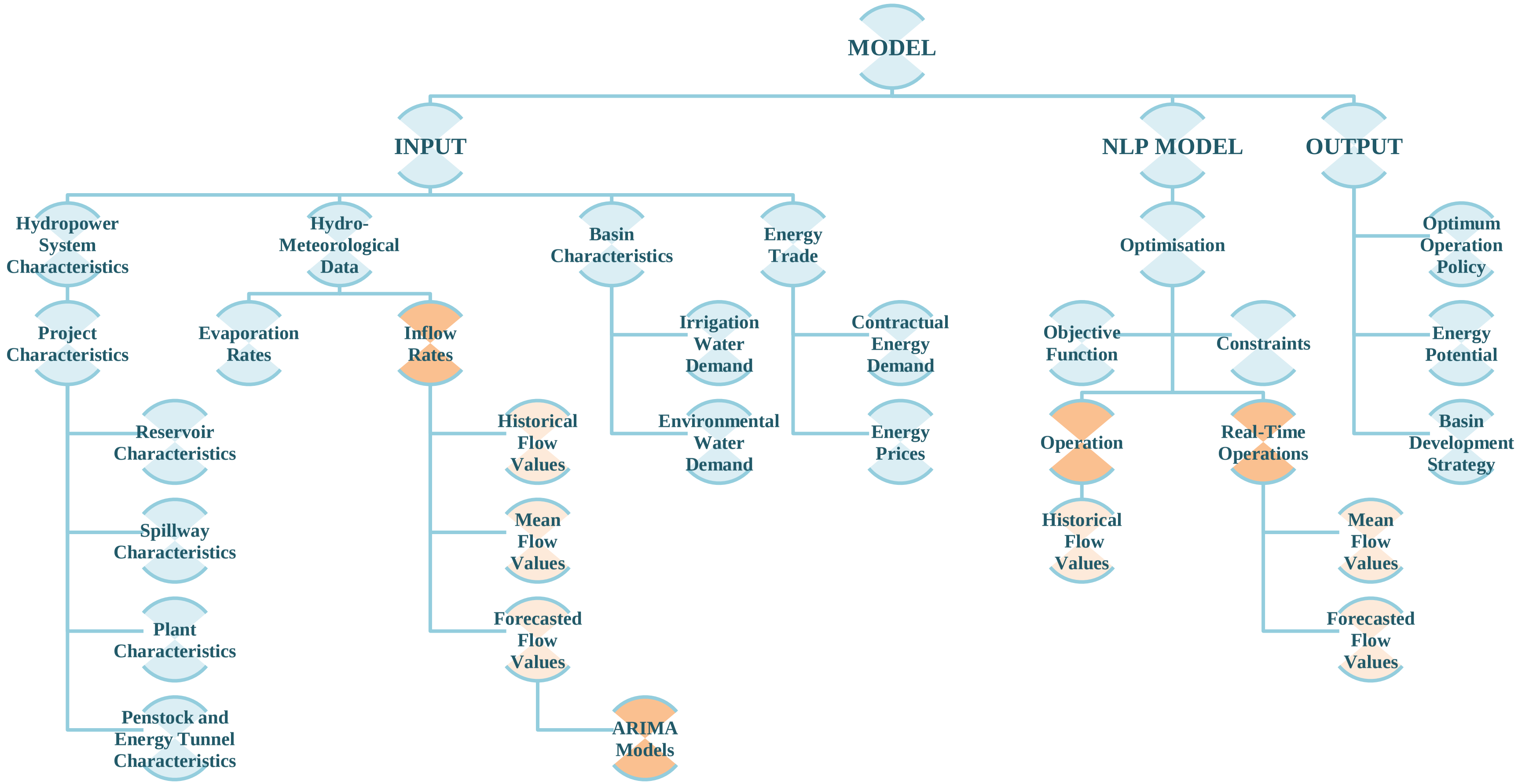


Figure 3 Nonlinear Programming Model

Table 1 Characteristics of the Garzan Projects

Characteristics	Unit	Aysehatun	Kor	Garzan
Purpose	-	Energy	Energy	Energy
Drainage Area	km^2	405.0	942.2	1266.0
Thalwag Elevation	m	1180.0	895.0	675.5
Maximum Water Level	m	1250.0	956.0	788.3
Minimum Water Level	m	1230.0	930.0	757.7
Tailwater Level	m	950.0	830.0	676.0
Design Discharge	m^3/s	13.36	26.54	43.60
Penstock: Number/Diameter/Length	-/m/m	1/2.3/250	1/2.5/210	1/3.2/210
Energy Tunnel: Number/Diameter/Length	-/m/m	1/3.5/8410	1/3.3/6370	1/4.0/382
Number of Units	-	2	2	2
Gross Head/Net Head	m/m	300.0/282.0	126.0/109.9	112.3/108.6
Turbine Type	-	Francis	Francis	Francis

meteorological station are used, and for the Garzan Reservoir, the records of the Siirt meteorological station are utilised (DMI, 2009). Assuming a 0.5°C decrease in temperature per 100 m increase in altitude, the temperature data observed at the relevant stations are transformed into the maximum water levels of the reservoirs (Limak, 2006). Then, the monthly total evaporation quantities corresponding to these transformed temperatures are determined based on correlations between the monthly mean temperature and monthly total evaporation records of these stations. Next, the calculated evaporation values are multiplied by the pan coefficient (0.7) to convert the pan evaporations into the actual evaporation that will occur from lake surfaces (Usul, 2009). Finally, the net evaporation rates per unit area are obtained by subtracting the precipitation records from the appropriate stations from the actual evaporation values. For the Aysehatun and Kor Projects, the monthly total precipitation data observed at the Mutki meteorological station are used, and for the Garzan Reservoir, the records from the Kozluk meteorological station are utilised (DMI, 2009).

3.2 Inflow Values

The historical, mean and forecasted flow values for the dry and rainy seasons are provided to the system as input to analyse the limits and effectiveness of the NLP model when applied to real-time operations. The results of optimisations using the historical and mean flow values represent the range of income that can be derived for the period under consideration.

To investigate how close to the upper bound results can be obtained, forecasted flows are generated using seasonal autoregressive integrated moving average (ARIMA) models based on historical flow values. ARIMA models have been extensively used for time series forecasting based on only past streamflow values (Maier & Dandy, 2000). Fernandez and Vega (2009), Huang, Xu, and Chan-Hilton (2004), Modarres (2007), Muhamad and Hassan (2005), Wang, Chau, Cheng, and Qui (2009) and Yurekli, Kurunc, and Simsek (2004) provided comprehensive literature reviews of the applications of these models in the context of water resources time series.

3.2.1 Historical Records and Averages for Months

The monthly mean flow records obtained from the Besiri (EIE 2603), Bogazonu (DSI 26-57), Kozluk (DSI 26-24), Kozluk (EIE 2634) and Meydanonu (DSI 26-58) hydrometric stations operated by DSI and the General Directorate of Electrical Power Resources Survey and Development Administration (EIE) are utilised to investigate the inflow potential at the dam locations (DSI, 2007; EIE, 2003). These stations are shown in Figure 2 and detailed in Table 2.

First, the raw flow data from the Besiri station are corrected for the upstream irrigation abstraction, which covers an area of 3362 ha and has been in operation since 1996, according to the Garzan-Kozluk irrigation module (Enersu, 2008). Then, the naturalised flow values and correlations are used to produce representative flow data for the 1971-2000 period. The discontinuities in the records of the Bogazonu and Meydanonu stations are patched based on the correlations with the flow rates of the Besiri gauging station. In the correlation studies, the upstream-downstream relationships along river branches are evaluated using the quantities for the corresponding months, and inappropriate data sets are not included. In the extension of the flow values measured at the Kozluk (DSI 26-24) station, the correlation equation obtained based on the naturalised flow rates of the Besiri gauging station is utilised for the 1985-1999 period. For the year 2000, the quantities are transformed from the observations at the Kozluk (EIE 2634) station based on the catchment area ratio between these stations.

Table 2 Characteristics of Stream Gauging Stations

Station Id	Station Name	Opening Date	Closing Date	Drainage Area (km^2)	Elevation (m)	Mean Discharge (m^3/s)
DSI 26-57	Keyburan Brook Bogazonu	24.10.1981	-	425.0	1200	8.6
DSI 26-58	Garzan Creek Meydanonu	29.11.1981	08.01.1999	783.2	909	15.8
DSI 26-24	Pisyar Creek Kozluk	01.08.1970	-	1359.3	620	26.0
EIE 2634	Garzan Creek Kozluk	19.10.1999	30.09.2000	1407.7	630	23.0
EIE 2603	Garzan Creek Besiri	01.11.1945	30.09.2000	2450.4	545	49.0

In the estimation of the monthly mean flow rates at the Mutki Weir location, the drainage area ratio among the weir and the intermediate catchment between the Meydanonu and Bogazonu gauging stations is utilised. The amounts diverted from Mutki Creek to Aysehatun Dam are determined from these values according to the transmission canal capacity of 25.74 m^3/s (DSI, 1987). The flow rates at the Aysehatun Dam location are converted from the extended data set from the Bogazonu station based on the catchment area ratio between them. The sums of these values with the diverted flows from Mutki Creek are utilised as the observed monthly mean inflow values of the Aysehatun Dam and HEPP Project.

The extended flows of the Meydanonu station are propagated to the Kor Dam site in proportion to the drainage areas. Then, the historical monthly mean inflow values of the Kor Dam and HEPP Project are determined by subtracting the produced runoff values at the Aysehatun Dam and Mutki Weir locations from these values.

The catchment area ratio is used to project the extended runoff rates at the Kozluk (DSI 26-24) gauging station to the Garzan Dam axis. The differences between these values and the flow amounts at the Kor Dam site are treated as the observed monthly mean inflow values of the Garzan Reservoir.

The monthly river flows at the Aysehatun, Kor and Garzan Dam locations for the 30-year period from 1971 to 2000 and their monthly averages are displayed in Figure 4.a, Figure 4.b and Figure 4.c, respectively. The water years 1988 and 1989 are determined to represent rainy and dry seasons, respectively, according to the statistics of the entire data set and those of the selected test years, as detailed in Table 3. The averages of the monthly mean flow values for the entire flow record are 35.65 hm^3, 54.90 hm^3 and 68.31 hm^3 at the Aysehatun, Kor and Garzan Dam axes, respectively. These amounts are, in turn, 77.19 hm^3, 120.87 hm^3 and 143.70 hm^3 in water year 1988, and 13.37 hm^3, 20.41 hm^3 and 24.86 hm^3 in water year 1989. Moreover, the maximum and minimum monthly mean flow amounts are observed in the rainiest and driest water years during the 1971-2000 period, respectively.

3.2.2 Forecasted Inflows

The time series are split into two sets, namely, the training and testing periods. The historical river flow data from 1971 to 1987 and from 1971 to 1988 are used as the training periods for calibrating the forecasting models, and the data from the years 1988 and 1989 are used as the test sets for verification of the models in the rainy and dry seasons, respectively (Table 3).

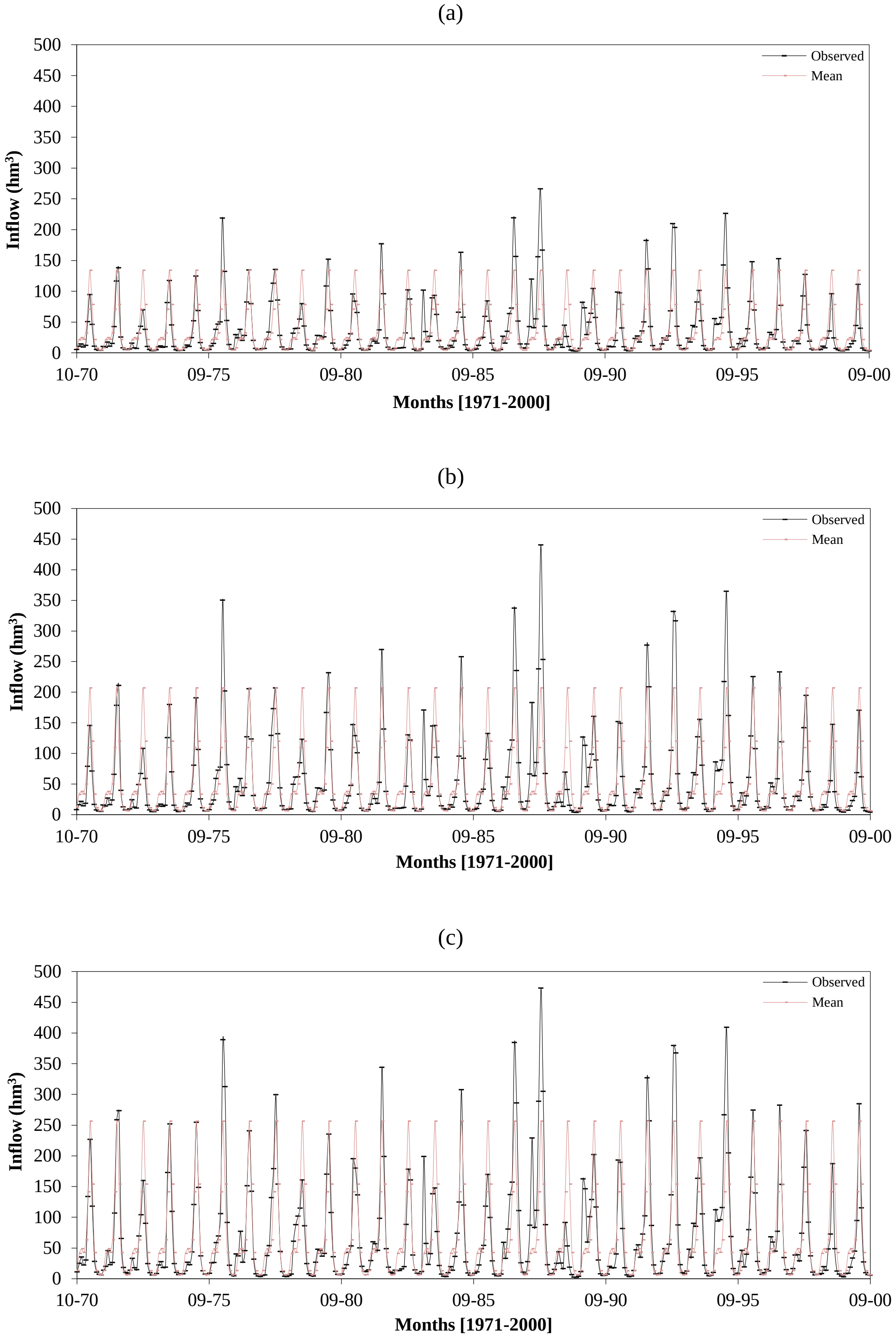


Figure 4 Time Series of Monthly Streamflow at (a) the Aysehatun Dam, (b) the Kor Dam and (c) the Garzan Dam Locations

Table 3 Statistics for Data Sets

Basin	Data set	Mean (hm^3)	Standard deviation (hm^3)	Skewness (hm^3)	Minimum (hm^3)	Maximum (hm^3)
Rainy period						
Aysehatun	Training	33.751	41.517	2.039	3.482	219.189
	Testing	77.188	82.286	1.295	4.700	266.183
	Entire	35.647	45.112	2.171	2.740	266.183
Kor	Training	51.844	64.168	2.058	4.877	349.872
	Testing	120.872	132.613	1.455	6.799	439.967
	Entire	54.899	70.269	2.251	3.704	439.967
Garzan	Training	65.049	80.187	1.859	2.943	388.378
	Testing	143.700	147.366	1.165	6.126	472.442
	Entire	68.631	85.840	1.936	1.767	472.442
Dry period						
Aysehatun	Training	36.164	45.534	2.159	3.482	266.183
	Testing	13.370	12.364	1.706	2.740	44.800
	Entire	35.647	45.112	2.171	2.740	266.183
Kor	Training	55.679	70.984	2.257	4.877	439.967
	Testing	20.406	19.337	1.694	3.704	69.448
	Entire	54.899	70.269	2.251	3.704	439.967
Garzan	Training	69.419	86.650	1.933	2.943	472.442
	Testing	24.857	26.259	1.642	1.767	90.823
	Entire	68.631	85.840	1.936	1.767	472.442

3.2.2.1 Fitting ARIMA Models

ARIMA models, as introduced by Box and Jenkins (1976), are represented by ARIMA (p,d,q) x $(P,D,Q)_s$. The terms (p,d,q) and $(P,D,Q)_s$ represent the orders of the non-seasonal and seasonal components, respectively, where d is the number of regular differencing, D is the number of seasonal differencing, p is the order of the non-seasonal autoregressive (AR), q is the order of the non-seasonal moving average (MA), P is the order of the seasonal AR, Q is the order of the seasonal MA and s is the season length, which is 12 for monthly data.

The general ARIMA models for a set of measurements $y = \{y_1, y_2, \dots, y_n\}^T$ are expressed as follows:

$$\phi(B)\ \Phi(B^s)\ (1-B)^d\ (1-B^s)^D\ y^t = \theta(B)\ \Theta(B^s)\varepsilon_t \quad (17)$$

with

$$\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_P B^P \tag{18}$$

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q \tag{19}$$

$$\Phi(B^s) = 1 - \Phi_1 B^s - \Phi_2 B^{2s} - \cdots - \Phi_P B^{Ps} \tag{20}$$

$$\Theta(B^s) = 1 - \Theta_1 B^s - \Theta_2 B^{2s} - \cdots - \Theta_Q B^{Qs} \tag{21}$$

where *t* is discrete time; B is the difference operator, $B(y_t) = y_{t-1}$; $\phi(B)$ is the non-seasonal AR operator of order *p*; $\theta(B)$ is the non-seasonal MA operator of order q; $\Phi(B^s)$ is the seasonal AR operator of order *P*; $\Theta(B^s)$ is the seasonal MA operator of order Q; $(1 - B)^d$ is the non-seasonal differencing operator of order *d*; $(1 - B^s)^D$ is the seasonal differencing operator of order *D*; and ε_t is the white noise series, which has a finite variance and a mean of zero (Ghanbarpour, Abbaspour, & Hipel, 2009).

Prior to fitting the ARIMA models, the time series are transformed via a logarithmic transformation to eliminate any difficulties arising from non-normality and heteroscedasticity in the estimated residuals (Hipel & McLeod, 1994). The autocorrelation functions (ACFs) and partial autocorrelation functions (PACFs) are examined to identify appropriate ARIMA models for the time series of river flows. First, the ACFs are differenced by a lag of 12 because of their seasonality. Then, the presence of non-seasonal and seasonal AR and MA terms in the models is evaluated in accordance with the Akaike Information Criterion (AIC) and Ljung-Box-Pierce statistics. Finally, the ACFs and PACFs of the residuals are checked to determine whether the residuals lie within confidence limits such that they satisfy the requirements of a white noise process (Shabri & Suhartono, 2012).

To determine the forecasted inflow rates for the first month of real-time operations during the rainy period, the sample ACFs and PACFs of the historical river flow data from 1971 to 1987 are plotted in Figure 5.a, Figure 6.a and Figure 7.a for the Aysehatun, Kor and Garzan Dam locations, respectively. The seasonal spikes are not truncated but rather are damped out in the PACFs, and they cut off after a lag of 1 in the ACFs, suggesting that a seasonal MA parameter is needed in the models. Therefore, $(P,D,Q) = (0,1,1)$ appears to be appropriate to test as the seasonal component of the models.

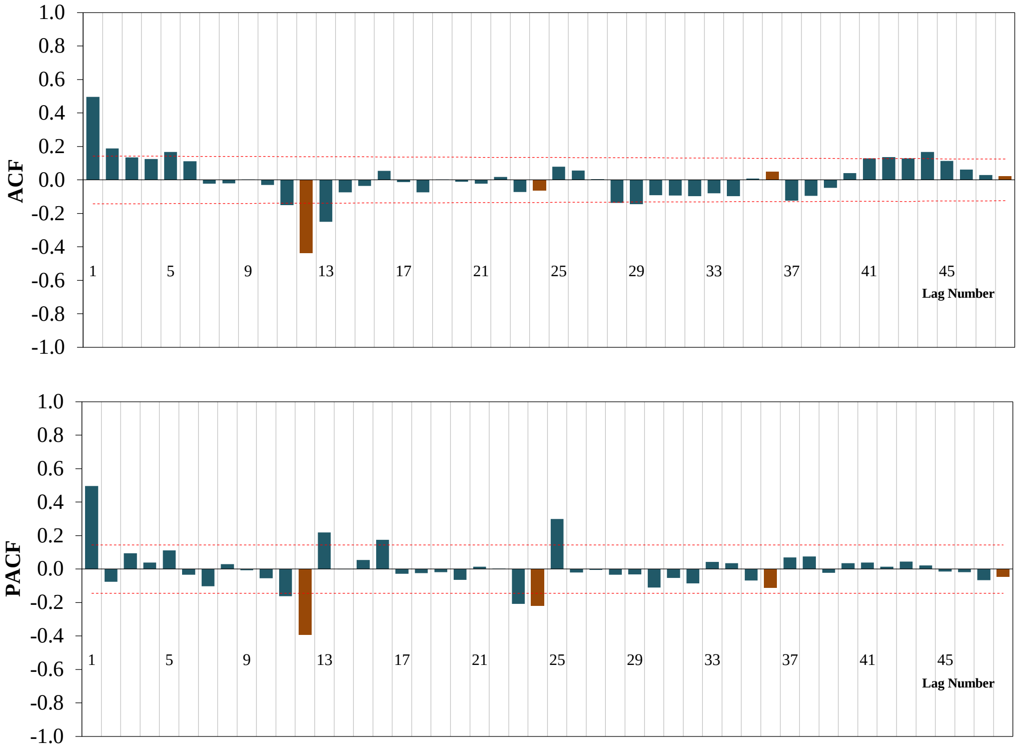
However, the non-seasonal patterns in the ACFs and PACFs are not as clear. They could indicate either an MA or an AR parameter. Thus, the non-seasonal component of the models (p,d,q) could be either (1,0,0) or (0,0,1). Based on the minimum AICs and Ljung-Box-Pierce statistics, the optimal model is shown to be the ARIMA $(0,0,1)\ (0,1,1)_{12}$ for all dam locations.

The residual plots showing the ACFs and PACFs of the residuals are presented in Figure 5.b, Figure 6.b and Figure 7.b for the Aysehatun, Kor and Garzan Dam locations, respectively. The ACFs and PACFs of the residuals lie within the confidence limits, and the residuals do not exhibit a significant correlation, thereby conforming that the residuals of the selected model are consistent with white noise (Shabri & Suhartono, 2012).

The ARIMA models to be used in each time step of the real-time operations are developed following the same procedure described above using the *IBM SPSS Forecasting* module (IBM Corporation, 2012). The selected models are listed in Table 4.

The observed, mean and forecasted flow rates at the Aysehatun Dam, Kor Dam and Garzan Dam locations during the rainy and dry seasons are displayed in Figure 8 and Figure 9, respectively. These graphs show that the ARIMA results are closer to the corresponding observed streamflow values than are the mean inflow rates.

(a)



(b)

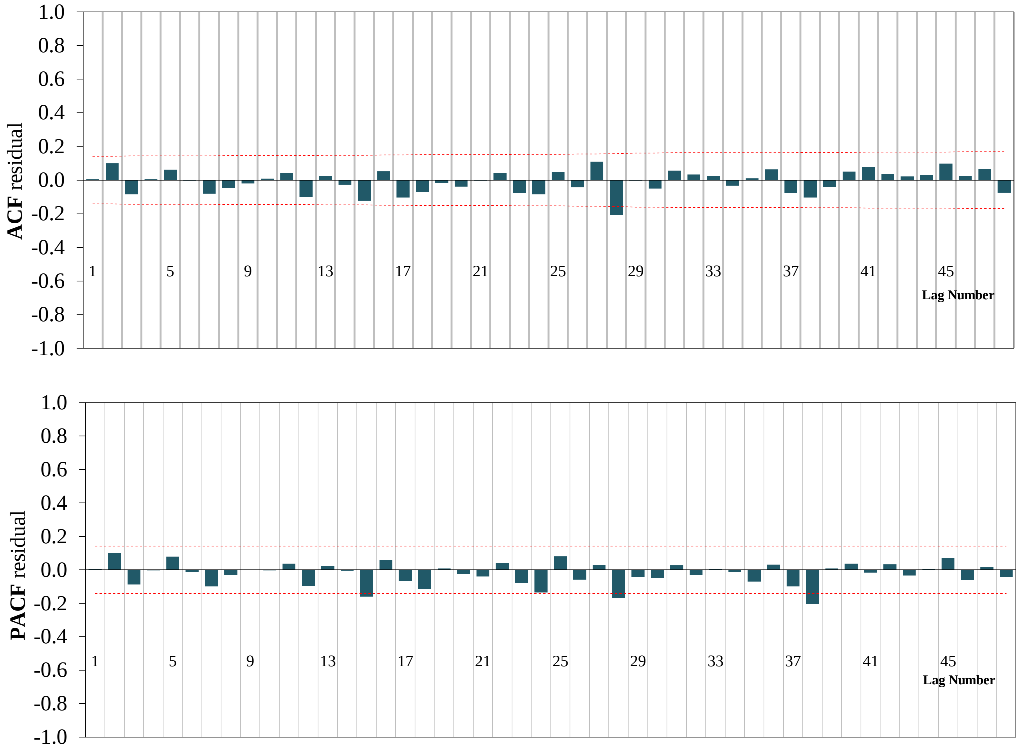


Figure 5 (a) ACF-PACF and (b) ACF-PACF Residual of Streamflow Series at the Aysehatun Dam Location

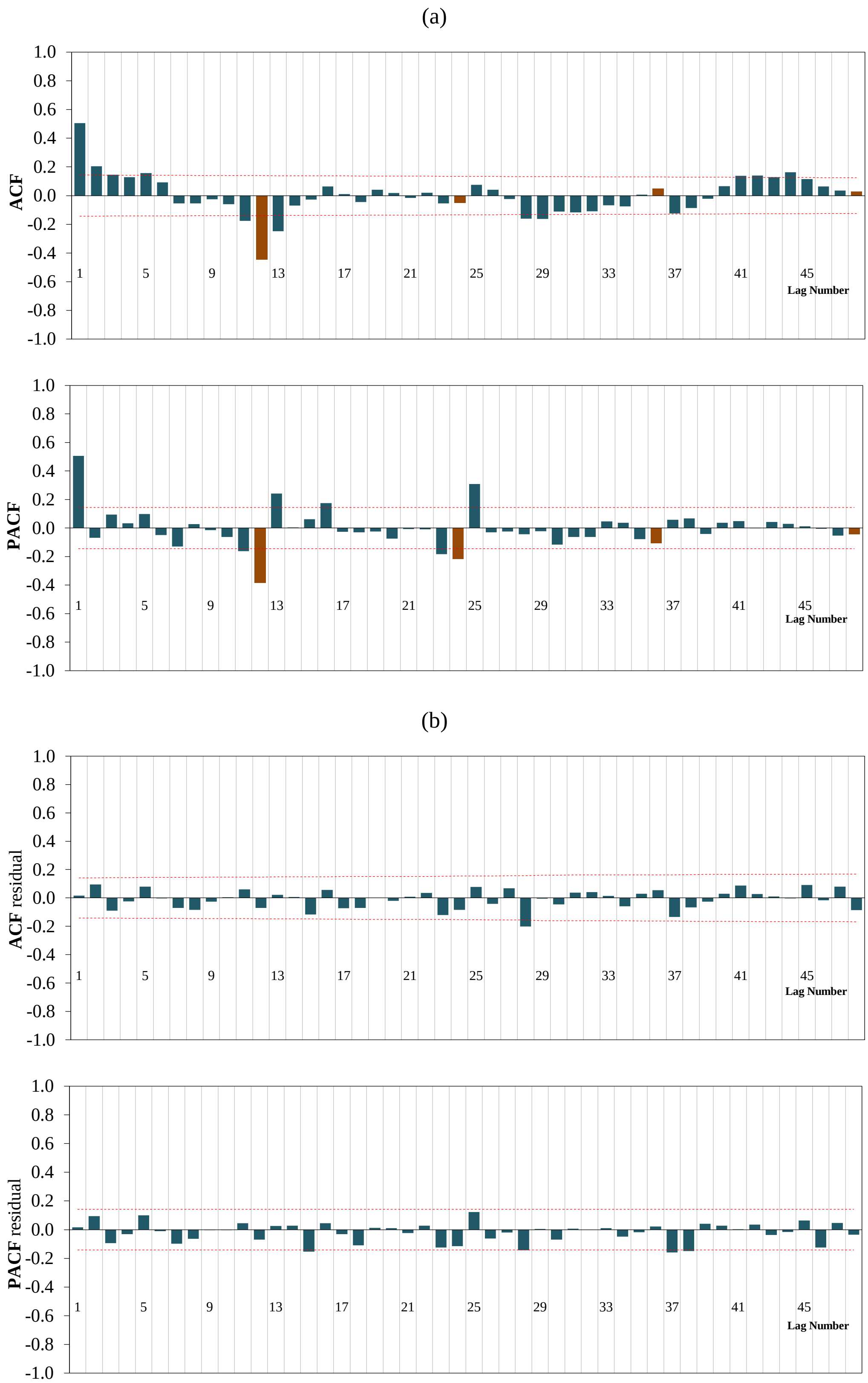
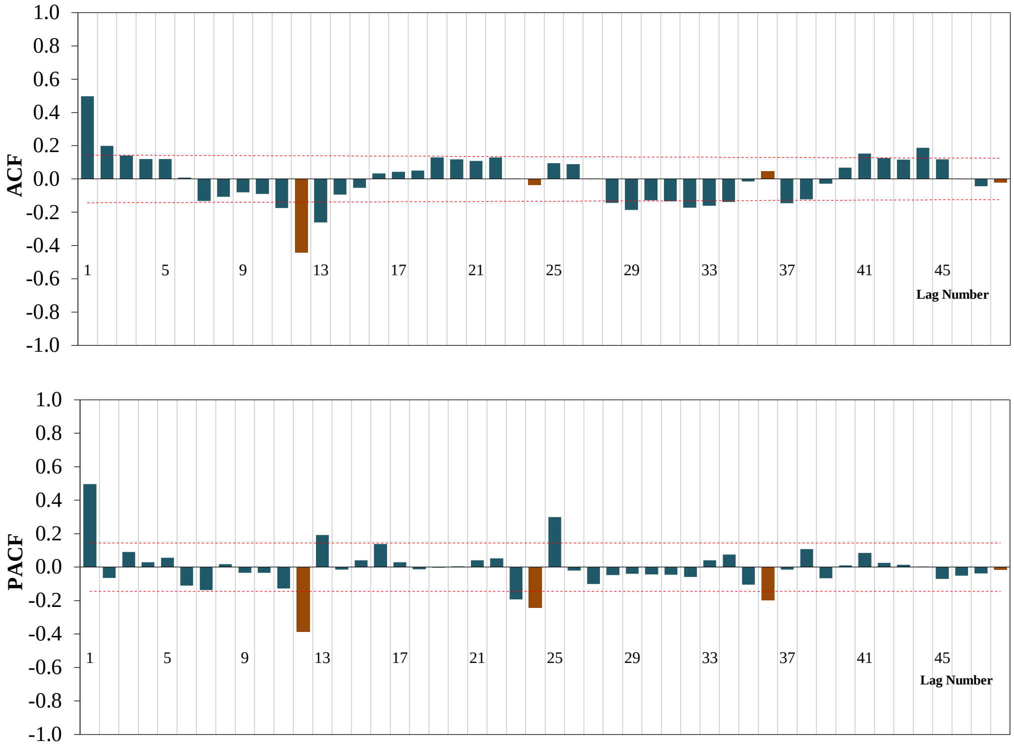


Figure 6 (a) ACF-PACF and (b) ACF-PACF Residual of Streamflow Series at the Kor Dam Location

(a)



(b)

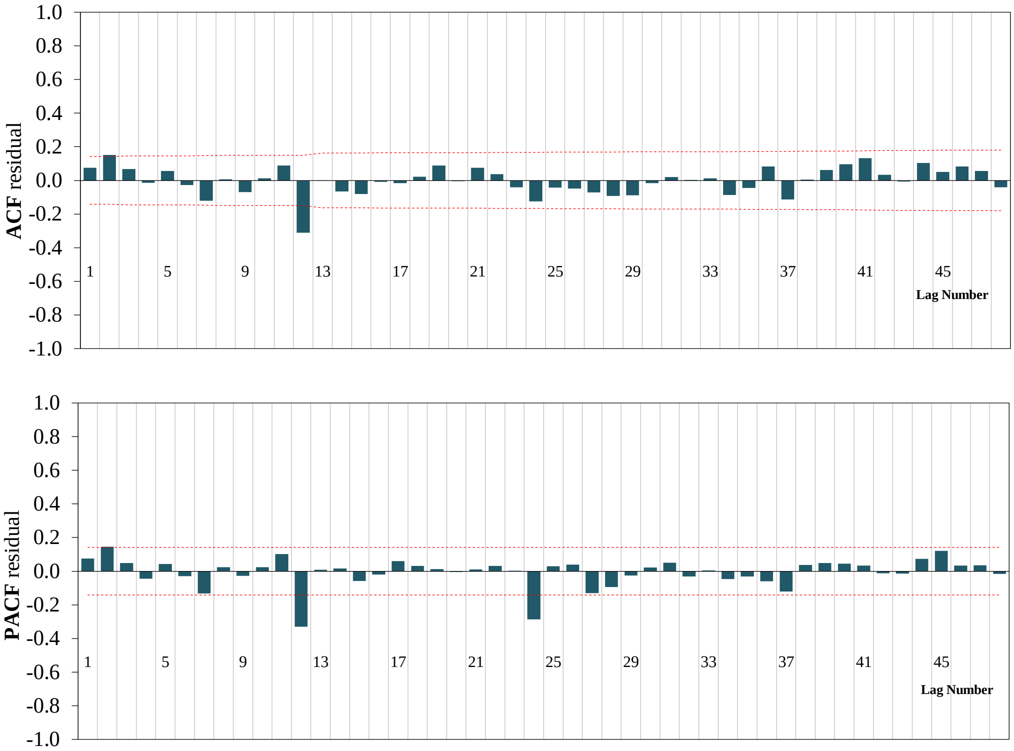


Figure 7 (a) ACF-PACF and (b) ACF-PACF Residual of Streamflow Series at the Garzan Dam Location

Table 4 Selected ARIMA Models

Run	Aysehatun	Kor	Garzan
		Rainy period	
Run1	$(0,0,1)\ (0,1,1)_{12}$	$(0,0,1)\ (0,1,1)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run2	$(0,0,1)\ (0,1,1)_{12}$	$(0,0,1)\ (0,1,1)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run3	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,1)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run4	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,1)_{12}$
Run5	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run6	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run7	$(0,0,1)\ (0,1,1)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,2)\ (1,1,1)_{12}$
Run8	$(0,0,1)\ (0,1,1)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,2)\ (1,1,1)_{12}$
Run9	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,2)\ (1,1,1)_{12}$
Run10	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,2)\ (1,1,1)_{12}$
Run11	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,2)\ (1,1,1)_{12}$
Run12	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
		Dry period	
Run1	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run2	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run3	$(0,0,1)\ (0,1,1)_{12}$	$(1,0,0)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run4	$(1,0,0)\ (0,1,0)_{12}$	$(1,0,0)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run5	$(1,0,2)\ (0,1,0)_{12}$	$(1,0,0)\ (0,1,0)_{12}$	$(1,0,0)\ (0,1,0)_{12}$
Run6	$(0,0,1)\ (0,1,1)_{12}$	$(0,0,1)\ (0,1,1)_{12}$	$(0,0,1)\ (0,1,0)_{12}$
Run7	$(1,0,0)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,1)_{12}$	$(1,0,0)\ (1,1,0)_{12}$
Run8	$(0,0,1)\ (0,1,0)_{12}$	$(0,0,1)\ (0,1,1)_{12}$	$(1,0,11)\ (1,1,0)_{12}$
Run9	$(1,0,0)\ (1,1,0)_{12}$	$(1,0,0)\ (0,1,1)_{12}$	$(0,0,2)\ (1,1,0)_{12}$
Run10	$(1,0,0)\ (0,1,1)_{12}$	$(2,0,1)\ (0,1,1)_{12}$	$(0,0,2)\ (1,1,0)_{12}$
Run11	$(1,0,0)\ (0,1,1)_{12}$	$(2,0,1)\ (0,1,1)_{12}$	$(0,0,2)\ (1,1,0)_{12}$
Run12	$(1,0,0)\ (0,1,0)_{12}$	$(1,0,0)\ (0,1,0)_{12}$	$(1,0,0)\ (1,1,1)_{12}$

3.2.2.2 Measures of Accuracy

The forecasting performance of the models at the testing stages is evaluated using the mean absolute error (MAE), the root mean square error (RMSE), the mean bias error (MBE), the normalised mean bias error (NMBE), the correlation coefficient (R) and the Nash-Sutcliffe coefficient of efficiency (CE), as defined in Equations (22), (23), (24), (25), (26) and (27), respectively. In addition, the RMSE/$\bar{y}^o$ error index is utilised to compare the results with those of other studies on river flow forecasting (Valipour, Banihabib, & Behbahani, 2013). Relatively small MAE, RMSE, MBE and RMSE/$\bar{y}^o$ values indicate the accuracy of the forecasting models. The tendency of the models towards over- or underestimation

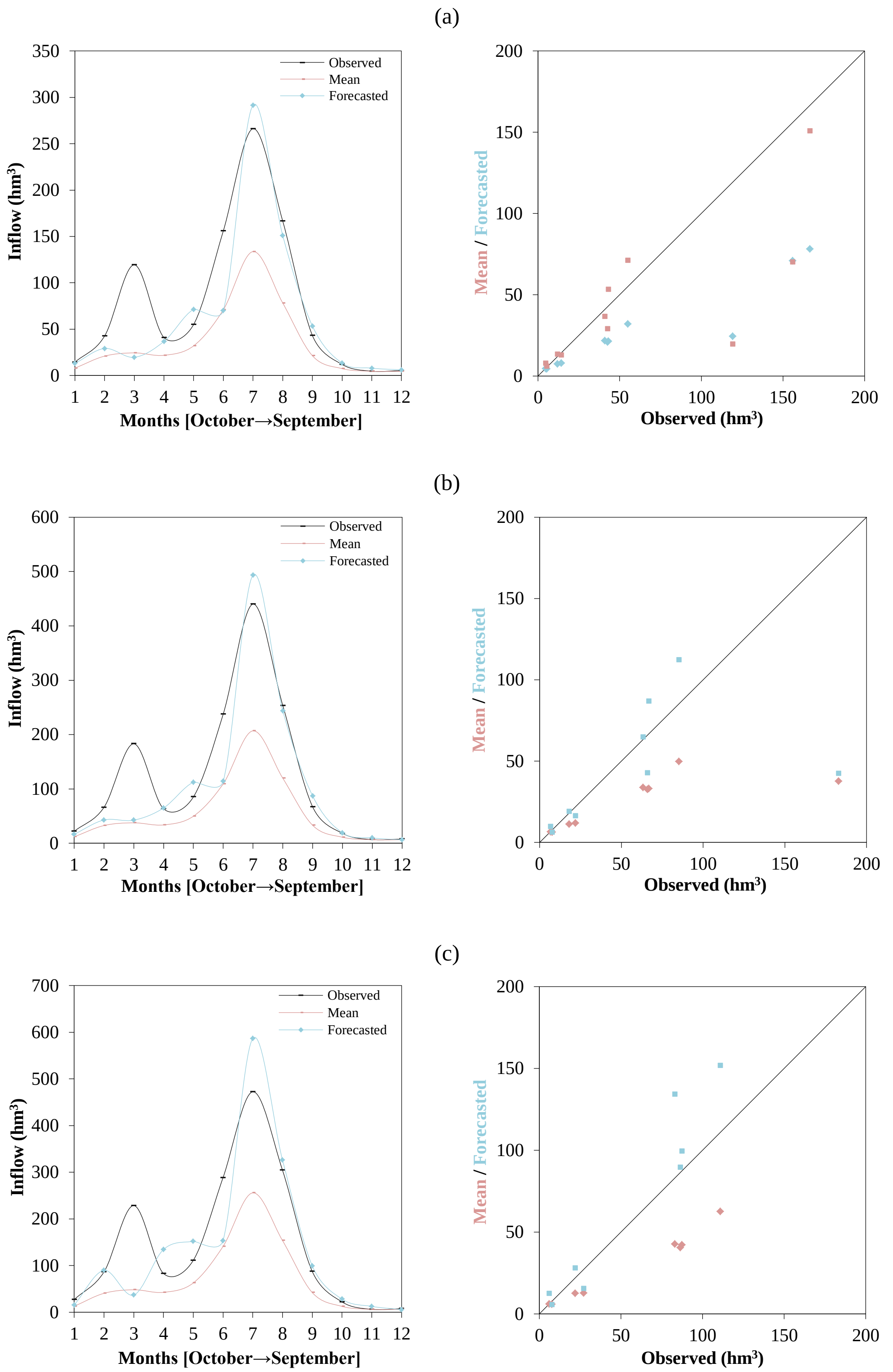


Figure 8 Observed, Mean and Forecasted River Flows during the Rainy Season at (a) the Aysehatun Dam, (b) the Kor Dam and (c) the Garzan Dam Locations

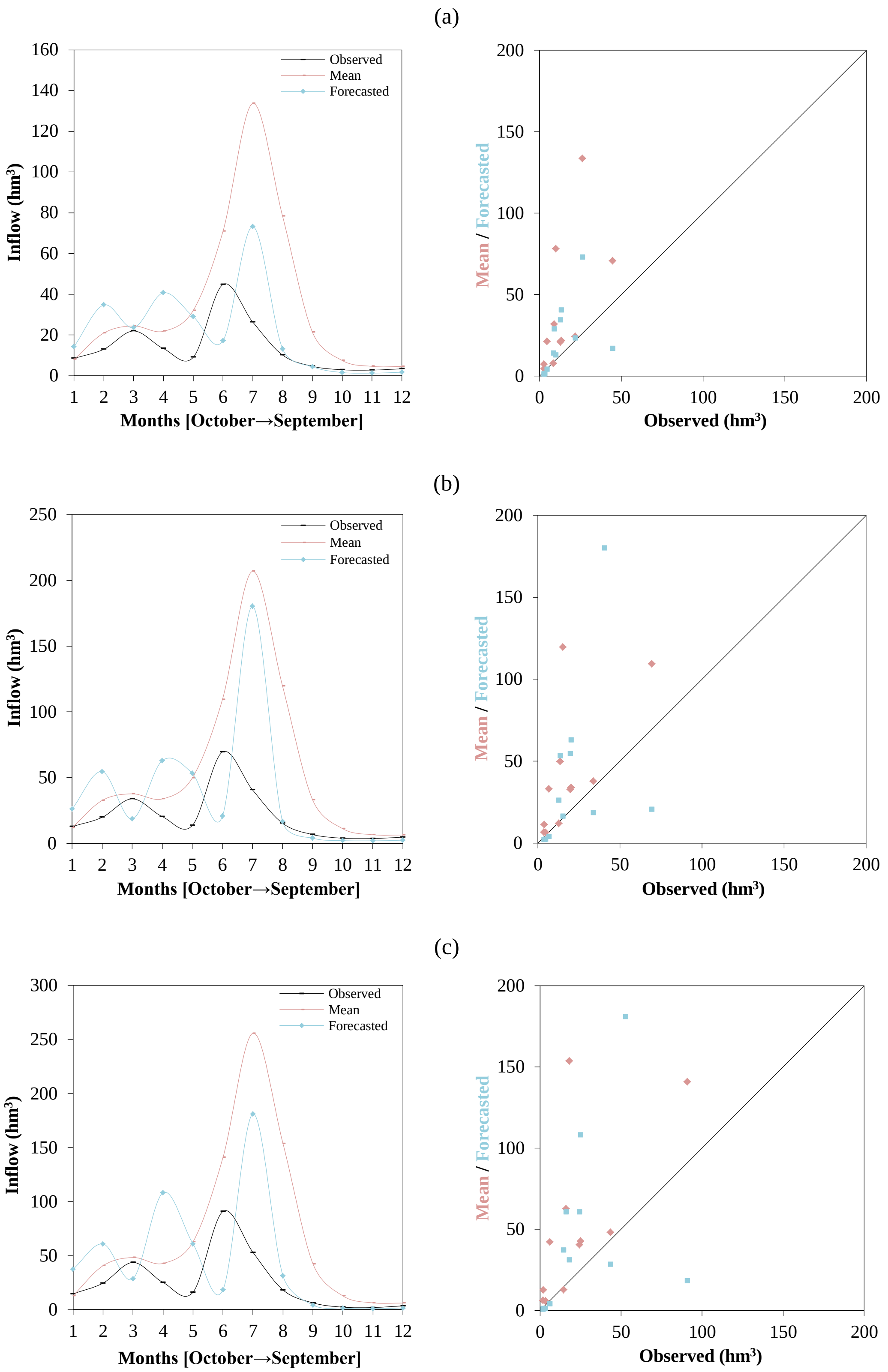


Figure 9 Observed, Mean and Forecasted River Flows during the Dry Season at (a) the Aysehatun Dam, (b) the Kor Dam and (c) the Garzan Dam Locations

can be observed from the NMBE values (Ghanbarpour et al., 2009). The R values measure the degree of linear correlation between the predicted and observed flow rates. The CE values provide an indication of the model performance at prediction values far from the mean of the historical time series.

$$MAE = \frac{1}{n}\sum_{t=1}^{n}\left|y_t^o - y_t^f\right| \tag{22}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(y_t^o - y_t^f\right)^2} \tag{23}$$

$$MBE = \frac{1}{n}\sum_{t=1}^{n}(y_t^o - y_t^f) \tag{24}$$

$$NMBE = \frac{\frac{1}{n}\sum_{t=1}^{n}(y_t^f - y_t^o)}{\frac{1}{n}\sum_{t=1}^{n} y_t^o} \tag{25}$$

$$R = \frac{\frac{1}{n}\sum_{t=1}^{n}(y_t^o - \bar{y}^o)(y_t^f - \bar{y}^f)}{\sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t^o - \bar{y}^o)^2}\sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t^f - \bar{y}^f)^2}} \tag{26}$$

$$CE = 1 - \frac{\sum_{t=1}^{n}(y_t^o - y_t^f)^2}{\sum_{t=1}^{n}(y_t^o - \bar{y}^o)^2} \tag{27}$$

where y_t^o is the observed value and y_t^f is the forecasted value at time *t*, *n* is the number of data points, and $\bar{y}^o$ and $\bar{y}^f$ are the means of the observed and forecasted values, respectively.

In Table 5, it is shown that for all dam locations and for both seasons, the ARIMA model demonstrates good performance with respect to the monthly averages in the testing phases. Although the mean flow rates are more highly correlated with the observed flows, this increase in the R values has no effect on the magnitudes of the other error measures.

Table 5 Forecasting Performance Indices of Mean and ARIMA Approaches

Basin	Model	MAE	RMSE	NMBE	RMSE/$\bar{y}^o$	MBE	R	CE
				Rainy period				
Aysehatun	Mean	41.541	60.222	-0.538	0.780	41.541	0.966	0.416
	ARIMA	23.116	39.558	-0.175	0.512	13.537	0.889	0.748
Kor	Mean	65.973	97.616	-0.546	0.808	65.973	0.971	0.409
	ARIMA	34.151	57.459	-0.136	0.475	16.461	0.912	0.795
Garzan	Mean	75.069	104.992	-0.522	0.731	75.069	0.962	0.446
	ARIMA	49.659	78.018	-0.049	0.543	7.015	0.876	0.694
				Dry period				
Aysehatun	Mean	22.369	38.555	1.666	2.884	-22.277	0.630	-9.608
	ARIMA	13.230	19.670	0.586	1.471	-7.838	0.468	-1.761
Kor	Mean	34.645	59.526	1.690	2.917	-34.494	0.632	-9.337
	ARIMA	28.643	47.341	0.811	2.320	-16.554	0.382	-5.538
Garzan	Mean	44.069	74.337	1.761	2.991	-43.774	0.646	-7.742
	ARIMA	35.134	52.321	0.787	2.105	-19.566	0.355	-3.331

3.3 Environmental and Irrigation Water Demands

For the maintenance of natural ecosystems, 10 percent of the monthly mean inflow values over the last 10 years (1991-2000) is left on the river bed as environmental water due to the energy tunnels of the system projects (DSI, 2014).

The Garzan irrigation scheme will be largely sourced from the outflows of the Garzan Reservoir. Hence, operations must be conducted such that the outflow rates are equal to or greater than the irrigation water demands of the corresponding months, which are determined in accordance with the Garzan irrigation module (FPGA, 1968).

3.4 Turbine Efficiency

Turbine efficiency depends on the type of turbine and the ratio of power release to capacity. The efficiency curves for Francis-type turbines, which are the type utilised in the system power plants, are defined in the model as high-order polynomials of the ratio of the power releases to the designed discharges (Pro-sem, 2008) (Appendix A).

3.5 Energy Prices

There are two types of prices on the day-ahead market, namely, the Market Clearing Price (MCP) and the System Marginal Price (SMP). If a producer supplies its expected amount of produced energy on time, as previously reported to PMUM, it receives payment at the MCP. If the produced energy is more or less than the reported amount, it leads to a system imbalance, and the SMP enters the calculation (Demirdizen, 2013). The MCP and SMP averages and the averages for months are presented in Figure 10 and Figure 11, respectively.

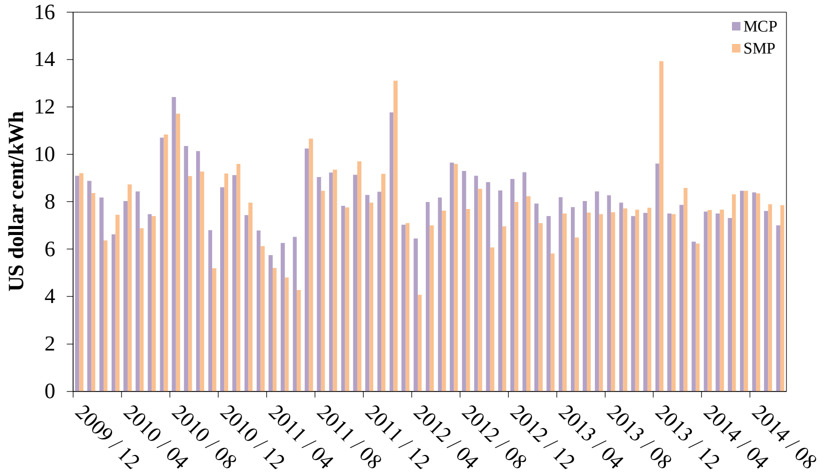


Figure 10 Market Clearing Price (MCP) and System Marginal Price (SMP) Averages

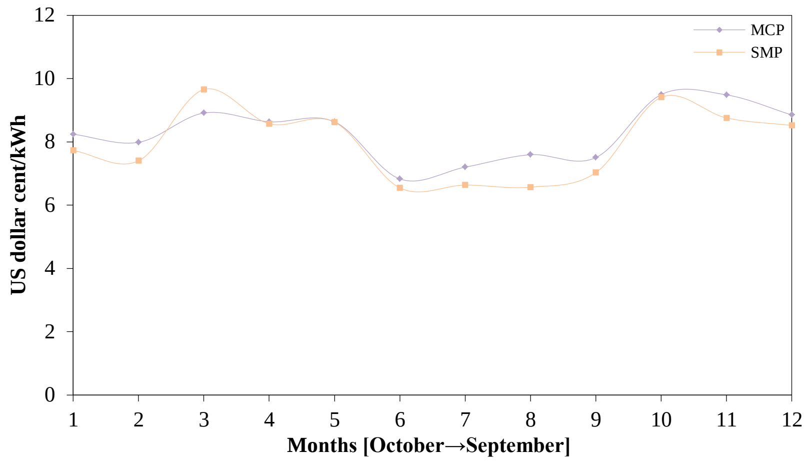


Figure 11 Market Clearing Price (MCP) and System Marginal Price (SMP) Averages for Months

The day-ahead market has been in operation since December 2009 (PMUM, 2014). There are not sufficient data available to apply a monthly forecasting procedure. Hence, the monthly SMP averages are utilised as inputs to the NLP model.

3.6 Operational Studies

Optimisation studies are performed for both the rainy and dry seasons using three different inflow sets. The initial and ending storage values of the system reservoirs are constrained to be equal to the dead volumes. In addition, the contractual energy demand is not considered, and the operations are optimised using a model that assumes that all produced energy will be sold on the day-ahead market (Appendix A).

The operations data based on the historical inflow rates provide an upper bound on the income that can be obtained for the period under consideration. Moreover, the system reservoirs are also operated sequentially using the historical data sets to evaluate the efficiency of the integrated operations plan. In these consecutive operations, the inflow values are obtained by adding the optimised outflows of the upstream projects to the intermediate basin flows.

Then, the monthly means of the extended data sets from 1971 to 2000 are utilised as input during the 12-month operation period for each fall season. These objective function values can be defined as the lower bounds on the combined system incomes. The optimisations are repeated 12 times at the beginning of each month based on the real states of the system reservoirs.

To provide an estimate of the income that can be achieved in real-time operations, the same procedure is performed using the successively renewed inflow forecasts obtained via the selected ARIMA models. The state of the system reservoirs is updated at the beginning of each month based on the observed inflow values from the previous month.

3.6.1 Rainy Season Operations

The objective function values for the combined and separate system operations based on the historical time series are presented in Figure 12. The total income for integrated system operation is found to be 55.57 million US dollars/year. According to the results of the sequential optimisation studies of the system reservoirs, the income during the period under consideration is determined to be 52.14 million US dollars/year. This means that for the same period of operation with the same initial and ending storage values, the integrated optimisation model yields 6.59% more revenue than does the separate reservoir optimisation approach (Table 6).

Figure 13 presents a comparison of the monthly storage variations of the system reservoirs, and Figure 14 shows a comparison of the income values obtained from three different inflow series. It can be observed that the NLP model based on the historical inflow rates yields 5.34% more income than does the model based on the mean inflow values and 3.66% more income than does the model based on the forecasting results (Table 6). The reason for this difference can be understood based on the amounts of spilled water for the Garzan Reservoir, presented in Figure 15. An integrated operation plan and adequate flow forecasts make a beneficial contribution to the effective management of the incoming water and, thus, the energy production.

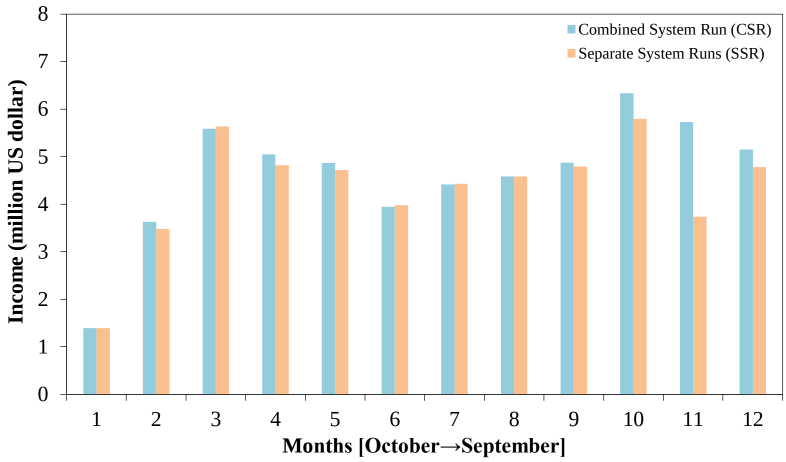


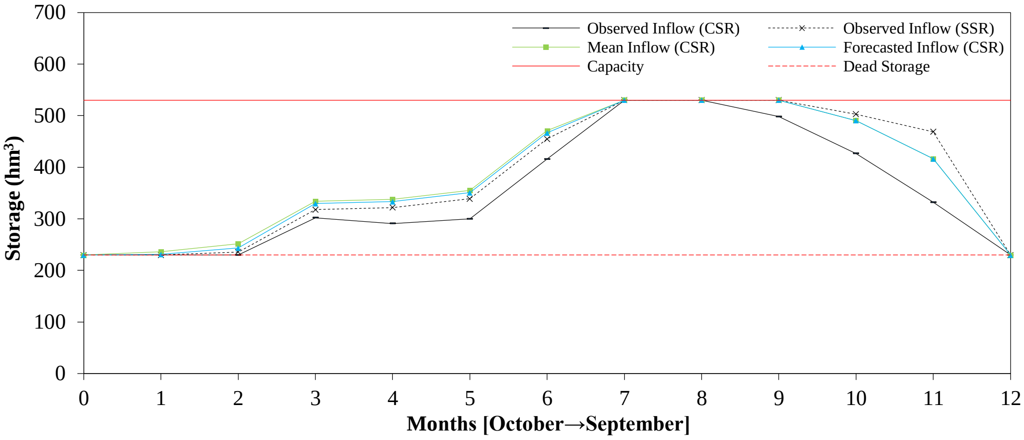
Figure 12 Comparison of Incomes Obtained from the Combined and Separate System Runs for the Rainy Season

3.6.2 Dry Season Operations

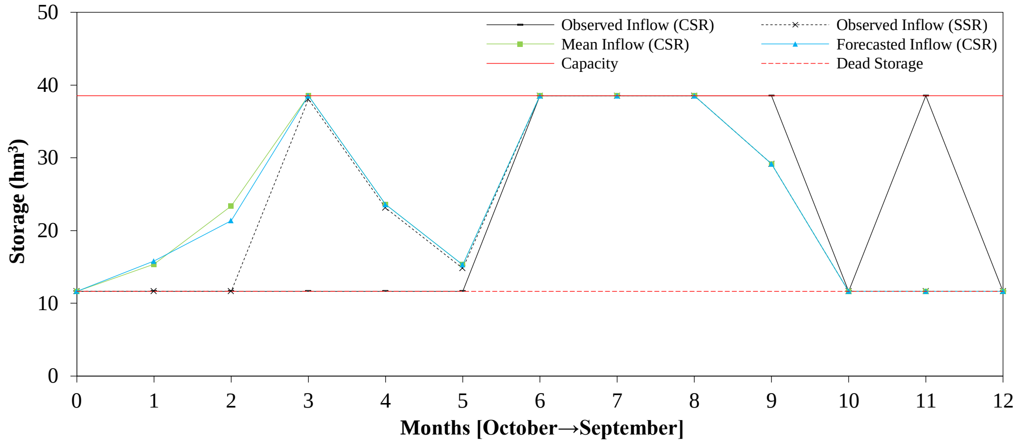
In water year 1989, the critical factor is the irrigation water needs of the Garzan irrigation scheme. In this year, 215.14 hm^3 of water must be supplied from the outflows of the Garzan Reservoir, but the total flow volume of the intermediate basin between the Kor and Garzan Reservoirs is only 59.21 hm^3. This means that the outflows of the Kor HEPP are critical for satisfying the irrigation water demand.

The income value of the combined system for water year 1989 is found to be 15.24 million US dollars/year. However, in the sequential optimisation studies of the system reservoirs, it is found that the Garzan Reservoir operation optimisation

(a)



(b)



(c)

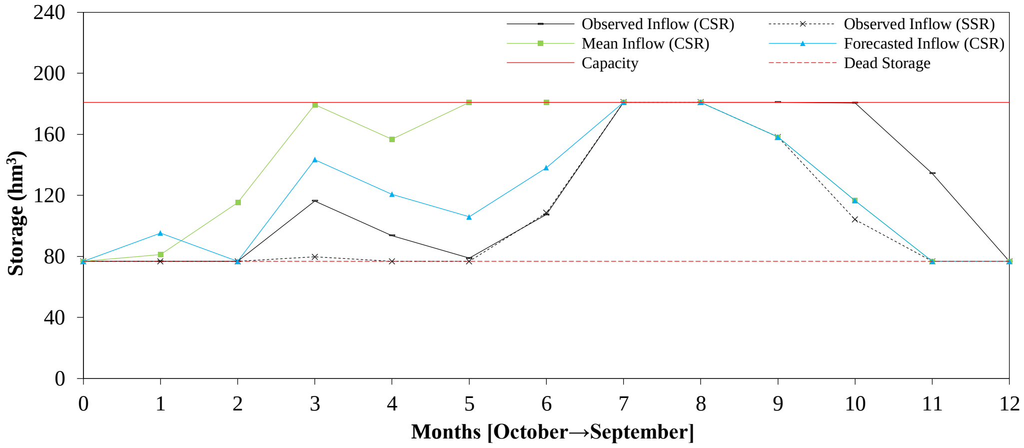


Figure 13 Storage Variations during the Rainy Season at (a) the Aysehatun Reservoir, (b) the Kor Reservoir and (c) the Garzan Reservoir

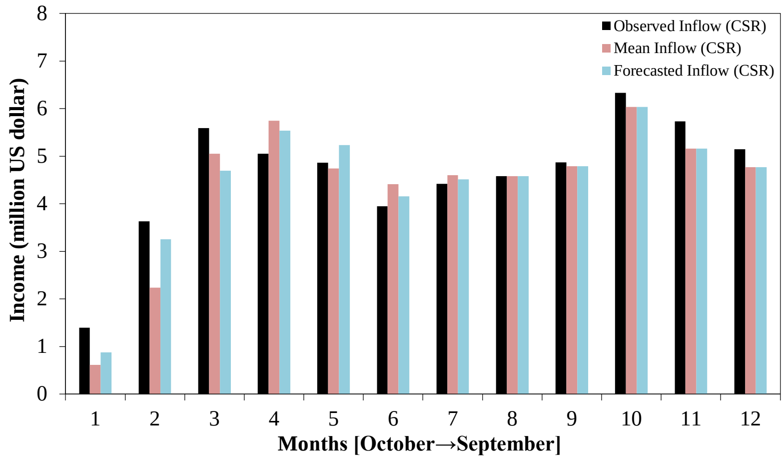


Figure 14 Comparison of Incomes Obtained via the Observed, Mean and Forecasted Inflow Series for the Rainy Season

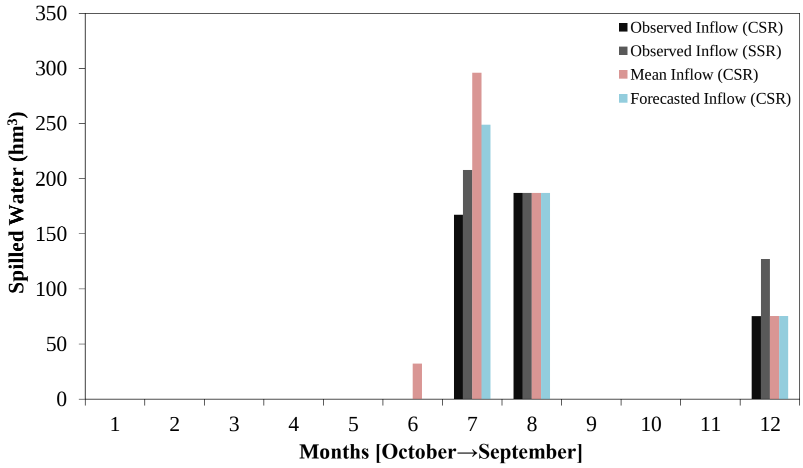


Figure 15 Comparison of Spilled Water Amounts Obtained via the Observed, Mean and Forecasted Inflow Series for the Rainy Season

does not converge because of the demand constraint defined in Equation (12). This outcome is likely to occur in real-life applications during such a dry season, when all reservoirs and the irrigation scheme are in operation. By decreasing the demand amounts until convergence is reached, it is found that the optimisation becomes feasible at 83% of the initial demand, and the total income of the reservoir system is found to be 15.16 million US dollars/year (Figure 16). Comparisons of the income values obtained from the combined and separate system operations and the monthly storage variations of the system reservoirs are presented in Figure 17 and Figure 18, respectively. As a result, for both fall seasons, the integrated system operation plans yield more income than do the sequential optimisation studies of the system reservoirs (Table 6). Moreover, in the dry season, the sequential system operation plans generate insufficient outflow rates that satisfy only 83 percent of the downstream irrigation demand.

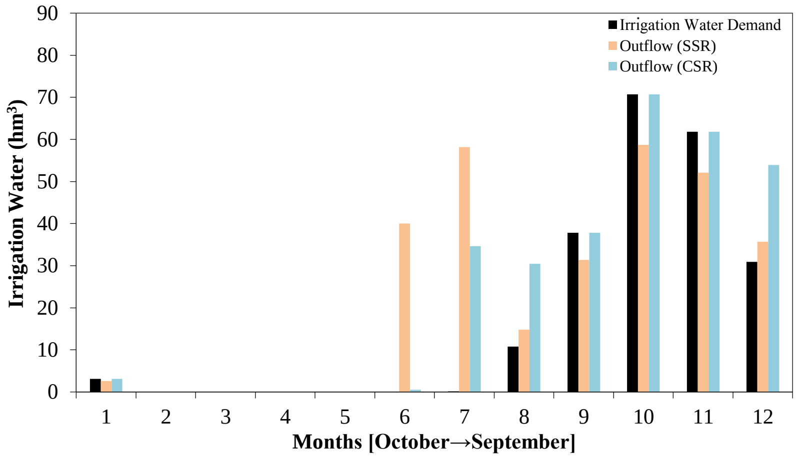


Figure 16 Comparison of Supplied Irrigation Water Amounts Obtained from the Combined and Separate System Runs for the Dry Season

Table 6 Results of the Operations for the Garzan Hydropower System

Income (million US dollar)		**Aysehatun**	**Kor**	**Garzan**	**Total**
		Rainy period			
Combined System Run	Historical	20.05	13.74	21.78	55.57
	Mean	19.47	13.55	19.74	52.76
	Forecasted	19.69	13.71	20.21	53.61
Separate System Runs	Historical	20.22	13.11	18.81	52.14
		Dry period			
Combined System Run	Historical	6.40	3.34	5.50	15.24
	Mean	infeasible			
	Forecasted	infeasible			
Separate System Runs	Historical	6.67	3.49	5.00	15.16

The same situation is also observed in the real-time operation optimisations. The NLP model, considering the system as a whole, begin to fail to converge after several steps when the monthly mean and forecasted flow values are taken as the inputs to the model. The optimisation does not converge in run-8 (May to September) using the mean flow values or in run-5 (February to September) using the updated ARIMA forecasts.

The reason for these non-convergences is that insufficient storage is allocated for the irrigation needs because of the inadequate inflow values. These findings illustrate the importance of forecasts to real-time operations. The CE and R values of the ARIMA forecasts and the mean flow rates are indicators of such a result. The negative CE values indicate that the observed mean is a better predictor than are the forecasting model results (Table 5).

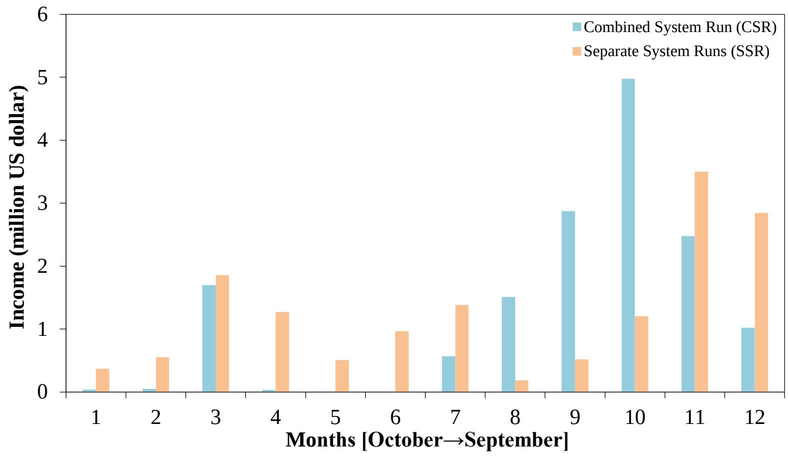


Figure 17 Comparison of Incomes Obtained from the Combined and Separate System Runs for the Dry Season

To enhance the forecasting performance of the ARIMA models, other hydroclimatic data, including precipitation, temperature and evaporation, can be integrated as independent variables. Moreover, other techniques for streamflow forecasting, such as least-squares support vector machine (LSSVM), artificial

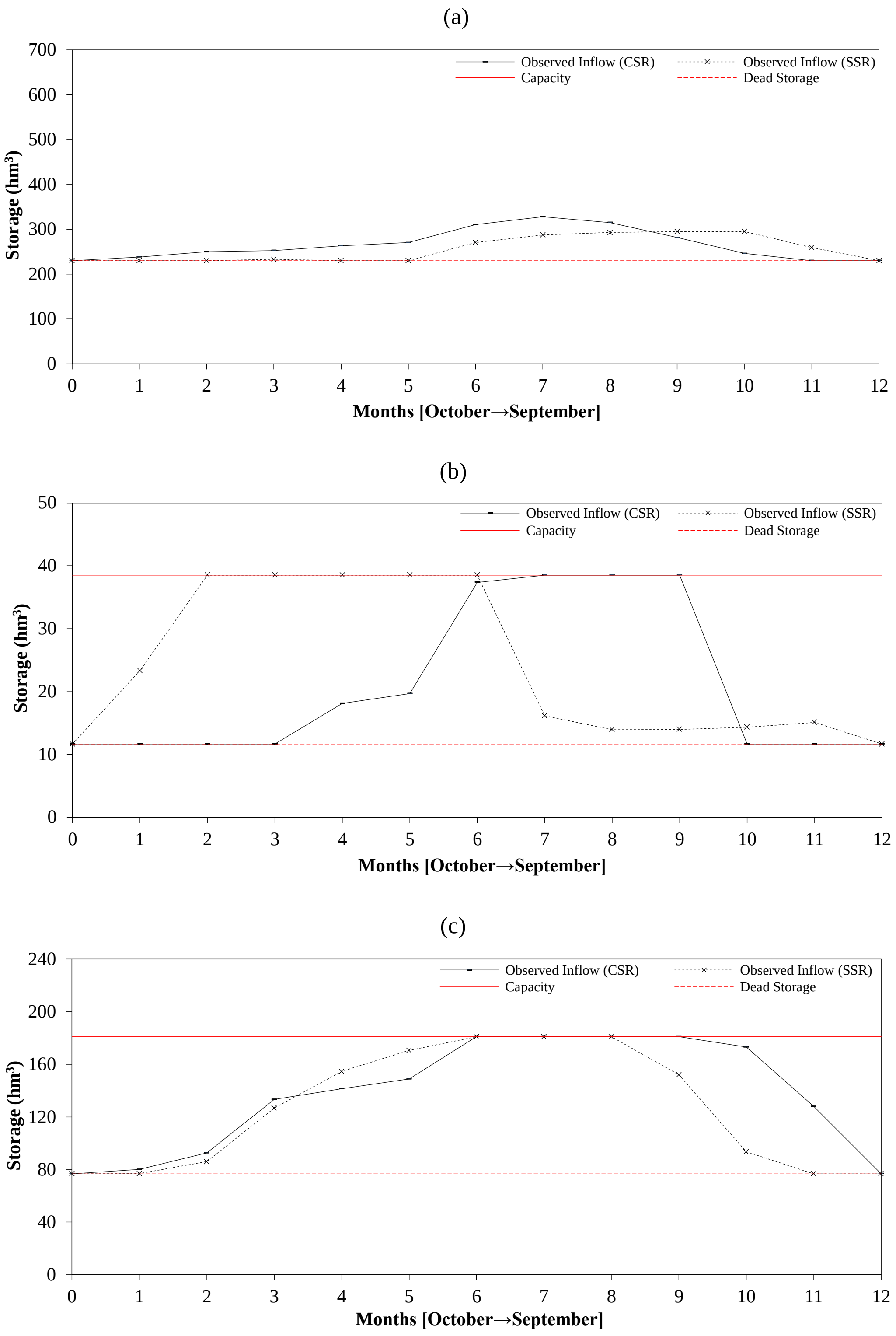


Figure 18 Storage Variations during the Dry Season at (a) the Aysehatun Reservoir, (b) the Kor Reservoir and (c) the Garzan Reservoir

neural network (ANN) and support vector machine (SVM) models, can be integrated into the optimisation system to achieve more accurate estimates (Shabri & Suhartono, 2012).

CHAPTER 4

THE TIGRIS HYDROPOWER SYSTEM

The Tigris River is one of the two main constituents of the Tigris-Euphrates River System. It is the second largest river in western Asia after the Euphrates. It originates near Lake Hazar in eastern Turkey and follows a south-eastern route of 523 km to Cizre, where it forms the border between Turkey and Syria for 32 km before entering Iraq (Altinbilek, 2004).

In the present study, the Tigris River basin is analysed up to the drainage area of the Ilisu Dam and HEPP Project. In this area of 36408 km^2, the main tributaries are Garzan, Bitlis, Botan and Batman Creeks, and the full upstream development comprises 30 dams and 8 pond projects, as presented in Figure 19 and listed in Table 7. It is planned that approximately 0.5 million hectares of land will be irrigated and over 14.5 million m^3 of water will be abstracted annually to supply domestic water for Diyarbakir, Van and Siirt Provinces. To date, all of the pond projects and 7 dams have been put into operation, and a gross area of 34756 ha has been irrigated through these schemes, as detailed in Table 8 (DSI, 2014).

4.1 Tigris Basin Projects

In addition to the Garzan Hydropower System projects, there are the Guzeldere Dam and HEPP Project and the Sirvan Dam and HEPP Project on Kezer Creek (DSI, 1986; Enersu, 2009). Moreover, there is a trans-basin diversion from Kotum Creek to Guzeldere Dam with a transmission canal that has a capacity of 12.00 m^3/s. A discharge of 0.35 m^3/s will be pumped from the Guzeldere Reservoir to supply the domestic water demand of Van Province (DSI, 1986). The Basoren

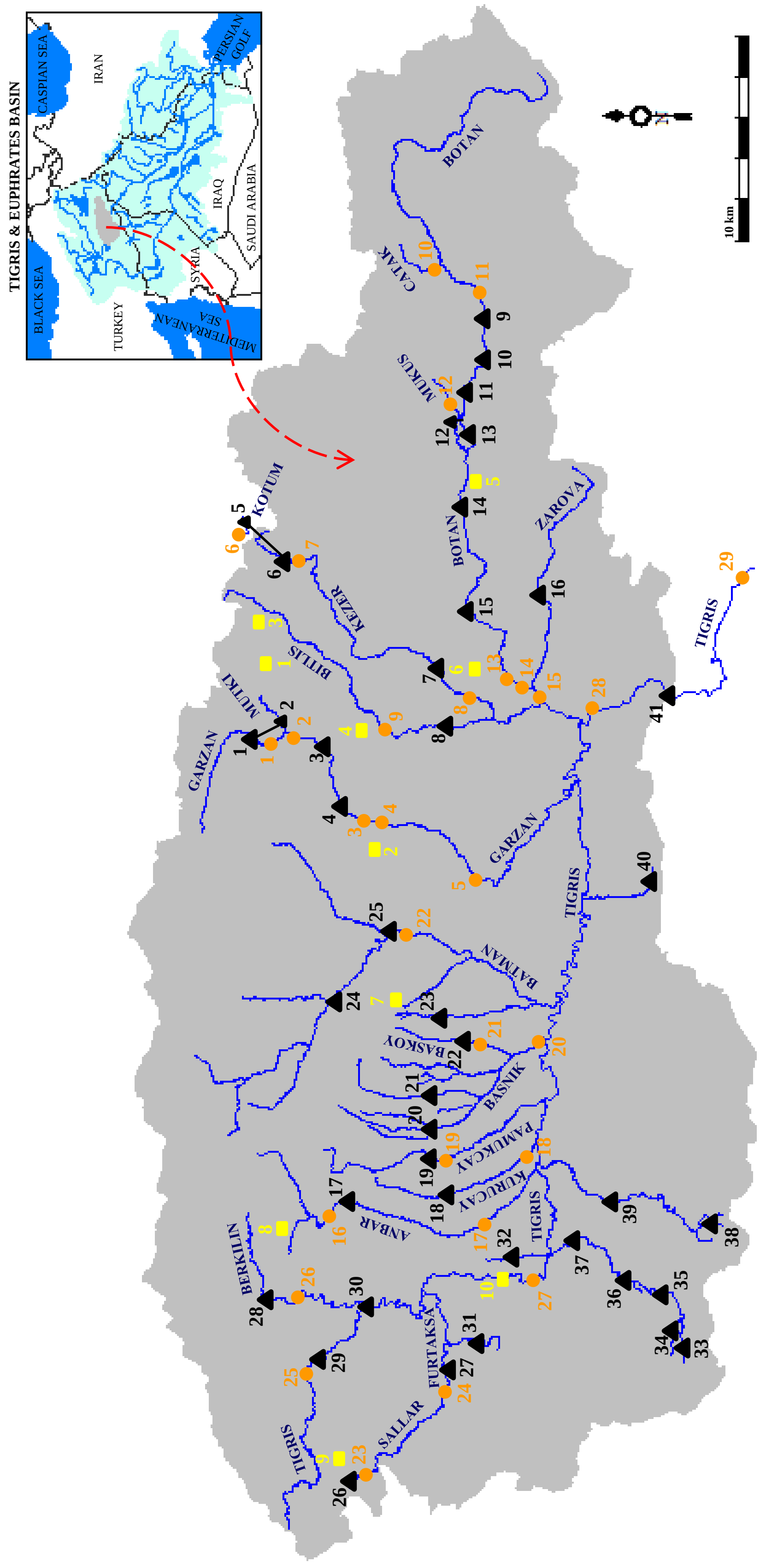


Figure 19 Location Map of the Study Area

Table 7 Legend for Location Map

	Projects ▲	In Planning	In Construction	In Operation		Stream Gauging Stations ●		Meteorological Stations ■
1	Aysehatun Dam and HEPP	■			**1**	DSI 26-57	**1**	Mutki
2	Mutki Derivation	■			**2**	DSI 26-58	**2**	Kozluk
3	Kor Dam and HEPP		■		**3**	DSI 26-24	**3**	Bitlis
4	Garzan Dam and HEPP			■	**4**	EIE 2634	**4**	Baykan
5	Kotum Derivation	■			**5**	EIE 2603	**5**	Pervari
6	Guzeldere Dam and HEPP	■			**6**	DSI 25-14	**6**	Siirt
7	Sirvan Dam and HEPP		■		**7**	DSI 26-28	**7**	Silvan
8	Basoren Dam and HEPP	■			**8**	EIE 2624	**8**	Hani
9	Narli Dam and HEPP	■			**9**	EIE 2610	**9**	Ergani
10	Oran Dam and HEPP	■			**10**	EIE 2609	**10**	Diyarbakir
11	Keskin Dam and HEPP	■			**11**	DSI 26-55		
12	Mukus Derivation		■		**12**	EIE 2615		
13	Pervari Dam and HEPP		■		**13**	EIE 2604/A		
14	Cetin Dam and HEPP		■		**14**	EIE 2633		
15	Alkumru Dam and HEPP			■	**15**	EIE 2626		
16	Eruh Dam and HEPP	■			**16**	EIE 2639		
17	Anbar Dam		■		**17**	DSI 26-18		
18	Kurucay Dam		■		**18**	EIE 2614		
19	Pamukcay Dam		■		**19**	EIE 2632		
20	Baslar Dam		■		**20**	EIE 2612		
21	Bulaklidere Dam	■			**21**	EIE 2660		
22	Kibris Dam	■			**22**	DSI 26-12		
23	Karacalar Dam	■			**23**	EIE 2662		
24	Silvan Dam and HEPP		■		**24**	EIE 2609		
25	Batman Dam and HEPP			■	**25**	DSI 26-17		
26	Ergani Dam		■		**26**	DSI 26-32		
27	Devegecidi Dam			■	**27**	DSI 26-05		
28	Dipni Dam and HEPP	■			**28**	EIE 2611		
29	Kralkizi Dam and HEPP			■	**29**	EIE 2606		
30	Dicle Dam and HEPP			■				
31	Gozegol Pond			■				
32	Kabakli Pond			■				
33	Serifbaba Pond			■				
34	Kunres Pond			■				
35	Ortaviran Pond			■				
36	Dilaver Dam	■						
37	Bespinar Pond			■				
38	Desan Pond			■				
39	Goksu Dam			■				
40	Kirkat Pond			■				
41	Ilisu Dam and HEPP		■					

Table 8 Irrigation Projects

Projects	Commissioning Date	In Operation Irrigation Area		In Planning Irrigation Area	
		Gross (ha)	**Net (ha)**	**Gross (ha)**	**Net (ha)**
Ortaviran	1963	550	516	550	516
Kahlara	1965	380	380	-	-
Serifbaba	1971	130	120	130	120
Devegecidi	1972	10600	5800	10600	5800
Silvan	1972	8790	7590	202306	176613
Gozegol	1974	650	550	650	550
Kunres	1979	19	19	19	19
Kabakli	1980	182	87	182	87
Bespinar	1980	140	121	140	121
Kirkat (Gercus)	1985	350	348	350	348
Goksu	1996	4234	3582	4234	3582
Kozluk	1996	3973	3362	-	-
Kralkizi-Dicle	2002	4758	4758	130159	110115
Garzan	-	-	-	60000	60000
Silvan Plain Dams					
Anbar	-	-	-	13498	11784
Kurucay	-	-	-	6013	5249
Pamukcay	-	-	-	5134	4482
Baslar	-	-	-	4309	3762
Bulaklidere	-	-	-	5890	5142
Kibris	-	-	-	3124	2727
Karacalar	-	-	-	5099	4451
Batman	-	-	-	37744	32951
Ergani	-	-	-	1861	1861
Total		**34756**	**27233**	**491992**	**430280**

Dam and HEPP Project is the single reservoir on Bitlis Creek (Yolsu, 2009). Downstream of the junction of Kezer and Bitlis Creeks, a discharge of 0.60 m^3/s will be abstracted from the river bed to supply the domestic water demand of Siirt Province (EIE, 1990).

There are the Narli Dam and HEPP Project, the Oran Dam and HEPP Project, the Keskin Dam and HEPP Project, the Pervari Dam and HEPP Project, the Cetin Dam and HEPP Project and the Alkumru Dam and HEPP Project on Botan Creek (EIE, 1986; Hidrokon, 2009; Limak, 2006; Su Yapi, 2007). In addition, the flows of Mukus Creek are diverted to the Pervari Reservoir by a transmission canal that has a capacity of 30 m^3/s (Su Yapi, 2007). Upstream of the junction of Botan

Creek with the Tigris River, the outflows of the Eruh Dam and HEPP Project enter Botan Creek. Eruh Dam is the single reservoir on Zarova Creek (Met, 2006).

The Batman-Silvan Project is the major irrigation scheme in the study area. It covers a gross area of 283117 ha (Table 8). The project consists of the Silvan Dam and HEPP Project, the Batman Dam and HEPP Project and the Silvan Plain Dam Projects, namely, Anbar, Kurucay, Pamukcay, Baslar, Bulaklidere, Kibris and Karacalar Dams. Gross areas of 202306 ha and 37744 ha will be irrigated by the Silvan and Batman Dam Projects, respectively. In addition, a gross area of 43067 ha will be irrigated by the Silvan Plain Dam Projects, with the understanding that when the demand is greater than the available storage in the plain dam reservoirs, this deficiency will be compensated for with water received from the Silvan Reservoir through canals (Suis and Sial, 2001).

In the upstream region of the Tigris River, there are the Ergani Dam and HEPP Project, the Devegecidi Dam Project, the Dipni Dam and HEPP Project, the Kralkizi Dam and HEPP Project and the Dicle Dam and HEPP Project (DSI, 1999; En-Su, 2008; FPGA, 1968; Ilisu Environment Group, 2005). Gross areas of 1861 ha, 10600 ha and 130159 ha will be irrigated by the Ergani, Devegecidi and Dicle Reservoirs, respectively. In addition, a discharge of 4.53 m^3/s will be pumped from the Dicle Reservoir to supply the domestic water demand of Diyarbakir Province. Because of the inadequate storage capacity of the Dicle Project, any deficiencies in satisfying this demand will be compensated for with water received from the Kralkizi Reservoir (FPGA, 1968; Ilisu Environment Group, 2005).

Finally, there are several irrigation schemes in the basin, namely, Gozegol Pond, Kabakli Pond, Kunres Pond, Serifbaba Pond, Ortaviran Pond, Dilaver Dam, Bespinar Pond, Desan Pond, Goksu Dam and Kirkat (Gercus) Pond (Table 8). These projects are not integrated into the operation algorithm because of a lack of sufficient data. To compensate for the effects of the presence of these schemes, it is assumed that the irrigation demand rates are equal to the inflow amounts at the project locations and that there is no spillway release from these reservoirs.

As in the case of the Garzan Hydropower System, the net evaporation rates, monthly mean inflow values, water demands, reservoir area and water level functions expressed as high-order polynomials of storage, and turbine efficiency curves are the inputs to the proposed model, together with the topographical and technical features of the projects listed in Table 9 (Appendix B). Contractual energy demands and energy prices are not considered, and operations are optimised to maximise the total energy production.

Table 9 Characteristics of the Tigris Projects

Characteristics	Unit	Aysehatun	Kor	Garzan	Guzeldere	Sirvan	Basoren	Narli	Oran	Keskin	Pervari
Purpose	-	Energy	Energy	Energy	Energy Water Supply	Energy	Energy	Energy	Energy	Energy	Energy
Drainage Area	km^2	405.0	942.2	1266.0	170.0	1010.0	737.3	3176.2	3275.0	4241.8	4288.1
Thalwag Elevation	m	1180.0	895.0	675.5	1690.0	600.0	540.0	1280.0	1180.0	980.0	820.0
Maximum Water Level	m	1250.0	956.0	788.3	1720.0	688.0	561.0	1370.0	1280.0	1180.0	980.0
Minimum Water Level	m	1230.0	930.0	757.7	1704.5	662.0	553.0	1345.0	1250.0	1137.5	930.0
Tailwater Level	m	950.0	830.0	676.0	1270.0	577.0	530.0	1280.0	1180.0	980.0	820.0
Design Discharge	m^3/s	13.36	26.54	43.60	8.00	33.80	34.92	55.20	55.97	108.25	160.00
Penstock: Number/Diameter/Length	-/m/m	1/2.3/250	1/2.5/210	1/3.2/210	2/1.1/1100	1/2.6/210.54	1/3.3/61	1/3.75/200	1/3.75/200	1/5.2/200	1/6.4/125
Energy Tunnel: Number/Diameter/Length	-/m/m	1/3.5/8410	1/3.3/6370	1/4.0/382	1/4.0/10000	1/3.5/2497	1/3.8/2360	-	-	-	1/7.15/600
Number of Units	-	2	2	2	2	2	2	2	2	3	4
Gross Head/Net Head	m/m	300.0/282.0	126.0/109.9	112.3/108.6	435.0/430.2	111.0/101.6	31.0/25.7	90.0/89.1	100.0/99.2	200.0/199.4	160.0/158.8
Turbine Type	-	Francis	Francis	Francis	Francis	Francis	Francis	Francis	Francis	Francis	Francis

Table 9 (cont'd)

Characteristics	Unit	Cetin	Alkumru	Eruh
Purpose	-	Energy	Energy	Energy
Drainage Area	km^2	7066.2	7562.5	600.0
Thalwag Elevation	m	677.0	542.0	682.0
Maximum Water Level	m	822.0	647.0	772.0
Minimum Water Level	m	760.0	611.8	725.0
Tailwater Level	m	647.0	541.8	545.0
Design Discharge	m^3/s	315.49	277.00	26.00
Penstock: Number/Diameter/Length	-/m/m	1/9.4~4.0/313	3/4.7/124	1/2.5/1375
Energy Tunnel: Number/Diameter/Length	-/m/m	1/9.4/5302	1/8.4/443	1/3.65/10875
Number of Units	-	5	3	2
Gross Head/Net Head	m/m	175.0/162.6	105.2/103.9	227.0/200.3
Turbine Type	-	Francis	Francis	Francis

Anbar	Kurucay	Pamukcay	Baslar	Bulaklidere	Kibris	Karacalar	Silvan
Irrigation	Irrigation	Irrigation	Irrigation	Irrigation	Irrigation	Irrigation	Energy Irrigation
480.0	122.0	312.5	136.0	88.0	150.0	32.5	2305.0
673.0	650.0	650.0	658.0	678.0	618.0	677.0	658.0
708.7	678.0	677.0	680.0	705.0	647.0	685.0	820.0
688.0	665.0	670.0	670.0	685.0	638.0	707.0	790.0
-	-	-	-	-	-	-	659.85
-	-	-	-	-	-	-	137.00
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	2/5/740+765
-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	160.15/148.42
-	-	-	-	-	-	-	Francis

Batman	Ergani	Devegecidi	Dipni	Kralkizi	Dicle	Ilisu
Energy Irrigation	Irrigation	Irrigation	Energy	Energy	Energy Water Supply Irrigation	Energy
4105.0	44.5	1576.0	1275.0	1300.0	3216.0	36408.0
596.0	873.5	724.0	746.0	707.0	640.0	400.0
666.0	916.32	757.0	850.0	815.75	710.0	525.0
645.0	889.5	740.0	820.0	762.0	702.5	485.0
595.5	-	-	715.0	708.0	641.0	400.0
362.00	-	-	25.00	144.00	155.00	1266.0
1/9.5~5.0/332	-	-	1/2.6/150	2/5.5/395	1/7.5/455	3/11.0/407.0
-	-	-	1/4.0/4600	1/6.8/500	1/6.6/500	-
3	-	-	2	2	2	6
70.50/70.02	-	-	135.00/129.5	107.75/106.5	69.00/67.83	125.0/118.4
Francis	-	-	Francis	Francis	Francis	Francis

4.2 Evaporation Rates

The net evaporation rates of the reservoirs are determined based on the records of meteorological stations operated by DMI. The same steps followed for the reservoirs of the Garzan Hydropower System are applied to the Tigris Basin Projects using the monthly mean temperature, monthly total evaporation and monthly total precipitation records of the appropriate stations (DMI, 2009). These stations are shown in Figure 19 and are detailed in Table 10.

Table 10 Meteorological Stations Used in Determination of Net Evaporation Rates

Project	Monthly Mean Temperature Data	Monthly Total Evaporation Data	Monthly Total Precipitation Data
Aysehatun Dam and HEPP	Bitlis MS	Bitlis MS	Mutki MS
Kor Dam and HEPP	Bitlis MS	Bitlis MS	Mutki MS
Garzan Dam and HEPP	Siirt MS	Siirt MS	Kozluk MS
Guzeldere Dam and HEPP	Bitlis MS	Bitlis MS	Tatvan MS
Sirvan Dam and HEPP	Siirt MS	Siirt MS	Siirt MS
Basoren Dam and HEPP	Siirt MS	Siirt MS	Baykan MS
Narli Dam and HEPP	Siirt MS	Siirt MS	Pervari MS
Oran Dam and HEPP	Siirt MS	Siirt MS	Pervari MS
Keskin Dam and HEPP	Siirt MS	Siirt MS	Pervari MS
Pervari Dam and HEPP	Siirt MS	Siirt MS	Pervari MS
Cetin Dam and HEPP	Siirt MS	Siirt MS	Siirt MS
Alkumru Dam and HEPP	Siirt MS	Siirt MS	Siirt MS
Eruh Dam and HEPP	Siirt MS	Siirt MS	Siirt MS
Anbar Dam	Diyarbakir MS	Diyarbakir MS	Diyarbakir MS
Kurucay Dam	Diyarbakir MS	Diyarbakir MS	Diyarbakir MS
Pamukcay Dam	Diyarbakir MS	Diyarbakir MS	Diyarbakir MS
Baslar Dam	Diyarbakir MS	Diyarbakir MS	Diyarbakir MS
Bulaklidere Dam	Diyarbakir MS	Diyarbakir MS	Silvan MS
Kibris Dam	Diyarbakir MS	Diyarbakir MS	Silvan MS
Karacalar Dam	Diyarbakir MS	Diyarbakir MS	Silvan MS
Silvan Dam and HEPP	Diyarbakir MS	Diyarbakir MS	Silvan MS
Batman Dam and HEPP	Diyarbakir MS	Diyarbakir MS	Silvan MS
Ergani Dam	Diyarbakir MS	Diyarbakir MS	Ergani MS
Devegecidi Dam	Diyarbakir MS	Diyarbakir MS	Diyarbakir MS
Dipni Dam and HEPP	Diyarbakir MS	Diyarbakir MS	Hani MS
Kralkizi Dam and HEPP	Diyarbakir MS	Diyarbakir MS	Ergani MS
Dicle Dam and HEPP	Diyarbakir MS	Diyarbakir MS	Ergani MS
Ilisu Dam and HEPP	Siirt MS	Siirt MS	Siirt MS

4.3 Inflow Values

The investigations of the water potential commence with the analysis of the monthly mean flow records obtained from a large number of stream gauging stations operated by DSI and EIE (DSI, 2007; EIE, 2003). These stations are shown in Figure 19 and are detailed in Table 11.

First, the raw flow data are corrected for the existing irrigation abstractions, as listed in Table 12. In accordance with the commissioning dates of the operating projects, 80 percent of the demand for the net irrigation areas is added to the observations under the assumption that 20 percent of the abstraction will return to the river bed (Ilisu Hydropower Consultants, 1983). For the Kozluk irrigation scheme, the irrigation water demand is determined in accordance with the Garzan-Kozluk irrigation module (Enersu, 2008). For the Devegecidi, Gozegol, Ortaviran, Serifbaba, Kunres, Bespinar, Kirkat (Gercus), Goksu irrigation schemes, the Tigris irrigation module is used (FPGA, 1968). The Batman-Silvan irrigation module is utilised for the Silvan and Kabakli irrigation schemes (Suis and Sial, 2001). In addition, the raw flow data from the Yolkopru station are corrected for the Kahlara irrigation scheme, which covers an area of 380 ha and has been in operation since 1965, by adding net abstraction amounts of 0.35 hm^3, 0.33 hm^3, 0.32 hm^3 and 0.27 hm^3 to the records from the months of June, July, August and September, respectively (DSI, 1999). As in the case of the Yolkopru station, the raw flow data of the Koprubasi station are corrected for the local upstream irrigations by adding net abstraction amounts of 3.86 hm^3, 2.61 hm^3 and 0.99 hm^3 to the records from the months of July, August and September, respectively (Suis and Sial, 2001).

The Kralkizi and Dicle Projects have been in operation since the end of the year 1997. The construction of the Batman Dam and HEPP Project was completed in the year 1999 (DSI, 2014). Because of the effects of these reservoirs on the flow regime, the records from the stream gauging stations located downstream of these schemes are not used for the months following the commissioning dates of these projects.

Table 11 Characteristics of Stream Gauging Stations in the Tigris Basin

Station Id	Station Name	Opening Date	Closing Date	Drainage Area (km^2)	Elevation (m)	Mean Discharge (m^3/s)
DSI 26-57	Keyburan Brook Bogazonu	24.10.1981	-	425.0	1200	8.6
DSI 26-58	Garzan Creek Meydanonu	29.11.1981	08.01.1999	783.2	909	15.8
DSI 26-24	Pisyar Creek Kozluk	01.08.1970	-	1359.3	620	26.0
EIE 2634	Garzan Creek Kozluk	19.10.1999	30.09.2000	1407.7	630	23.0
EIE 2603	Garzan Creek Besiri	01.11.1945	30.09.2000	2450.4	545	49.0
DSI 25-14	Kotum Brook Kucuksu	01.10.1964	31.10.1972	78.9	1721.0	2.1
DSI 26-28	Guzeldere Kuscukoyu	01.10.1973	08.01.1999	125.8	1594.0	3.9
EIE 2624	Kezer Creek Pinarca	01.10.1971	30.09.2000	1169.6	530.0	20.2
EIE 2610	Bitlis Creek Baykan	14.09.1954	30.09.2000	640.4	910.0	18.8
EIE 2609	Catak Brook Catak	12.09.1954	22.02.1972	2339.5	1625.0	27.5
EIE 2604/A	Botan Creek Billoris	31.07.1962	01.10.1970	8747.3	465.0	189.1
EIE 2626	Botan Creek Billoris	01.10.1970	03.10.1996	8761.2	457.0	156.8
EIE 2633	Botan Creek Billoris	03.10.1996	30.09.2000	8747.3	465.0	118.2
EIE 2615	Mukus Creek Begendik	11.08.1964	01.02.1973	505.6	1250.0	19.1
DSI 26-55	Catak Brook Dalbasti	01.10.1980	-	3069.0	1350.0	40.5
DSI 26-39	Anbar Creek Hani	01.06.1977	-	292.0	800.0	2.9
EIE 2618	Anbar Creek Koprubasi	01.11.1968	01.10.1998	976.0	595.0	7.7
DSI 26-14	Kurucay Yasince	19.08.1962	01.11.1986	240.0	520.0	1.2
DSI 26-32	Pamuk Creek Karahan Bridge	01.08.1974	-	305.0	738.0	2.0

Table 11 (cont'd)

Station Id	Station Name	Opening Date	Closing Date	Drainage Area (km^2)	Elevation (m)	Mean Discharge (m^3/s)
DSI 26-12	Basnik Creek Salat	13.07.1960	-	1060.0	1085.0	3.4
DSI 26-60	Baskoy Creek Salikan	28.05.1985	-	118.5	620.0	0.5
EIE 2612	Batman Creek Malabadi Bridge	06.02.1957	30.09.2000	4105.2	597.0	124.0
DSI 26-62	Sallar Creek Yolkopru	17.02.1998	-	51.6	850.0	0.8
DSI 26-09	Furtaksa Brook DDY Bridge	01.12.1959	01.10.1965	1607.0	705.0	8.8
EIE 2632	Berkilin Creek Cayustu	16.09.1988	13.01.1998	1503.6	689.0	28.2
EIE 2617	Tigris River Cayonu	01.11.1968	01.12.1997	1186.0	695.0	24.3
EIE 2605	Tigris River Diyarbakir	13.11.1945	30.09.2000	5655.2	570.0	68.4
EIE 2604	Botan Creek Billoris	07.11.1945	31.07.1962	7857.3	473.0	122.5
EIE 2606	Tigris River Cizre	27.11.1945	01.09.2000	38280.7	370.0	517.8
EIE 2611	Tigris River Rezuk	01.03.1955	07.03.1975	34493.1	427.0	424.9

Then, the naturalised flow values and correlations are used to produce representative flow data for the 1971-2000 period. Although the flows in the Tigris River and its tributaries are monitored by a comprehensive network of stations, for some branches, these correlations remain insufficient to constitute a longer data set. In the correlation studies, the upstream-downstream relationships along river branches are evaluated using the quantities for corresponding months, and inappropriate data sets are not included. If it is not possible to calculate correlations, then the observations are extended based on the catchment area ratio between the appropriate stations. If this is also not possible, then the monthly averages of the extended or observed data sets are utilised, as detailed in Table 12.

Table 12 Generation of Flow Data for the 1971-2000 Period

Station	Valuable Years	Naturalised due to	Extended by
DSI 26-57	1983-1987	-	1971-1982 1988-2000 ▪ Correlation → EIE 2603
DSI 26-58	1982-1984	-	1971-1981 1985-2000 ▪ Correlation → EIE 2603
DSI 26-24	1971-1984	-	1985-1999 ▪ Correlation → EIE 2603 2000 ▪ Area ratio → EIE 2634
EIE 2634	2000	-	-
EIE 2603	1946-1960 1962-2000	1996-2000 ▪ Kozluk Irrigation Gross: 3973 ha Net: 3362 ha ▪ Commissioning Date: 1996 ▪ Garzan - Kozluk Irrigation Module ▪ Rate of return: 20%	-
DSI 25-14	1965-1972	-	1973-2000 ▪ Monthly means of observations
DSI 26-28	1977-1993	-	1971 ▪ Correlation → EIE 2610 1972 - 1976 1994 - 2000 ▪ Correlation → EIE 2624
EIE 2624	1972-2000	-	1971 ▪ Correlation → EIE 2610
EIE 2610	1955-2000	-	-
EIE 2609	1961-1971	-	-
EIE 2604/A	1963-1970	-	-
EIE 2626	1972-1996	-	-
EIE 2633	1997-2000	-	1963-1970 ▪ EIE 2604/A 1971 ▪ Correlation → EIE 2609 1972-1996 ▪ Area ratio → EIE 2626
EIE 2615	1965-1972	-	1973-2000 ▪ Correlation → EIE 2633
DSI 26-55	1981-1986	-	1971-1980 1987-2000 ▪ Correlation → EIE 2633

Table 12 (cont'd)

Station	Valuable Years	Naturalised due to	Extended by
DSI 26-39	1978-1980 1982-1986 1989-1993 2000	-	1971-1977 1981 1987-1988 1994-1998 ▪ Correlation → EIE 2618 1999 ▪ Extended monthly means of observations
EIE 2618	1969-1998	1969-1998 ▪ July: + 3.86 hm^3 August: + 2.61 hm^3 September : + 0.99 hm^3	1999-2000 ▪ Monthly means of observations
DSI 26-14	1965-1969 1972-1980 1983-1984	-	1971 1981-1982 1985-1998 ▪ Correlation → EIE 2618 1999-2000 ▪ Extended monthly means of observations
DSI 26-32	1980-1982 1984-1985 1989-1999	-	1971-1979 1983 1986-1988 ▪ Correlation → EIE 2618 2000 ▪ Extended monthly means of observations
DSI 26-12	1965 1970-1974 1981-1986 1997-2000	-	1975-1980 1987-1996 ▪ Correlation → EIE 2618
DSI 26-60	1989-1992 2000	-	1971-1988 1993-1998 ▪ Correlation → EIE 2618 1999 ▪ Extended monthly means of observations
EIE 2612	1961-1962 1965-2000	1999-2000 ▪ Batman Dam ▪ Commissioning Date: 1999	1999-2000 ▪ Monthly means of observations

Table 12 (cont'd)

Station	Valuable Years	Naturalised due to	Extended by
DSI 26-62	1989-1994 1996-2000	1989-1994 1996-2000 ▪ Kahlara Irrigation Gross: 380 ha Net: 380 ha ▪ Commissioning Date: 1965 ▪ June: + 0.35 hm^3 July: + 0.33 hm^3 August: + 0.32 hm^3 September : + 0.27 hm^3	1971 ▪ Extended monthly means of observations 1972-1988 1995 ▪ Correlation → EIE 2617
DSI 26-09	1962-1964	-	1971-1997 ▪ Correlation → EIE 2605 1998-2000 ▪ Extended monthly means of observations
EIE 2632	1989-1997	-	1971 ▪ Extended monthly means of observations 1972-1988 ▪ Correlation → EIE 2617 1998-2000 ▪ Extended monthly means of observations
EIE 2617	1972-1997	-	1971 1998-2000 ▪ Extended monthly means of observations
EIE 2605	1946-1952 1955-2000 1946-1952 ▪ Drainage area 5655.2 km^2 1955-1963 ▪ Drainage area 6675.6 km^2 1964-1969 ▪ Drainage area 6298.4 km^2 1970-2000 ▪ Drainage area 5655.2 km^2	1972-2000 ▪ Devegecidi Irrigation Gross: 10600 ha Net: 5800 ha ▪ Commissioning Date: 1972 ▪ Gozegol Irrigation Gross: 650 ha Net: 550 ha ▪ Commissioning Date: 1974 ▪ Tigris Irrigation Module ▪ Rate of return: 20% 1998-2000 ▪ Kralkizi Dam ▪ Commissioning Date: October 1997 ▪ Dicle Dam ▪ Commissioning Date: December 1997	1998-2000 ▪ Extended monthly means of observations
EIE 2604	1946-1962	-	-

Table 12 (cont'd)

Station	Valuable Years	Naturalised due to	Extended by
EIE 2606	1969-1993 1999-2000	1969-1993 1999-2000 ▪ Silvan Irrigation Gross: 8790 ha Net: 7590 ha ▪ Commissioning Date: 1972 ▪ Kabakli Irrigation Gross: 182 ha Net: 87 ha ▪ Commissioning Date: 1980 ▪ Batman - Silvan Irrigation Module ▪ Rate of return: 20% ▪ Kozluk Irrigation Gross: 3973 ha Net: 3362 ha ▪ Commissioning Date: 1996 ▪ Garzan - Kozluk Irrigation Module ▪ Rate of return: 20% ▪ Ortaviran Irrigation Gross: 550 ha Net: 516 ha ▪ Commissioning Date: 1963 ▪ Serifbaba Irrigation Gross: 130 ha Net: 120 ha ▪ Commissioning Date: 1971 ▪ Devegecidi Irrigation Gross: 10600 ha Net: 5800 ha ▪ Commissioning Date: 1972 ▪ Gozegol Irrigation Gross: 650 ha Net: 550 ha ▪ Commissioning Date: 1974 ▪ Kunres Irrigation Gross: 19 ha Net: 19 ha ▪ Commissioning Date: 1979	-

Table 12 (cont'd)

Station	Valuable Years	Naturalised due to	Extended by
EIE 2606 (cont'd)	1969-1993 1999-2000	▪ Bespinar Irrigation Gross: 140 ha Net: 121 ha ▪ Commissioning Date: 1980 ▪ Kirkat (Gercus) Irrigation Gross: 350 ha Net: 348 ha ▪ Commissioning Date: 1985 ▪ Goksu Irrigation Gross: 4234 ha Net: 3582 ha ▪ Commissioning Date: 1996 ▪ Tigris Irrigation Module ▪ Rate of return: 20% 1998-2000 ▪ Kralkizi Dam ▪ Commissioning Date: October 1997 ▪ Dicle Dam ▪ Commissioning Date: December 1997	-
EIE 2611	1956-1962 1965-1968 1972-1974	1965-1968 1972-1974 ▪ Silvan Irrigation Gross: 8790 ha Net: 7590 ha ▪ Commissioning Date: 1972 ▪ Batman - Silvan Irrigation Module ▪ Rate of return: 20% ▪ Ortaviran Irrigation Gross: 550 ha Net: 516 ha ▪ Commissioning Date: 1963 ▪ Serifbaba Irrigation Gross: 130 ha Net: 120 ha ▪ Commissioning Date: 1971 ▪ Devegecidi Irrigation Gross: 10600 ha Net: 5800 ha ▪ Commissioning Date: 1972	1971 1975-1993 ▪ Correlation → ∑(EIE 2606 1994-1997 ▪ Correlation → ∑(EIE 2633 + EIE 2603 + EIE 2612 + EIE 2605) 1998 ▪ Correlation → ∑(EIE 2633 + EIE 2603 + EIE 2612) 1999-2000 ▪ Correlation → ∑(EIE 2633 + EIE 2603)

Table 12 (cont'd)

Station	Valuable Years	Naturalised due to	Extended by
EIE 2611 (cont'd)		▪ Gozegol Irrigation Gross: 650 ha Net: 550 ha ▪ Commissioning Date: 1974 ▪ Tigris Irrigation Module ▪ Rate of return: 20%	

The equations listed in Table 13 are used to project the extended runoff rates of the stream gauging stations to the dam axes. The inflow values to be used in the proposed model are the intermediate basin flows. Therefore, the intermediate basin flow rates of a scheme are obtained by subtracting the produced flow series of the upstream reservoir/reservoirs from those of the project of interest.

In the NLP model, the relation enforcing the conservation of mass and energy between projects is defined by the flow continuity equation, expressed in Equation (8). The outflows of the upstream schemes and the return water from the upstream irrigation systems are added to the intermediate basin flows through this constraint. The upstream-downstream irrigation and water supply schemes for each of the system reservoirs are summarised in Table 14. The *upstream* column of this table provides necessary information about the upstream projects regarding their gross and net irrigated areas, the irrigation modules used, the assumed rate of return ratios and the domestic water demand rates. The *downstream* column is reserved for the abstractions supplied by the outflows of the projects. In addition, the abstractions supplied directly from the system reservoirs are listed in the *reservoir* column.

Table 13 Determination of Monthly Streamflow Rates at Project Axes

Project	Equation
Mutki Derivation	$Q_{Mutki} = (Q_{26-58} - Q_{26-57})\frac{A_{Mutki}}{A_{26-58} - A_{26-57}}$
Aysehatun Dam and HEPP	$Q_{Aysehatun} = Q_{26-57}\frac{A_{Aysehatun}}{A_{26-57}}$
Kor Dam and HEPP	$Q_{Kor} = Q_{26-58}\frac{A_{Kor}}{A_{26-58}}$
Garzan Dam and HEPP	$Q_{Garzan} = Q_{26-24}\frac{A_{Garzan}}{A_{26-24}}$
Kotum Derivation	$Q_{Kotum} = Q_{25-14}$
Guzeldere Dam and HEPP	$Q_{Guzeldere} = Q_{26-28}\frac{A_{Guzeldere}}{A_{26-28}}$
Sirvan Dam and HEPP	$Q_{Sirvan} = Q_{2624}\frac{A_{Sirvan}}{A_{2624}}$
Basoren Dam and HEPP	$Q_{Basoren} = Q_{2610}\frac{A_{Basoren}}{A_{2610}}$
Narli Dam and HEPP	$Q_{Narli} = Q_{26-55} + (Q_{2633} - Q_{2615} - Q_{26-55})\frac{A_{Narli} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}}$
Oran Dam and HEPP	$Q_{Oran} = Q_{26-55} + (Q_{2633} - Q_{2615} - Q_{26-55})\frac{A_{Oran} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}}$
Keskin Dam and HEPP	$Q_{Keskin} = Q_{26-55} + (Q_{2633} - Q_{2615} - Q_{26-55})\frac{A_{Keskin} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}}$
Mukus Derivation	$Q_{Mukus} = Q_{2615}$
Pervari Dam and HEPP	$Q_{Pervari} = Q_{26-55} + (Q_{2633} - Q_{2615} - Q_{26-55})\frac{A_{Pervari} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}}$
Cetin Dam and HEPP	$Q_{Cetin} = Q_{2615} + Q_{26-55} + (Q_{2633} - Q_{2615} - Q_{26-55})\frac{A_{Cetin} - A_{2615} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}}$
Alkumru Dam and HEPP	$Q_{Alkumru} = Q_{2615} + Q_{26-55} + (Q_{2633} - Q_{2615} - Q_{26-55})\frac{A_{Alkumru} - A_{2615} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}}$
Eruh Dam and HEPP	$Q_{Eruh} = Q_{2633}\frac{A_{Eruh}}{A_{2633}}$
Anbar Dam	$Q_{Anbar} = Q_{26-39} + (Q_{2618} - Q_{26-39})\frac{A_{Anbar} - A_{26-39}}{A_{2618} - A_{26-39}}$
Kurucay Dam	$Q_{Kurucay} = Q_{26-14}\frac{A_{Kurucay}}{A_{26-14}}$
Pamukcay Dam	$Q_{Pamukcay} = Q_{26-32}\frac{A_{Pamukcay}}{A_{26-32}}$
Baslar Dam	$Q_{Baslar} = Q_{26-12}\frac{A_{Baslar}}{A_{26-12}}$

Table 13 (cont'd)

Project	Equation
Bulaklidere Dam	$Q_{Bulaklidere} = Q_{26-12}\frac{A_{Bulaklidere}}{A_{26-12}}$
Kibris Dam	$Q_{Kibris} = Q_{26-60}\frac{A_{Kibris}}{A_{26-60}}$
Karacalar Dam	$Q_{Karacalar} = Q_{26-60}\frac{A_{Karacalar}}{A_{26-60}}$
Silvan Dam and HEPP	$Q_{Silvan} = Q_{2612}\frac{A_{Silvan}}{A_{2612}}$
Batman Dam and HEPP	$Q_{Batman} = Q_{2612}\frac{A_{Batman}}{A_{2612}}$
Ergani Dam	$Q_{Ergani} = Q_{26-62}\frac{A_{Ergani}}{A_{26-62}}$
Devegecidi Dam	$Q_{Devegecidi} = Q_{26-09}\frac{A_{Devegecidi}}{A_{26-09}}$
Dipni Dam and HEPP	$Q_{Dipni} = Q_{2632}\frac{A_{Dipni}}{A_{2632}}$
Kralkizi Dam and HEPP	$Q_{Kralkizi} = Q_{2617}\frac{A_{Kralkizi}}{A_{2617}}$
Dicle Dam and HEPP	$Q_{Dicle} = Q_{2617} + Q_{2632} + (Q_{2605} - Q_{26-09} - Q_{2632} - Q_{2617})\frac{A_{Dicle} - A_{2632} - A_{2617}}{A_{2605} - A_{26-09} - A_{2632} - A_{2617}}$
Ilisu Dam and HEPP	$Q_{Ilisu} = Q_{2611}\frac{A_{Ilisu}}{A_{2611}}$

In these calculations, the net abstractions are used for the upstream irrigations under the assumption that 20 percent of the demand will return to the river bed (Ilisu Hydropower Consultants, 1983). This rate of return is 15 percent for the Batman-Silvan Projects (Suis and Sial, 2001). For the Garzan irrigation scheme, the irrigation water demand is determined in accordance with the Garzan irrigation module (FPGA, 2008). The Batman-Silvan irrigation module is utilised for the Batman-Silvan and Kabakli irrigation schemes (Suis and Sial, 2001). The water demand rates of the Ergani irrigation scheme are determined in accordance with the Ergani irrigation module (DSI, 1999). For the Devegecidi, Dicle-Kralkizi, Gozegol, Bespinar, Kirkat (Gercus), Goksu irrigation schemes, the Tigris irrigation module is used (FPGA, 1968).

Table 14 Irrigation and Water Supply Projects

Project	Upstream	Reservoir	Downstream
Aysehatun Dam and HEPP	-	-	-
Kor Dam and HEPP	-	-	-
Garzan Dam and HEPP	-	-	▪Garzan Irrigation Net: 60000 ha ▪Garzan Irrigation Module ▪Rate of return: 20%
Guzeldere Dam and HEPP	-	▪Tatvan Water Supply Demand: 0.35 m^3/s	-
Sirvan Dam and HEPP	-	-	▪Siirt Water Supply Demand: 0.60 m^3/s
Basoren Dam and HEPP	-	-	
Narli Dam and HEPP	-	-	-
Oran Dam and HEPP	-	-	-
Keskin Dam and HEPP	-	-	-
Pervari Dam and HEPP	-	-	-
Cetin Dam and HEPP	-	-	-
Alkumru Dam and HEPP	-	-	-
Eruh Dam and HEPP	-	-	-
Anbar Dam	▪Return flows of Silvan Irrigation Gravity-Fed Gross: 2475 ha Net: 2161 ha Pumping-Fed Gross: 275 ha Net: 240 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	▪Anbar Irrigation Gravity-Fed Gross: 13498 ha Net: 11784 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	-
Kurucay Dam	▪Return flows of Silvan Irrigation Gravity-Fed Gross: 4250 ha Net: 3710 ha Pumping-Fed Gross: 6375 ha Net: 5565 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	▪Kurucay Irrigation Gravity-Fed Gross: 6013 ha Net: 5249 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	-
Pamukcay Dam	▪Return flows of Silvan Irrigation Gravity-Fed Gross: 6000 ha Net: 5238 ha Pumping-Fed Gross: 4000 ha Net: 3492 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	▪Pamukcay Irrigation Gravity-Fed Gross: 5134 ha Net: 4482 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	-

Table 14 (cont'd)

Project	Upstream	Reservoir	Downstream
Baslar Dam	▪Return flows of Silvan Irrigation Gravity-Fed Gross: 3375 ha Net: 2946 ha Pumping - Fed Gross: 3375 ha Net: 2946 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	▪Baslar Irrigation Gravity-Fed Gross: 4309 ha Net: 3762 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	-
Bulaklidere Dam	▪Return flows of Silvan Irrigation Gravity-Fed Gross: 1675 ha Net: 1462 ha Pumping-Fed Gross: 1675 ha Net: 1462 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	▪Bulaklidere Irrigation Gravity-Fed Gross: 5890 ha Net: 5142 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	-
Kibris Dam	▪Return flows of Silvan Irrigation Gravity-Fed Gross: 7650 ha Net: 6678 ha Pumping-Fed Gross: 850 ha Net: 742 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	▪Kibris Irrigation Gravity-Fed Gross: 3124 ha Net: 2727 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	-
Karacalar Dam	▪Return flows of Silvan Irrigation Gravity-Fed Gross: 1000 ha Net: 873 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	▪Karacalar Irrigation Gravity-Fed Gross: 5099 ha Net: 4451 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	-

Table 14 (cont'd)

Project	Upstream	Reservoir	Downstream
Silvan Dam and HEPP	-	▪Silvan Irrigation Gravity - Fed Gross: 171284 ha Net: 149531 ha Pumping - Fed Gross: 31022 ha Net: 27082 ha	-
Batman Dam and HEPP	-	▪Batman Irrigation Gravity- Fed Gross: 37744 ha Net: 32951 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15%	-
Ergani Dam	-	▪Ergani Irrigation Gross: 1861 ha Net: 1861 ha ▪Ergani Irrigation Module ▪Rate of return: 20%	-
Devegecidi Dam	▪Return flows of Ergani Irrigation Gross: 1861 ha Net: 1861 ha ▪Ergani Irrigation Module ▪Rate of return: 20%	▪Devegecidi Irrigation Gross: 10600 ha Net: 5800 ha ▪Tigris Irrigation Module ▪Rate of return: 20%	-
Dipni Dam and HEPP	-	-	-
Kralkizi Dam and HEPP	-	-	-
Dicle Dam and HEPP	-	▪Dicle - Kralkizi Irrigation Gross: 130159 ha Net: 110115 ha ▪Tigris Irrigation Module ▪Rate of return: 20% ▪Dicle Water Supply Demand: 4.53 m^3/s	-
Ilisu Dam and HEPP	▪Return flows of Garzan Irrigation Net: 60000 ha ▪Garzan Irrigation Module ▪Rate of return: 20% ▪Siirt Water Supply Demand: 0.60 m^3/s	-	-

Table 14 (cont'd)

Project	Upstream	Reservoir	Downstream
Ilisu Dam and HEPP (cont'd)	▪Return flows of Batman Plain Dams Irrigation Gravity-Fed Gross: 43067 ha Net: 37597 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15% ▪Return flows of Silvan Irrigation Gravity-Fed Gross: 144859 ha Net: 126463 ha Pumping-Fed Gross: 14472 ha Net: 12635 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15% ▪Return flows of Batman Irrigation Gravity- Fed Gross: 37744 ha Net: 32951 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 15% ▪Return flows of Devegecidi Irrigation Gross: 10600 ha Net: 5800 ha ▪Tigris Irrigation Module ▪Rate of return: 20% ▪Return flows of Dicle - Kralkizi Irrigation Gross: 130159 ha Net: 110115 ha ▪Tigris Irrigation Module ▪Rate of return: 20%		

Table 14 (cont'd)

Project	Upstream	Reservoir	Downstream
Ilisu Dam and HEPP (cont'd)	▪Return flows of Kabakli Irrigation Gross: 182 ha Net: 87 ha ▪Batman - Silvan Irrigation Module ▪Rate of return: 20% ▪Return flows of Gozegol Irrigation Gross: 650 ha Net: 550 ha ▪Return flows of Bespinar Irrigation Gross: 140 ha Net: 121 ha ▪Return flows of Goksu Irrigation Gross: 4234 ha Net: 3582 ha ▪Return flows of Kirkat (Gercus) Irrigation Gross: 350 ha Net: 348 ha ▪Tigris Irrigation Module ▪Rate of return: 20%		

4.4 NLP Model

In the NLP model (Appendix B), the flow continuity equation of Equation (8) is modified for the Dicle Dam and Silvan Plain Dam Projects to transfer water from the Kralkizi and Silvan Reservoirs, respectively. In the flow continuity equations for the Dicle and Silvan Plain Dam Reservoirs, a term $T_{i,t}$ is added to the incoming flows to represent the water transfer from the upstream reservoir that is provided when the demand is greater than the available storage, as described in Equation (28). Conversely, in the flow continuity equations for the upstream reservoirs that are used to satisfy the deficiency, a term $T_{i+1,t}$ is added to the outflows as a non-power release, as described in Equation (29).

$$S_{i,t} = S_{i,t-1} + I_{i,t} + \boldsymbol{T_{i,t}} + \sum_j R^p_{i-1,j,t} + R^s_{i-1,t} + R^{de}_{i-1,t} + r_{i-1}\, R^{di}_{i-1,t} - e_{i,t}\, A_{i,t-1} - \sum_j R^p_{i,j,t} - R^s_{i,t} - R^{de}_{i,t} - R^{di}_{i,t} - R^{dw}_{i,t} \quad (28)$$

$$S_{i,t} = S_{i,t-1} + I_{i,t} + \sum_j R^p_{i-1,j,t} + R^s_{i-1,t} + R^{de}_{i-1,t} + r_{i-1}\, R^{di}_{i-1,t} - e_{i,t}\, A_{i,t-1} - \sum_j R^p_{i,j,t} - R^s_{i,t} - R^{de}_{i,t} - R^{di}_{i,t} - R^{dw}_{i,t} - \boldsymbol{T_{i+1,t}} \quad (29)$$

Moreover, an additional constraint, expressed by Equation (30), is integrated into the algorithm to ensure that the outflows of the Basoren and Sirvan Reservoirs are sufficient to supply the domestic water demand of Siirt Province, D_{Siirt}.

$$\sum_j R^p_{Basoren,j,t} + R^s_{Basoren,t} + R^{de}_{Basoren,t} + \sum_j R^p_{Sirvan,j,t} + R^s_{Sirvan,t} + R^{de}_{Sirvan,t} \geq D_{Siirt} \quad (30)$$

As in the case of the Garzan Hydropower System, for the maintenance of natural ecosystems, 10 percent of the monthly mean inflow values of the last 10 years (1991-2000) is left on the river bed as environmental water due to the energy tunnels of the system projects (DSI, 2014). Likewise, the efficiency curves for Francis-type turbines, which are utilised in all of the catchment power plants, are defined in the model as-high order polynomials of the ratio of the power releases to the designed discharges (Pro-sem, 2008).

4.5 Operational Studies

The operations of the Tigris Hydropower System are optimised to maximise the total energy production. As in the case of the Garzan Hydropower System, the initial and ending storage values of the system reservoirs are constrained to be equal to the dead volumes. In the NLP model, the contractual energy demand and energy prices are not considered, and the monthly means of the extended data sets from 1971 to 2000 are utilised as inputs during the 12-month operation period. The total energy production for this integrated system operation plan is found to be 7371.82 GWh/year, as detailed in Table 15.

Downstream of the Tigris Hydropower System, there are the Silopi and Nusaybin-Idil-Cizre irrigation schemes, which cover an area of 121000 ha (Ilisu Environment Group, 2005). They represent a demand of approximately 767.30 hm^3 of water per year, which is planned to be supplied by the Cizre Reservoir, located immediately downstream of Ilisu Dam (Ilisu Hydropower Consultants, 1983). Because of the inadequate storage capacity of this reservoir, the outflows of the Ilisu Project are used to enable Cizre Dam to supply the irrigation water demand.

The operational results are analysed to confirm whether the power releases from the Ilisu Reservoir are equal to or greater than the downstream irrigation demand, and it is found that the releases do not meet the need (Figure 20). Thus, a minimum release constraint, expressed by Equation (31), is integrated into the algorithm to ensure that the outflows of the Ilisu Reservoir are sufficient to supply the water demands of the Silopi and Nusaybin-Idil-Cizre irrigation areas, $D_{Cizre,t}$.

$$\sum_{j} R^{p}_{Ilisu,j,t} + R^{s}_{Ilisu,t} \geq D_{Cizre,t} \tag{31}$$

The optimisation study is repeated with this additional constraint. The total energy production of the system is found to decrease to 7342.01 GWh/year. This decrease is expected. The objective function value obtained in the first run is the maximum energy that can be produced by the system, and the imposition of an additional constraint regarding the system releases leads to a lower production value.

Table 15 Operation Results of the Tigris Power Plants

	Item	Unit	Months											
			10	11	12	1	2	3	4	5	6	7	8	9
Aysehatun Dam	Efficiency of turbine 1	-	0.00	0.42	0.74	0.51	0.91	0.92	0.92	0.92	0.92	0.90	0.92	0.00
	Efficiency of turbine 2	-	0.82	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.00	0.56
	Net head	m	266.00	261.20	258.44	266.00	250.36	261.92	247.96	250.90	250.45	255.88	262.10	265.87
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	19.95	79.84	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	0.00	0.00	0.00	0.00	0.00	3.60	6.54	19.05	13.41	5.19	0.00	0.00
	Produced energy	GWh	4.24	11.80	13.79	12.37	18.07	22.57	21.35	21.60	21.56	18.04	11.28	1.13
Kor Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.71	0.92	0.92	0.92	0.92	0.92	0.00	0.00
	Efficiency of turbine 2	-	0.75	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.00	0.00	0.93
	Net head	m	95.01	92.16	91.43	95.01	87.61	79.80	91.17	104.28	90.78	96.63	110.76	104.16
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	16.16	77.65	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	0.00	0.00	0.00	0.00	0.00	0.00	100.00	95.54	0.00	23.99	96.39	0.00
	Produced energy	GWh	2.00	6.70	7.64	7.01	8.99	13.65	15.59	17.81	15.53	6.06	0.00	7.70
Garzan Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.33	0.92	0.92	0.92	0.83	0.64	0.26	0.00
	Efficiency of turbine 2	-	0.24	0.94	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.87
	Net head	m	79.54	78.77	77.03	77.68	76.52	73.88	87.98	102.68	104.51	100.94	86.50	77.40
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	13.46	0.00	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	9.73	0.00	0.00	0.00	0.00	0.00	99.16	100.00	100.00	59.03	0.00	0.00
	Produced energy	GWh	0.15	9.82	9.05	8.07	11.06	20.76	24.72	28.85	20.22	16.27	12.36	5.43
Guzeldere Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.88	0.00	0.00	0.92	0.92	0.92	0.92	0.92	0.00
	Efficiency of turbine 2	-	0.91	0.93	0.00	0.92	0.93	0.00	0.92	0.92	0.92	0.92	0.92	0.92
	Net head	m	410.27	409.50	415.73	410.77	412.77	417.60	396.43	398.75	403.92	404.49	399.33	408.93
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	33.49	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	0.00	0.00	27.04	0.00	0.00	48.84	0.00	63.24	76.45	51.54	11.62	0.00
	Produced energy	GWh	7.46	8.36	0.00	16.30	8.58	0.00	20.44	20.56	20.82	20.85	20.59	10.47

Table 15 (Cont'd)

	Item	Unit	Months											
			10	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Sirvan Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.82	0.92	0.91	0.00	0.92	0.00	0.00
	Efficiency of turbine 2	-	0.00	0.92	0.83	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.85	0.68
	Net head	m	81.93	80.64	81.28	81.28	81.28	78.91	75.00	82.33	86.63	75.54	80.75	81.14
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	4.15	0.00	0.00	0.00	0.00	0.00	25.92	28.09	25.18	0.00	0.00	0.00
	Produced energy	GWh	0.00	6.24	3.48	7.08	8.02	11.80	16.34	15.31	9.44	16.45	3.85	1.53
Basoren Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.94	0.92	0.92	0.04	0.00	0.00	0.00
	Efficiency of turbine 2	-	0.56	0.90	0.92	0.90	0.93	0.92	0.92	0.92	0.92	0.28	0.83	0.58
	Net head	m	23.22	22.69	21.13	21.28	20.47	17.24	16.25	20.41	24.23	25.64	25.40	21.81
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	71.67	12.14	0.00	0.00	0.00	0.00
	Storage ratio	%	33.89	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	100.00	0.00	0.00
	Produced energy	GWh	0.27	1.59	1.76	1.56	2.17	3.67	3.66	4.59	2.73	0.06	1.12	0.27
Narli Dam	Efficiency of turbine 1	-	0.00	0.04	0.74	0.00	0.83	0.92	0.92	0.92	0.92	0.87	0.81	0.00
	Efficiency of turbine 2	-	0.64	0.92	0.92	0.72	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.90
	Net head	m	73.59	82.55	70.57	73.58	73.03	61.08	60.77	60.84	72.62	84.92	73.16	61.65
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	125.54	187.05	38.60	0.00	0.00	0.00
	Storage ratio	%	100.00	70.14	0.00	100.00	0.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00
	Produced energy	GWh	1.89	14.69	15.50	2.74	17.95	18.58	21.62	21.64	25.83	22.51	17.39	6.90
Oran Dam	Efficiency of turbine 1	-	0.00	0.30	0.75	0.00	0.83	0.92	0.92	0.92	0.92	0.87	0.93	0.00
	Efficiency of turbine 2	-	0.57	0.92	0.92	0.73	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.90
	Net head	m	68.46	68.18	66.22	66.59	66.03	65.90	65.61	70.29	84.40	94.40	79.90	66.51
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	136.12	189.65	12.03	0.00	0.00	0.00
	Storage ratio	%	9.42	0.00	0.00	0.00	0.00	0.00	0.00	24.60	100.00	100.00	0.00	0.00
	Produced energy	GWh	1.29	12.57	14.83	2.74	16.52	20.76	23.67	25.35	30.44	25.60	28.09	7.60

Table 15 (Cont'd)

	Item	Unit	Months											
			10	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Keskin Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.92	0.92	0.87	0.00	0.00
	Efficiency of turbine 2	-	0.00	0.00	0.60	0.00	0.74	0.93	0.92	0.92	0.92	0.92	0.92	0.00
	Efficiency of turbine 3	-	0.70	0.92	0.92	0.80	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.89
	Net head	m	149.62	149.49	149.44	149.61	149.36	149.21	148.37	168.50	184.15	169.02	153.63	149.57
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	119.87	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	70.23	16.99	0.00	0.00
	Produced energy	GWh	6.68	34.76	39.01	11.55	43.07	61.81	103.51	117.55	128.46	99.18	71.15	20.38
Pervari Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.92	0.00	0.92	0.00	0.00
	Efficiency of turbine 2	-	0.00	0.00	0.00	0.00	0.00	0.12	0.92	0.92	0.00	0.92	0.16	0.00
	Efficiency of turbine 3	-	0.00	0.53	0.77	0.00	0.83	0.92	0.92	0.92	0.92	0.92	0.92	0.00
	Efficiency of turbine 4	-	0.84	0.92	0.92	0.88	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
	Net head	m	104.71	104.62	104.59	104.70	104.53	104.41	114.55	115.70	129.01	127.01	104.40	104.68
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	2.14	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	0.00	0.00	0.00	0.00	0.00	0.00	40.79	3.55	100.00	0.00	0.00	0.00
	Produced energy	GWh	11.04	29.27	34.44	15.17	37.15	53.95	118.12	119.30	66.51	130.96	53.98	20.25
Cetin Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.82	0.00	0.00
	Efficiency of turbine 2	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.81	0.00	0.92	0.00	0.00
	Efficiency of turbine 3	-	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.83	0.92	0.00	0.00
	Efficiency of turbine 4	-	0.00	0.71	0.00	0.00	0.29	0.00	0.92	0.92	0.92	0.92	0.92	0.00
	Efficiency of turbine 5	-	0.00	0.92	0.92	0.86	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.88
	Net head	m	113.80	113.37	107.92	108.22	107.83	120.86	139.06	154.73	160.42	134.53	115.04	108.18
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	14.37	0.00	0.00	0.00	0.00	34.91	67.99	100.00	83.35	22.30	0.00	0.00
	Produced energy	GWh	0.00	55.55	43.88	20.67	44.79	36.68	169.64	210.47	155.23	238.54	93.56	23.36

Table 15 (Cont'd)

	Item	Unit	Months											
			10	11	12	1	2	3	4	5	6	7	8	9
Alkumru Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.92	0.88	0.00
	Efficiency of turbine 2	-	0.00	0.00	0.00	0.00	0.00	0.00	0.87	0.92	0.92	0.92	0.92	0.00
	Efficiency of turbine 3	-	0.30	0.92	0.92	0.83	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.84
	Net head	m	66.50	70.51	70.44	66.47	66.36	66.50	82.80	98.41	99.21	98.41	82.54	66.46
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.16	0.00	0.00
	Storage ratio	%	0.00	19.38	0.00	0.00	0.00	0.00	100.00	100.00	100.00	100.00	0.00	0.00
	Produced energy	GWh	0.89	30.75	41.91	15.44	33.18	28.34	73.76	175.67	118.07	175.67	125.19	15.84
Eruh Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.93	0.00	0.92	0.00	0.00	0.00
	Efficiency of turbine 2	-	0.69	0.76	0.77	0.74	0.78	0.91	0.92	0.92	0.92	0.00	0.93	0.64
	Net head	m	173.23	173.24	173.24	173.24	172.32	170.10	150.46	174.57	152.73	177.25	173.05	172.92
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.43	0.00	0.00	0.00
	Storage ratio	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.89	0.00	10.19	0.00	0.00
	Produced energy	GWh	2.69	3.77	4.05	3.41	4.07	9.66	22.63	14.62	25.59	0.00	11.62	2.12
Silvan Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Efficiency of turbine 2	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Efficiency of turbine 3	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Efficiency of turbine 4	-	0.00	0.93	0.92	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Net head	m	123.64	123.09	123.13	123.55	125.36	127.86	131.70	135.05	135.48	132.46	127.92	124.66
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Transferred water	hm^3	28.47	30.53	26.60	0.00	0.00	0.00	0.00	0.00	0.00	20.04	27.26	15.91
	Storage ratio	%	0.00	0.00	1.12	2.37	7.42	17.03	30.76	38.21	33.54	19.01	5.82	0.00
	Produced energy	GWh	0.00	23.54	27.18	27.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 15 (Cont'd)

	Item	Unit	Months											
			10	11	12	1	2	3	4	5	6	7	8	9
Batman Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00	0.00
	Efficiency of turbine 2	-	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Efficiency of turbine 3	-	0.38	0.86	0.00	0.92	0.86	0.93	0.92	0.77	0.00	0.00	0.00	0.00
	Net head	m	47.02	47.02	50.48	50.42	47.01	46.97	46.91	50.08	53.65	52.73	49.81	47.66
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	0.00	0.00	30.01	0.00	0.00	0.00	0.00	26.44	31.02	18.22	5.29	0.00
	Produced energy	GWh	1.41	17.26	0.00	49.09	16.90	34.95	47.62	10.79	0.00	0.00	0.00	0.00
Dipni Dam	Efficiency of turbine 1	-	0.00	0.52	0.92	0.92	0.92	0.00	0.00	0.00	0.00	0.92	0.00	0.00
	Efficiency of turbine 2	-	0.87	0.92	0.92	0.92	0.92	0.00	0.00	0.00	0.92	0.92	0.63	0.61
	Net head	m	99.81	98.28	94.74	94.74	93.52	104.69	112.72	117.82	117.84	108.32	100.12	100.13
	Spillway release	hm^3	0.00	0.00	7.33	4.51	37.18	0.00	0.00	0.00	0.00	322.58	0.00	0.00
	Storage ratio	%	0.00	0.00	0.00	0.00	0.00	21.10	41.11	52.01	51.11	0.00	0.00	0.00
	Produced energy	GWh	3.96	8.56	15.26	15.26	15.07	0.00	0.00	0.00	9.49	17.46	1.14	1.01
Kralkizi Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Efficiency of turbine 2	-	0.31	0.59	0.83	0.83	0.89	0.00	0.00	0.92	0.00	0.00	0.93	0.93
	Net head	m	52.35	52.35	52.35	52.35	52.10	56.80	64.92	67.28	66.94	67.45	63.64	55.66
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Transferred water	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	0.00	0.00	0.00	0.00	0.00	11.30	21.59	18.54	19.80	20.00	9.34	0.00
	Produced energy	GWh	0.60	2.83	9.44	9.25	14.66	0.00	0.00	22.55	0.00	0.00	28.24	21.99

Table 15 (Cont'd)

	Item	Unit	Months											
			10	11	12	1	2	3	4	5	6	7	8	9
Dicle Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Efficiency of turbine 2	-	0.00	0.00	0.92	0.92	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Net head	m	58.56	59.73	60.03	58.86	61.32	64.56	64.71	65.04	63.01	61.26	60.24	58.42
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	3.89	32.78	24.98	0.00	81.53	90.78	85.69	100.00	28.64	50.91	0.00	0.00
	Produced energy	GWh	0.00	0.00	26.11	29.76	2.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilisu Dam	Efficiency of turbine 1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Efficiency of turbine 2	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00
	Efficiency of turbine 3	-	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.92	0.92	0.00
	Efficiency of turbine 4	-	0.00	0.00	0.00	0.00	0.00	0.53	0.92	0.00	0.00	0.92	0.92	0.00
	Efficiency of turbine 5	-	0.00	0.00	0.66	0.92	0.85	0.92	0.92	0.00	0.00	0.92	0.92	0.00
	Efficiency of turbine 6	-	0.67	0.92	0.92	0.92	0.92	0.92	0.92	0.00	0.00	0.92	0.92	0.84
	Net head	m	81.13	81.12	81.12	81.10	81.11	81.09	81.04	86.81	95.39	94.74	86.14	81.13
	Spillway release	hm^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Storage ratio	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.17	33.67	19.13	0.00	0.00
	Produced energy	GWh	18.99	110.31	127.92	220.55	159.96	229.95	345.63	0.00	0.00	515.33	500.10	46.25
System	Produced energy: **7371.82** GWh		63.58	388.38	435.26	475.29	462.44	567.12	1028.28	826.67	649.93	1302.97	979.66	192.24

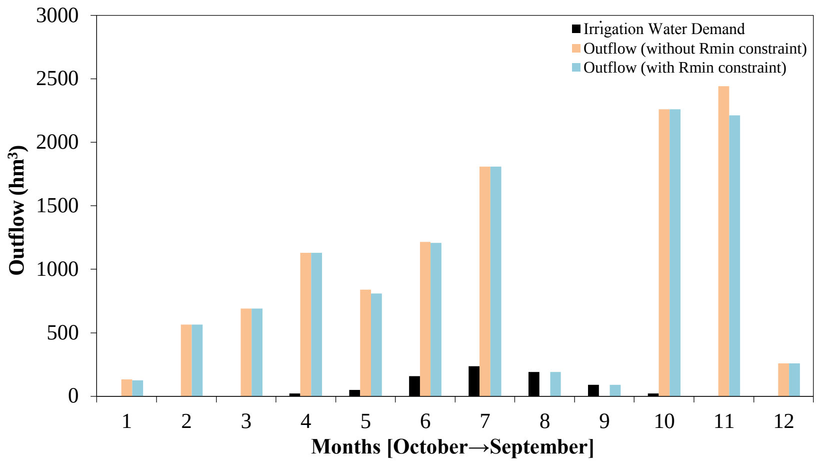


Figure 20 Outflow Amounts of the Ilisu Power Plant

4.5.1 The Ilisu Dam and HEPP Project

When the results of these two system runs are analysed in terms of reservoir and plant capacity usage, it is found that several power plant units will not be used after the commissioning of the irrigation schemes and that there is no need for large storage capacities for some of the projects, as in the case of the Ilisu Project. Figure 21 presents the monthly storage variations of the Ilisu Reservoir. These circumstances were previously noted by Yalcin (2010), who claimed that "the flow regulation capability of the upstream reservoirs eliminates the need for such an enormous storage volume".

The Ilisu Dam and HEPP Project has been under debate for more than half a century because of concerns regarding the inundation of the archaeological sites around Hasankeyf (Figure 22). To protect this ancient settlement from inundation, the maximum water level must be lowered from 525 m to 457 m (Yalcin, 2010). The energy loss caused by such a decrease and the capability of this reduced level of storage to supply the downstream water needs can be analysed using the proposed NLP model. However, before such a trial is performed, it is necessary to assess its dead storage volume.

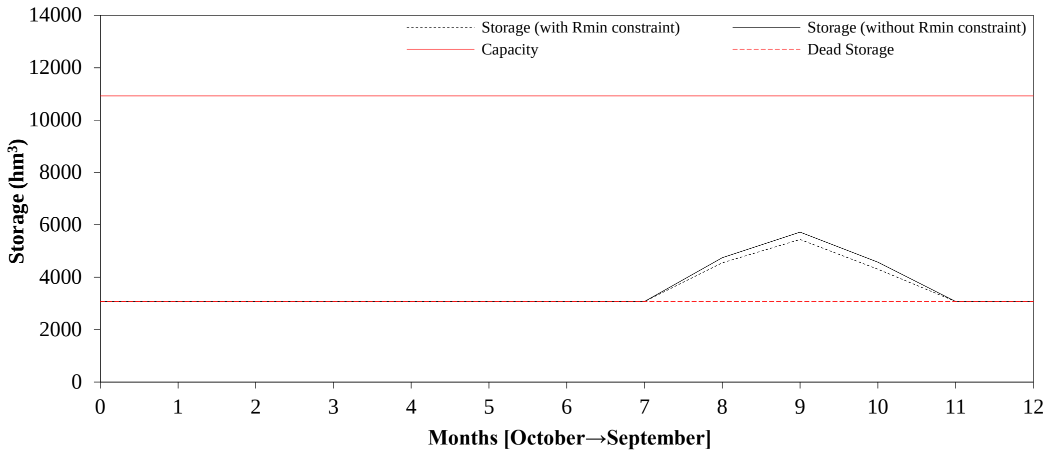


Figure 21 Storage Variations at the Ilisu Reservoir

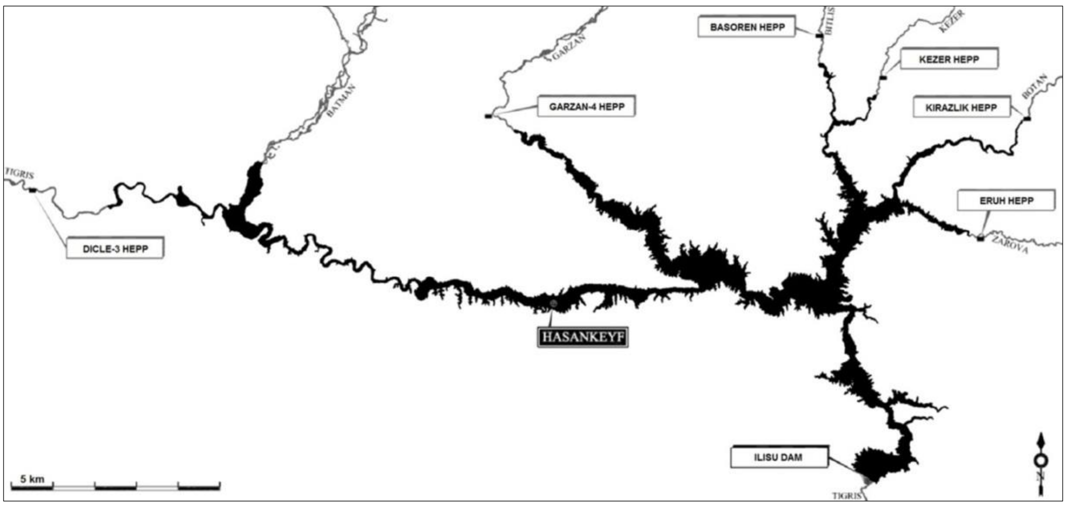


Figure 22 Ilisu Dam and HEPP Project (Yalcin, 2010)

The basin applications in Turkey have appeared to commission the farthest downstream dams first. Thus, the dead volume calculations are performed accordingly, resulting in enormous dead volume allocations (Tigrek & Aras, 2011). The dead storage volume of the Ilisu Reservoir is designated to be 3078.7 hm^3 at a level of 485.0 m (Ilisu Environment Group, 2005). This design is based on the calculations for the existing upstream conditions at that time (Ilisu Dam and HEPP Engineering and Consultancy Services Consortium, 2008).

To investigate the dead storage required for the scenario corresponding to the full development of the Tigris Basin, the sediment transport analysis conducted by EIE (2000) using the data collected at the Cizre sediment gauging station (EIE 2606) in the vicinity of the dam site is utilised. The results of this analysis indicate that the suspended sediment yield in the basin is 733 ton/year/km^2 and the submerged specific weight is 1.31 t/m^3. Under the assumption that the bed load is 25 percent of the suspended sediments, the total sediment load in the basin is determined to be 699 m^3/year/km^2. The total area controlled by the upstream projects is 23016.8 km^2. By subtracting this area from the total drainage area of the Ilisu Reservoir, a region of 13391.2 km^2 is identified as the catchment that contributes to sediment transport. Thus, the amount of sediment that will be deposited in the reservoir during the economic lifetime of the project is found to be 468.31 hm^3 (Table 16). Assuming the horizontal deposition of sediments across the reservoir, this volume will reach a level of 446.81 m after 50 years, as depicted in Figure 23.

Then, the operations of the Tigris Hydropower System are re-optimised based on the reduced storage of the Ilisu Reservoir considering the downstream irrigation schemes. The objective function value is found to be 6469.61 GWh/year (Table 17). This represents a reduction of approximately 12 percent in the total energy production. Figure 24 presents a comparison of the monthly storage variations for the existing and reduced-capacity reservoirs. Although there is a 93 percent decrease in the active volume, the reduced storage capacity remains sufficient to supply the irrigation water demand. This result illustrates the efficacy of integrated operations for flow regulation.

Table 16 Determination of Dead Storage for the Ilisu Reservoir

EIE 2606 Dicle River - Cizre					
Net drainage area	:	30774.7	km^2		
Degree of dispersion	: Clay + Silt	49.7%			
	Sand	50.3%			
Submerged specific weight	:	1.31	t/m^3		
Sediment amount	:	22557064	t/year		
		17219133	m^3/year		
Sediment yield	:	733	t/year/km²		
		560	m^3/year/km²		
Suspended sediment load	:	733	ton/year/km²		
Bed load	:	183	ton/year/km²		
Total sediment load	:	916	ton/year/km²		
		699	m^3/year/km²		
Ilisu Dam					
Drainage area	:	36408.0	km^2		
Net drainage area	:	13391.2	km^2	*Upstream Projects*	*Catchment Area (km^2)*
				Alkumru Dam	7562.5
				Batman Dam	4105.0
				Dicle Dam	3216.0
				Devegecidi Dam	1576.0
				Garzan Dam	1266.0
				Sirvan Dam	1010.0
				Basoren Dam	737.3
				Bespinar Pond	733.0
				Goksu Dam	672.0
				Eruh Dam	600.0
				Anbar Dam	480.0
				Pamukcay Dam	312.5
				Gozegol Pond	156.2
				Kibris Dam	150.0
				Baslar Dam	136.0
				Kurucay Dam	122.0
				Bulaklidere Dam	88.0
				Kirkat Pond	40.3
				Karacalar Dam	32.5
				Kabakli Pond	21.5
				Total	*23016.8*
Economic lifetime period	:	50	year		
Total sediment amount	:	**468.31**	hm^3		

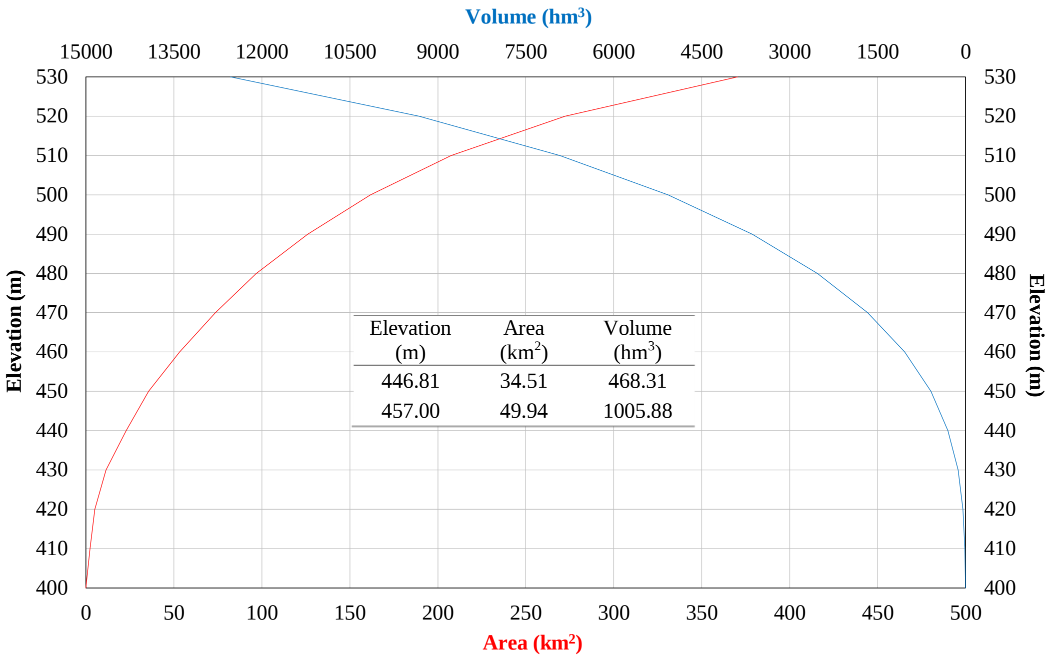


Figure 23 Volume-Area Curve of the Ilisu Reservoir

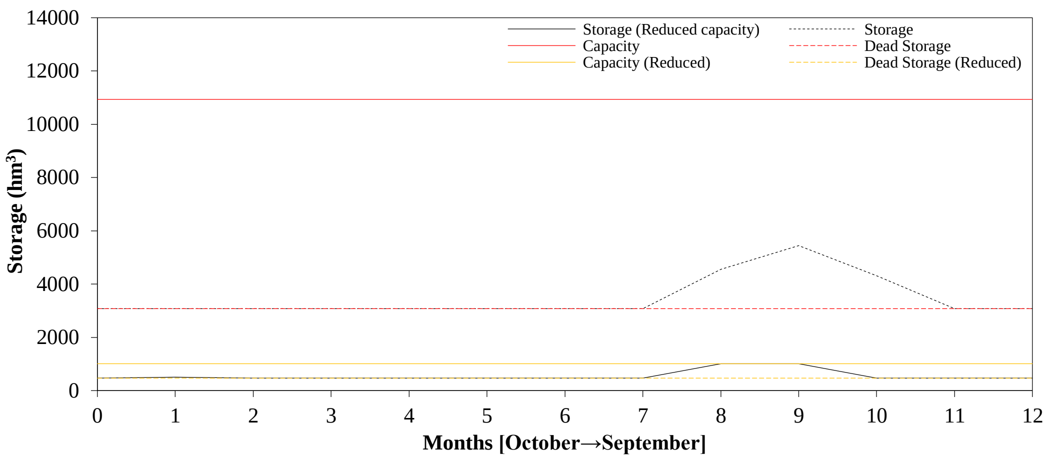


Figure 24 Storage Variations at the Ilisu Reservoir for Reduced Capacity

Table 17 Results of the Operations for the Tigris Hydropower System

Produced Energy (GWh)												
						Months						
10	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
without constraint on Silopi and Nusaybin-Idil-Cizre Irrigations												
63.6	388.4	435.3	475.3	462.4	567.1	1028.3	826.7	649.9	1303.0	979.7	192.2	**7371.8**
with constraint on Silopi and Nusaybin-Idil-Cizre Irrigations												
55.8	391.6	435.3	475.7	442.7	562.8	1028.3	856.0	661.8	1300.6	939.1	192.2	**7342.0**
with constraint on Silopi and Nusaybin-Idil-Cizre Irrigations & reduced storage of the Ilisu Reservoir												
57.6	323.2	400.9	410.5	339.6	412.7	853.0	997.8	824.3	988.5	672.6	188.9	**6469.6**

4.5.2 State of the Garzan Sub-System in the Integrated Tigris Operations Plan

In this study, the operations of the Tigris Hydropower System are optimised for three cases. According to the optimisation results, the total amounts of energy produced by the Garzan Hydropower System are found to be 453.26 GWh/year in the first run (neglecting the downstream irrigation schemes), 448.68 GWh/year in the second run (considering the downstream irrigation schemes) and 462.34 GWh/year in the third run (considering the downstream irrigation schemes and the reduced storage capacity of the Ilisu Reservoir) (Table 18).

To investigate the maximum energy that can be produced by the Garzan Hydropower System, the operations of the Garzan sub-system are re-optimised without considering the contractual energy demand and the energy prices. The operations are performed on a monthly basis for a thirty-year period using the extended historical inflow series from 1971 to 2000 and for a one-year period using the monthly means of the extended data sets. Accordingly, the energy production capacities of the sub-system are found to be 507.67 GWh/year and 487.48 GWh/year for long- and short-term operation, respectively (Table 18). These results mean that the amounts of energy produced by the Garzan sub-system in the optimised operations of the entire system are lower than its production capacity.

Table 18 Comparison of the Operations for the Garzan Hydropower System

Optimised System	Operation Period	Inflow Values	Special Case	Produced Energy (GWh)			
				Aysehatun	**Kor**	**Garzan**	**Total**
Tigris	1-year	Mean	-	177.81	108.69	166.76	**453.26**
Tigris	1-year	Mean	with constraint on Silopi and Nusaybin-Idil-Cizre Irrigations	170.80	109.65	168.23	**448.68**
Tigris	1-year	Mean	with constraint on Silopi and Nusaybin-Idil-Cizre Irrigations & reduced storage of the Ilisu Reservoir	186.52	108.80	167.02	**462.34**
Garzan	1-year	Mean	-	212.98	124.90	149.60	**487.48**
Garzan	30-year	Historical	-	211.41	119.07	177.19	**507.67**

Possible decreases in the energy production levels of the sub-systems during the optimisation of the operations of the entire system, as in the case of the Garzan sub-system, can generate conflicts related to revenue allocation among participants. Although such decreases may be an obstacle to implementation, the intent of the integrated system operations plan is not to optimise the income of its individual components but rather to maximise the energy production of the entire system while satisfying the water needs in the basin.

CHAPTER 5

CONCLUSION

Integrated reservoir operation is a must for hydropower system reservoirs from which water is subtracted for agriculture activities, human settlements and industrial needs. Particularly, in a cascade system composed of state- and private-sector-owned reservoirs, the manner in which reservoirs are operated in terms of the volume and timing of water releases to meet downstream water supply demands is a problem of some concern.

This issue becomes more problematic in the case of international shared basins. Although the International Law Association and the International Law Commission laid down certain rules regulating water-sharing agreements, these are only principles (Pantulu, 1983; Teclaff, 1996; Zaman, Biswas, Khan, & Nishat, 1983). When one of the co-riparian countries is much more powerful than the others, these rules are inadequate (Barrow, 2001).

The integrated operation of cascade hydropower projects is also beneficial for avoiding energy imbalances and enormous price differences. When the performance of the integrated algorithm is verified against the sequential optimisation of the system reservoirs, it is observed that the catchment-based optimisation model produces more energy by maximising head and minimising spill. It is also seen in this study that improvement in the accuracy of the forecasts used in a real-time process yields economic benefits as a consequence of optimal reservoir operation. Even a small percentage increase in energy production is, in reality, quite substantial. Consequently, instead of optimising projects individually, basin-scale operation models must be applied to use hydropower potential more efficiently.

Moreover, basin projects can be analysed using the proposed model under various hydrological scenarios to assess the results of delaying or advancing the schedule of a power plant, expanding the capacity of existing plants or adjusting the normal and minimum operating levels of system reservoirs.

It is clear that such an operation model can only be implemented through a catchment- or even tributary-based management policy enacted by an individual state or private-sector organisation that takes full responsibility for the manner in which schemes are planned, operated and managed under supportive legislation.

Thus, cascade hydropower systems for which single-reservoir simulation models are employed in the operation of each of the system reservoirs, as in the case of Turkey, must be planned and operated through an integrated management process. The application of such a process not only reduces conflicts but also increases benefits because “the whole is greater than the sum of its parts” (Barrow, 2001).

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APPENDIX A

NLP MODEL OF THE GARZAN HYDROPOWER SYSTEM

GarzanES.gms

```
$Title Optimisation of the Garzan Hydropower System Operations
$Ontext
i   from 1 to i        : Reservoir i
j   from 1 to j        : Turbine j
k                      : Number of turbines
day(t)      (day)      : Number of days in a month
Si(t)       (m3)       : Final storage in the ith reservoir at the end
                         of time period t
Si_max      (m3)       : Maximum storage in the ith reservoir
Si_min      (m3)       : Minimum storage in the ith reservoir
beg_Si      (m3)       : Initial storage in the ith reservoir
Ai(t)       (m2)       : Reservoir area of the ith reservoir at the end
                         of time period t
beg_Ai      (m2)       : Initial reservoir area of the ith reservoir
WLi(t)      (m)        : Water level of the ith reservoir at the end of
                         time period t
beg_WLi     (m)        : Initial water level of the ith reservoir
Qi(t)       (m3)       : Forecasted inflow into the ith reservoir during
                         time period t
Di(t)       (m3)       : Non-power release from the ith reservoir during
                         time period t
Ei(t)       (m)        : Net evaporation rate per unit area of the ith
                         reservoir during time period t
Rti_jt(t)   (m3)       : Power release through the jth turbine of the ith
                         reservoir during time period t
Rti_kt_max  (m3)       : Maximum power release through a turbine of the
                         ith reservoir
Rsi(t)      (m3)       : Non-power release through the spillway from the
                         ith reservoir during time period t
Rsi_max     (m3)       : Spillway capacity of the ith reservoir
Ri_min(t)   (m3)       : Minimum release required to supply irrigation
                         water demand from the ith reservoir during time
                         period t
AvWLi(t)    (m)        : Average water level of the ith reservoir during
                         time period t
NtHi(t)     (m)        : Net head in the ith reservoir during time
                         period t
twei        (m)        : Tail water level of the ith reservoir
flKi        (m/(m3/s)^2): Friction loss coefficient for the penstocks
                         and/or energy tunnels of the ith reservoir
effi_jt(t)  (-)        : Efficiency of turbine j of the ith reservoir
                         during time period t
ep(t)       (cent/kWh) : Estimated energy price on the day-ahead market
                         for time period t
pwri(t)     (kW)       : Power of the ith plant during time period t
inci(t)     (cent)     : Income of the ith plant during time period t
$Offtext
```

```
*Aysehatun Dam and HEPP
SCALAR S1_max /530370000/;
SCALAR S1_min /229920000/;
SCALAR Rt1_2t_max /17891712/;
SCALAR beg_S1 /229920000/;
SCALAR beg_A1 /11730013.31/;
SCALAR beg_WL1 /1230.00/;
SCALAR twe1 /950/;
SCALAR flK1 /0.1008/;
SCALAR Rs1_max /2461047840/;

*Kor Dam and HEPP
SCALAR S2_max /38520000/;
SCALAR S2_min /11650000/;
SCALAR Rt2_2t_max /35542368/;
SCALAR beg_S2 /11650000/;
SCALAR beg_A2 /719999.94/;
SCALAR beg_WL2 /930.01/;
SCALAR twe2 /830/;
SCALAR flK2 /0.0216/;
SCALAR Rs2_max /4882723200/;

*Garzan Dam and HEPP
SCALAR S3_max /181000000/;
SCALAR S3_min /76780000/;
SCALAR Rt3_2t_max /58389120/;
SCALAR beg_S3 /76780000/;
SCALAR beg_A3 /2549173.15/;
SCALAR beg_WL3 /757.77/;
SCALAR twe3 /676/;
SCALAR flK3 /0.0020/;
SCALAR Rs3_max /5624640000/;

SET
t /t1, t2, t3, t4, t5, t6, t7, t8, t9, t10, t11, t12/;

$include Day.inc
$include Price.inc
$include Aysehatun.inc
$include Kor.inc
$include Garzan.inc

POSITIVE VARIABLES
*Aysehatun Dam and HEPP
S1(t), A1(t), WL1(t), Rt1_1t(t), Rt1_2t(t), Rs1(t), AvWL1(t),
NtH1(t), eff1_1t(t), eff1_2t(t), inc1(t),

*Kor Dam and HEPP
S2(t), A2(t), WL2(t), Rt2_1t(t), Rt2_2t(t), Rs2(t), AvWL2(t),
NtH2(t), eff2_1t(t), eff2_2t(t), inc2(t),

*Garzan Dam and HEPP
S3(t), A3(t), WL3(t), Rt3_1t(t), Rt3_2t(t), Rs3(t), AvWL3(t),
NtH3(t), eff3_1t(t), eff3_2t(t), inc3(t);

S1.UP(t)=S1_max;
S1.LO(t)=S1_min;
S2.UP(t)=S2_max;
```

```
S2.LO(t)=S2_min;
S3.UP(t)=S3_max;
S3.LO(t)=S3_min;

Rs1.UP(t)=Rs1_max;
Rs2.UP(t)=Rs2_max;
Rs3.UP(t)=Rs3_max;

S1.UP('t12')=S1_min;
S2.UP('t12')=S2_min;
S3.UP('t12')=S3_min;

Rt1_1t.UP(t)= Rt1_2t_max;
Rt1_2t.UP(t)= Rt1_2t_max;
Rt2_1t.UP(t)= Rt2_2t_max;
Rt2_2t.UP(t)= Rt2_2t_max;
Rt3_1t.UP(t)= Rt3_2t_max;
Rt3_2t.UP(t)= Rt3_2t_max;

*starting points
Rt1_1t.L(t)= Rt1_2t_max;
Rt1_2t.L(t)= Rt1_2t_max;
Rt2_1t.L(t)= Rt2_2t_max;
Rt2_2t.L(t)= Rt2_2t_max;
Rt3_1t.L(t)= Rt3_2t_max;
Rt3_2t.L(t)= Rt3_2t_max;


VARIABLES
obj;

EQUATIONS
objective,

*Aysehatun Dam and HEPP
balance1(t), min_release1(t), area1(t), level1(t), ave_level1(t),
net_head1(t), efficiency1_1t(t), efficiency1_2t(t), income1(t),

*Kor Dam and HEPP
balance2(t), min_release2(t), area2(t), level2(t), ave_level2(t),
net_head2(t), efficiency2_1t(t), efficiency2_2t(t), income2(t),

*Garzan Dam and HEPP
balance3(t), min_release3(t), area3(t), level3(t), ave_level3(t),
net_head3(t), efficiency3_1t(t), efficiency3_2t(t), income3(t);

objective.. obj =E= SUM(t,(inc1(t) + inc2(t) + inc3(t)));

*Aysehatun Dam and HEPP
balance1(t).. S1(t) =E= beg_S1$(ord(t) EQ 1) + S1(t-1)$(ord(t) GT
1) + Q1(t) - Rt1_1t(t)  - Rt1_2t(t) - Rs1(t) - D1(t) - E1(t) *
(beg_A1$(ord(t) EQ 1) + A1(t-1)$(ord(t) GT 1));

min_release1(t).. Rt1_1t(t) + Rt1_2t(t) + Rs1(t) + D1(t) =G=
R1_min(t);

area1(t).. A1(t) =E= -0.000000000010405 * S1(t)**2 +
0.030310742571682 * S1(t) + 5311009.03784554;
```

```
level1(t).. WL1(t) =E= -0.00000000000000005026 * S1(t)**2 +
0.0000001047779418573 * S1(t) + 1208.56628735606;

ave_level1(t).. AvWL1(t) =E= ((beg_WL1 $(ord(t) EQ 1) + WL1(t-
1)$(ord(t) GT 1)) + WL1(t)) / 2;

net_head1(t).. NtH1(t)=E= (AvWL1(t) - twe1) * 0.95 - ((Rt1_1t(t) /
(24 * day(t) * 3600)) + (Rt1_2t(t) / (24 * day(t) * 3600))) *
((Rt1_1t(t) / (24 * day(t) * 3600)) + (Rt1_2t(t) / (24 * day(t) *
3600))) * flK1;

efficiency1_1t(t).. eff1_1t(t) =E= - (1.4849 * ((Rt1_1t(t) /
Rt1_2t_max)**6)) + (7.4008 * ((Rt1_1t(t) / Rt1_2t_max)**5)) -
(16.7253 * ((Rt1_1t(t) / Rt1_2t_max)**4)) + (20.2156 * ((Rt1_1t(t)
/ Rt1_2t_max)**3)) - (13.6479 * ((Rt1_1t(t) / Rt1_2t_max)**2)) +
(5.1611 * (Rt1_1t(t) / Rt1_2t_max));

efficiency1_2t(t).. eff1_2t(t) =E= - (1.4849 * ((Rt1_2t(t) /
Rt1_2t_max)**6)) + (7.4008 * ((Rt1_2t(t) / Rt1_2t_max)**5)) -
(16.7253 * ((Rt1_2t(t) / Rt1_2t_max)**4)) + (20.2156 * ((Rt1_2t(t)
/ Rt1_2t_max)**3)) - (13.6479 * ((Rt1_2t(t) / Rt1_2t_max)**2)) +
(5.1611 * (Rt1_2t(t) / Rt1_2t_max));

income1(t).. inc1(t) =E= ep(t) * 0.985 * 0.975 * 24 * day(t) *
9.81 * NtH1(t) * ((eff1_1t(t) * (Rt1_1t(t) / (24 * day(t) *
3600))) + (eff1_2t(t) * (Rt1_2t(t) / (24 * day(t) * 3600))));

*Kor Dam and HEPP
balance2(t).. S2(t) =E= beg_S2$(ord(t) EQ 1) + S2(t-1)$(ord(t) GT
1) + Q2(t) - Rt2_1t(t) - Rt2_2t(t) - Rs2(t) - D2(t) - E2(t) *
(beg_A2$(ord(t) EQ 1) + A2(t-1)$(ord(t) GT 1)) + Rt1_1t(t) +
Rt1_2t(t) + Rs1(t) + D1(t);

min_release2(t).. Rt2_1t(t) + Rt2_2t(t) + Rs2(t) + D2(t) =G=
R2_min(t);

area2(t).. A2(t) =E= 0.000000000285871 * S2(t)**2 +
0.011932486521108 * S2(t) + 542187.347991712;

level2(t).. WL2(t) =E= -0.000000000000011 * S2(t)**2 +
0.000001523717615 * S2(t) + 913.753068954999;

ave_level2(t).. AvWL2(t) =E= ((beg_WL2 $(ord(t) EQ 1) + WL2(t-
1)$(ord(t) GT 1)) + WL2(t)) / 2;

net_head2(t).. NtH2(t) =E= (AvWL2(t) - twe2) * 0.95 - ((Rt2_1t(t)
/ (24 * day(t) * 3600)) + (Rt2_2t(t) / (24 * day(t) * 3600))) *
((Rt2_1t(t) / (24 * day(t) * 3600)) + (Rt2_2t(t) / (24 * day(t) *
3600))) * flK2;

efficiency2_1t(t).. eff2_1t(t) =E= - (1.4849 * ((Rt2_1t(t) /
Rt2_2t_max)**6)) + (7.4008 * ((Rt2_1t(t) / Rt2_2t_max)**5)) -
(16.7253 * ((Rt2_1t(t) / Rt2_2t_max)**4)) + (20.2156 * ((Rt2_1t(t)
/ Rt2_2t_max)**3)) - (13.6479 * ((Rt2_1t(t) / Rt2_2t_max)**2)) +
(5.1611 * (Rt2_1t(t) / Rt2_2t_max));

efficiency2_2t(t).. eff2_2t(t) =E= - (1.4849 * ((Rt2_2t(t) /
Rt2_2t_max)**6)) + (7.4008 * ((Rt2_2t(t) / Rt2_2t_max)**5)) -
```

```
(16.7253 * ((Rt2_2t(t) / Rt2_2t_max)**4)) + (20.2156 * ((Rt2_2t(t)
/ Rt2_2t_max)**3)) - (13.6479 * ((Rt2_2t(t) / Rt2_2t_max)**2)) +
(5.1611 * (Rt2_2t(t) / Rt2_2t_max));

income2(t).. inc2(t) =E= ep(t) * 0.985 * 0.975 * 24 * day(t) *
9.81 * NtH2(t) * ((eff2_1t(t) * (Rt2_1t(t) / (24 * day(t) *
3600))) + (eff2_2t(t) * (Rt2_2t(t) / (24 * day(t) * 3600))));

*Garzan Dam and HEPP
balance3(t).. S3(t) =E= beg_S3$(ord(t) EQ 1) + S3(t-1)$(ord(t) GT
1) + Q3(t) - Rt3_1t(t) - Rt3_2t(t) - Rs3(t) - D3(t) - E3(t) *
(beg_A3$(ord(t) EQ 1) + A3(t-1)$(ord(t) GT 1)) + Rt2_1t(t) +
Rt2_2t(t) + Rs2(t) + D2(t);

min_release3(t).. Rt3_1t(t) + Rt3_2t(t) + Rs3(t) + D3(t) =G=
R3_min(t);

area3(t).. A3(t) =E= -0.00000000004851553382 * S3(t)**2 +
0.0281158312067894 * S3(t) + 676446.867711646;

level3(t).. WL3(t) =E= -0.0000000000000000100122 * S3(t)**2 +
0.0000000549749108011169 * S3(t) + 721.461681514073;

ave_level3(t).. AvWL3(t) =E= ((beg_WL3 $(ord(t) EQ 1) + WL3(t-
1)$(ord(t) GT 1)) + WL3(t)) / 2;

net_head3(t).. NtH3(t) =E= (AvWL3(t) - twe3) * 0.95 - ((Rt3_1t(t)
/ (24 * day(t) * 3600)) + (Rt3_2t(t) / (24 * day(t) * 3600))) *
((Rt3_1t(t) / (24 * day(t) * 3600)) + (Rt3_2t(t) / (24 * day(t) *
3600))) * flK3;

efficiency3_1t(t).. eff3_1t(t) =E= - (1.4849 * ((Rt3_1t(t) /
Rt3_2t_max)**6)) + (7.4008 * ((Rt3_1t(t) / Rt3_2t_max)**5)) -
(16.7253 * ((Rt3_1t(t) / Rt3_2t_max)**4)) + (20.2156 * ((Rt3_1t(t)
/ Rt3_2t_max)**3)) - (13.6479 * ((Rt3_1t(t) / Rt3_2t_max)**2)) +
(5.1611 * (Rt3_1t(t) / Rt3_2t_max));

efficiency3_2t(t).. eff3_2t(t) =E= - (1.4849 * ((Rt3_2t(t) /
Rt3_2t_max)**6)) + (7.4008 * ((Rt3_2t(t) / Rt3_2t_max)**5)) -
(16.7253 * ((Rt3_2t(t) / Rt3_2t_max)**4)) + (20.2156 * ((Rt3_2t(t)
/ Rt3_2t_max)**3)) - (13.6479 * ((Rt3_2t(t) / Rt3_2t_max)**2)) +
(5.1611 * (Rt3_2t(t) / Rt3_2t_max));

income3(t).. inc3(t) =E= ep(t) * 0.985 * 0.975 * 24 * day(t) *
9.81 * NtH3(t) * ((eff3_1t(t) * (Rt3_1t(t) / (24 * day(t) *
3600))) + (eff3_2t(t) * (Rt3_2t(t) / (24 * day(t) * 3600))));

OPTION ITERLIM= 100000000;
OPTION OPTCR= 0.0000000000000000000000001;
OPTION LIMROW= 12;
OPTION nlp = minos5;

MODEL GarzanES / ALL /;
SOLVE GarzanES USING NLP MAXIMIZING obj;

PARAMETER
pwr1(t), pwr2(t), pwr3(t);
```

```
pwr1(t) = 9.81 * NtH1.L(t) * ((eff1_1t.L(t) * (Rt1_1t.L(t) / (24 *
day(t) * 3600))) + (eff1_2t.L(t) * (Rt1_2t.L(t) / (24 * day(t) *
3600))));

pwr2(t) = 9.81 * NtH2.L(t) * ((eff2_1t.L(t) * (Rt2_1t.L(t) / (24 *
day(t) * 3600))) + (eff2_2t.L(t) * (Rt2_2t.L(t) / (24 * day(t) *
3600))));

pwr3(t) = 9.81 * NtH3.L(t) * ((eff3_1t.L(t) * (Rt3_1t.L(t) / (24 *
day(t) * 3600))) + (eff3_2t.L(t) * (Rt3_2t.L(t) / (24 * day(t) *
3600))));

FILE res /GarzanES.txt/;
PUT res

PUT "Aysehatun Dam and HEPP"/;
PUT " t    day(t)    S1(t)    A1(t)    WL1(t)    Q1(t)    D1(t)    E1(t)
Rt1_1t(t)    Rt1_2t(t)    Rs1(t)    R1_min(t)    AvWL1(t)    NtH1(t)
eff1_1t(t)    eff1_2t(t)    pwr1(t)    inc1(t)"/;
PUT "t0","      --   ", beg_S1, beg_A1, beg_WL1/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S1.L(t):13.2, A1.L(t):13.2,
WL1.L(t):13.2, Q1(t):13.2, D1(t):13.2, E1(t):13.2,
Rt1_1t.L(t):13.2, Rt1_2t.L(t):13.2, Rs1.L(t):13.2, R1_min(t):13.2,
AvWL1.L(t):13.2, NtH1.L(t):13.2, eff1_1t.L(t):13.2,
eff1_2t.L(t):13.2, pwr1(t):13.2, inc1.L(t):13.2/;);

PUT "        "/;

PUT "Kor Dam and HEPP"/;
PUT " t    day(t)    S2(t)    A2(t)    WL2(t)    Q2(t)    D2(t)    E2(t)
Rt2_1t(t)    Rt2_2t(t)    Rs2(t)    R2_min(t)    AvWL2(t)    NtH2(t)
eff2_1t(t)    eff2_2t(t)    pwr2(t)    inc2(t)"/;
PUT "t0","      --   ", beg_S2, beg_A2, beg_WL2/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S2.L(t):13.2, A2.L(t):13.2,
WL2.L(t):13.2, Q2(t):13.2, D2(t):13.2, E2(t):13.2,
Rt2_1t.L(t):13.2, Rt2_2t.L(t):13.2, Rs2.L(t):13.2, R2_min(t):13.2,
AvWL2.L(t):13.2, NtH2.L(t):13.2, eff2_1t.L(t):13.2,
eff2_2t.L(t):13.2, pwr2(t):13.2, inc2.L(t):13.2/;);

PUT "        "/;

PUT "Garzan Dam and HEPP"/;
PUT " t    day(t)    S3(t)    A3(t)    WL3(t)    Q3(t)    D3(t)    E3(t)
Rt3_1t(t)    Rt3_2t(t)    Rs3(t)    R3_min(t)    AvWL3(t)    NtH3(t)
eff3_1t(t)    eff3_2t(t)    pwr3(t)    inc3(t)"/;
PUT "t0","      --   ", beg_S3, beg_A3, beg_WL3/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S3.L(t):13.2, A3.L(t):13.2,
WL3.L(t):13.2, Q3(t):13.2, D3(t):13.2, E3(t):13.2,
Rt3_1t.L(t):13.2, Rt3_2t.L(t):13.2, Rs3.L(t):13.2, R3_min(t):13.2,
AvWL3.L(t):13.2, NtH3.L(t):13.2, eff3_1t.L(t):13.2,
eff3_2t.L(t):13.2, pwr3(t):13.2, inc3.L(t):13.2/;);

PUT "        "/;

PUT "Income:", Obj.L:25.2/;
```

APPENDIX B

NLP MODEL OF THE TIGRIS HYDROPOWER SYSTEM

TigrisES.gms

```
$Title Optimisation of the Tigris Hydropower System Operations
$Ontext
i   from 1 to i         : Reservoir i
j   from 1 to j         : Turbine j
k                       : Number of turbines
day(t)      (day)       : Number of days in a month
Si(t)       (m3)        : Final storage in the ith reservoir at the end
                          of time period t
Si_max      (m3)        : Maximum storage in the ith reservoir
Si_min      (m3)        : Minimum storage in the ith reservoir
beg_Si      (m3)        : Initial storage in the ith reservoir
Ai(t)       (m2)        : Reservoir area of the ith reservoir at the end
                          of time period t
beg_Ai      (m2)        : Initial reservoir area of the ith reservoir
WLi(t)      (m)         : Water level of the ith reservoir at the end of
                          time period t
beg_WLi     (m)         : Initial water level of the ith reservoir
Qi(t)       (m3)        : Forecasted inflow into the ith reservoir during
                          time period t
Di(t)       (m3)        : Non-power release from the ith reservoir during
                          time period t
Ei(t)       (m)         : Net evaporation rate per unit area of the ith
                          reservoir during time period t
Rti_jt(t)   (m3)        : Power release through the jth turbine of the ith
                          reservoir during time period t
Rti_kt_max (m3)         : Maximum power release through a turbine of the
                          ith reservoir
Rsi(t)      (m3)        : Non-power release through the spillway from the
                          ith reservoir during time period t
Rsi_max     (m3)        : Spillway capacity of the ith reservoir
Ri_min(t)   (m3)        : Minimum release required to supply irrigation
                          water demand from the ith reservoir during time
                          period t
AvWLi(t)    (m)         : Average water level of the ith reservoir during
                          time period t
NtHi(t)     (m)         : Net head in the ith reservoir during time
                          period t
twei        (m)         : Tail water level of the ith reservoir
flKi        (m/(m3/s)^2): Friction loss coefficient for the penstocks
                          and/or energy tunnels of the ith reservoir
effi_jt(t) (-)          : Efficiency of turbine j of the ith reservoir
                          during time period t
pwri(t)     (kW)        : Power of the ith plant during time period t
engi(t)     (kWh)       : Energy production of the ith plant during time
                          period t
$Offtext
```

```
*Aysehatun Dam and HEPP
SCALAR S1_max /530370000/;
SCALAR S1_min /229920000/;
SCALAR Rt1_2t_max /17891712/;
SCALAR beg_S1 /229920000/;
SCALAR beg_A1 /11730013.31/;
SCALAR beg_WL1 /1230.00/;
SCALAR twe1 /950/;
SCALAR flK1 /0.1008/;
SCALAR Rs1_max /2461047840/;

*Kor Dam and HEPP
SCALAR S2_max /38520000/;
SCALAR S2_min /11650000/;
SCALAR Rt2_2t_max /35542368/;
SCALAR beg_S2 /11650000/;
SCALAR beg_A2 /719999.94/;
SCALAR beg_WL2 /930.01/;
SCALAR twe2 /830/;
SCALAR flK2 /0.0216/;
SCALAR Rs2_max /4882723200/;

*Garzan Dam and HEPP
SCALAR S3_max /181000000/;
SCALAR S3_min /76780000/;
SCALAR Rt3_2t_max /58389120/;
SCALAR beg_S3 /76780000/;
SCALAR beg_A3 /2549173.15/;
SCALAR beg_WL3 /757.77/;
SCALAR twe3 /676/;
SCALAR flK3 /0.0020/;
SCALAR Rs3_max /5624640000/;

*Guzeldere Dam and HEPP
SCALAR S4_max /44093750/;
SCALAR S4_min /10604808.24/;
SCALAR Rt4_2t_max /10713600/;
SCALAR beg_S4 /10604808.24/;
SCALAR beg_A4 /1246433.80/;
SCALAR beg_WL4 /1704.49/;
SCALAR twe4 /1270/;
SCALAR flK4 /0.3098/;
SCALAR Rs4_max /1514501280/;

*Sirvan Dam and HEPP
SCALAR S5_max /417000000/;
SCALAR S5_min /152220000/;
SCALAR Rt5_2t_max /45264960/;
SCALAR beg_S5 /152220000/;
SCALAR beg_A5 /6968229.53/;
SCALAR beg_WL5 /662.56/;
SCALAR twe5 /577/;
SCALAR flK5 /0.0083/;
SCALAR Rs5_max /2745360000/;

*Basoren Dam and HEPP
SCALAR S6_max /19204505.04/;
SCALAR S6_min /7906268.35/;
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SCALAR Rt6_2t_max /46764864/;
SCALAR beg_S6 /7906268.35/;
SCALAR beg_A6 /1141782.26/;
SCALAR beg_WL6 /553/;
SCALAR twe6 /530/;
SCALAR flK6 /0.0043/;
SCALAR Rs6_max /2745360000/;

*Narli Dam and HEPP
SCALAR S7_max /66546625/;
SCALAR S7_min /27200203.52/;
SCALAR Rt7_2t_max /73923840/;
SCALAR beg_S7 /27200203.52/;
SCALAR beg_A7 /1122704.30/;
SCALAR beg_WL7 /1345/;
SCALAR twe7 /1280/;
SCALAR flK7 /0.0003/;
SCALAR Rs7_max /11750140800/;

*Oran Dam and HEPP
SCALAR S8_max /63281250/;
SCALAR S8_min /21437500/;
SCALAR Rt8_2t_max /74955024/;
SCALAR beg_S8 /21437500/;
SCALAR beg_A8 /859947.70/;
SCALAR beg_WL8 /1250.12/;
SCALAR twe8 /1180/;
SCALAR flK8 /0.0003/;
SCALAR Rs8_max /11750140800/;

*Keskin Dam and HEPP
SCALAR S9_max /357843500/;
SCALAR S9_min /161730541.32/;
SCALAR Rt9_3t_max /96645600/;
SCALAR beg_S9 /161730541.32/;
SCALAR beg_A9 /3043948.66/;
SCALAR beg_WL9 /1137.50/;
SCALAR twe9 /980/;
SCALAR flK9 /0.0001/;
SCALAR Rs9_max /11750140800/;

*Pervari Dam and HEPP
SCALAR S10_max /237406250/;
SCALAR S10_min /93000000/;
SCALAR Rt10_4t_max /107136000/;
SCALAR beg_S10 /93000000/;
SCALAR beg_A10 /2092069.94/;
SCALAR beg_WL10 /930.24/;
SCALAR twe10 /820/;
SCALAR flK10 /0.00005/;
SCALAR Rs10_max /11750140800/;

*Cetin Dam and HEPP
SCALAR S11_max /605765266.33/;
SCALAR S11_min /155240000/;
SCALAR Rt11_5t_max /169001683.20/;
SCALAR beg_S11 /155240000/;
SCALAR beg_A11 /4403687.90/;
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SCALAR beg_WL11 /761.02/;
SCALAR twe11 /647/;
SCALAR flK11 /0.0001/;
SCALAR Rs11_max /15660604800/;

*Alkumru Dam and HEPP
SCALAR S12_max /431373403.52/;
SCALAR S12_min /151177877.36/;
SCALAR Rt12_3t_max /247305600/;
SCALAR beg_S12 /151177877.36/;
SCALAR beg_A12 /5281732.08/;
SCALAR beg_WL12 /611.8/;
SCALAR twe12 /541.8/;
SCALAR flK12 /0.00002/;
SCALAR Rs12_max /16097184000/;

*Eruh Dam and HEPP
SCALAR S13_max /220000000/;
SCALAR S13_min /43050000/;
SCALAR Rt13_2t_max /34819200/;
SCALAR beg_S13 /43050000/;
SCALAR beg_A13 /2100987.24/;
SCALAR beg_WL13 /727.35/;
SCALAR twe13 /545/;
SCALAR flK13 /0.0395/;
SCALAR Rs13_max /3415495680/;

*Anbar Dam
SCALAR S14_max /132110000/;
SCALAR S14_min /15500000/;
SCALAR beg_S14 /15500000/;
SCALAR beg_A14 /2600000/;
SCALAR Rs14_max /4282761600/;

*Kurucay Dam
SCALAR S15_max /43270000/;
SCALAR S15_min /8500000/;
SCALAR beg_S15 /8500000/;
SCALAR beg_A15 /1360000/;
SCALAR Rs15_max /961545600/;

*Pamukcay Dam
SCALAR S16_max /37600000/;
SCALAR S16_min /17000000/;
SCALAR beg_S16 /17000000/;
SCALAR beg_A16 /1890000/;
SCALAR Rs16_max /1936483200/;

*Baslar Dam
SCALAR S17_max /28870000/;
SCALAR S17_min /7500000/;
SCALAR beg_S17 /7500000/;
SCALAR beg_A17 /1150000/;
SCALAR Rs17_max /1074038400/;

*Bulaklidere Dam
SCALAR S18_max /28140000/;
SCALAR S18_min /2400000/;
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SCALAR beg_S18 /2400000/;
SCALAR beg_A18 /410000/;
SCALAR Rs18_max /755308800/;

*Kibris Dam
SCALAR S19_max /14240000/;
SCALAR S19_min /4100000/;
SCALAR beg_S19 /4100000/;
SCALAR beg_A19 /580000/;
SCALAR Rs19_max /1502582400/;

*Karacalar Dam
SCALAR S20_max /24490000/;
SCALAR S20_min /2350000/;
SCALAR beg_S20 /2350000/;
SCALAR beg_A20 /380000/;
SCALAR Rs20_max /350870400/;

*Silvan Dam and HEPP
SCALAR S21_max /6840000000/;
SCALAR S21_min /2773000000/;
SCALAR Rt21_4t_max /91735200/;
SCALAR beg_S21 /2773000000/;
SCALAR beg_A21 /93740000.03/;
SCALAR beg_WL21 /790/;
SCALAR twe21 /659.85/;
SCALAR flK21 /0.0006/;
SCALAR Rs21_max /14318726400/;

*Batman Dam and HEPP
SCALAR S22_max /1202647537.62/;
SCALAR S22_min /470876065.08/;
SCALAR Rt22_3t_max /323193600/;
SCALAR beg_S22 /470876065.08/;
SCALAR beg_A22 /26884177.37/;
SCALAR beg_WL22 /645/;
SCALAR twe22 /595.50/;
SCALAR flK22 /0.000004/;
SCALAR Rs22_max /17613158400/;

*Ergani Dam
SCALAR S23_max /14592373.14/;
SCALAR S23_min /1172913.27/;
SCALAR beg_S23 /1172913.27/;
SCALAR beg_A23 /213952.40/;
SCALAR Rs23_max /325157760/;

*Devegecidi Dam
SCALAR S24_max /183000000/;
SCALAR S24_min /7000000/;
SCALAR beg_S24 /7000000/;
SCALAR beg_A24 /2157916.42/;
SCALAR Rs24_max /7437916800/;

*Dipni Dam and HEPP
SCALAR S25_max /949000000/;
SCALAR S25_min /209000000/;
SCALAR Rt25_2t_max /33480000/;
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SCALAR beg_S25 /209000000/;
SCALAR beg_A25 /1317200.98/;
SCALAR beg_WL25 /820.45/;
SCALAR twe25 /715/;
SCALAR flK25 /0.0087/;
SCALAR Rs25_max /10962691200/;

*Kralkizi Dam and HEPP
SCALAR S26_max /1919600000/;
SCALAR S26_min /208000000/;
SCALAR Rt26_2t_max /192844800/;
SCALAR beg_S26 /208000000/;
SCALAR beg_A26 /8621336.50/;
SCALAR beg_WL26 /763.10/;
SCALAR twe26 /708/;
SCALAR flK26 /0.0001/;
SCALAR Rs26_max /8383392000/;

*Dicle Dam and HEPP
SCALAR S27_max /595000000/;
SCALAR S27_min /340000000/;
SCALAR Rt27_2t_max /180792000/;
SCALAR beg_S27 /340000000/;
SCALAR beg_A27 /17424869.05/;
SCALAR beg_WL27 /702.5/;
SCALAR twe27 /641/;
SCALAR flK27 /0.0001/;
SCALAR Rs27_max /19346083200/;

*Ilisu Dam and HEPP
SCALAR S28_max /10926322092.69/;
SCALAR S28_min /3078721306.26/;
SCALAR Rt28_6t_max /565142400/;
SCALAR beg_S28 /3078721306.26/;
SCALAR beg_A28 /112440535.39/;
SCALAR beg_WL28 /485.40/;
SCALAR twe28 /400/;
SCALAR flK28 /0.0000002/;
SCALAR Rs28_max /54524188800/;

SET
t /t1, t2, t3, t4, t5, t6, t7, t8, t9, t10, t11, t12/;

$include 0_Day.inc
$include 1_Aysehatun.inc
$include 2_Kor.inc
$include 3_Garzan.inc
$include 4_Guzeldere.inc
$include 4-1_Tatvan_WD.inc
$include 5_Sirvan.inc
$include 6_Basoren.inc
$include 6-1_Siirt_WD.inc
$include 7_Narli.inc
$include 8_Oran.inc
$include 9_Keskin.inc
$include 10_Pervari.inc
$include 11_Cetin.inc
$include 12_Alkumru.inc
```

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$include 13_Eruh.inc
$include 14_Anbar.inc
$include 15_Kurucay.inc
$include 16_Pamukcay.inc
$include 17_Baslar.inc
$include 18_Bulaklidere.inc
$include 19_Kibris.inc
$include 20_Karacalar.inc
$include 21_Silvan.inc
$include 22_Batman.inc
$include 23_Ergani.inc
$include 23-1_Ergani_Irrigation.inc
$include 24_Devegecidi.inc
$include 25_Dipni.inc
$include 26_Kralkizi.inc
$include 27_Dicle.inc
$include 28_Ilisu.inc
$include 28-1_Int_Basin.inc

POSITIVE VARIABLES
*Aysehatun Dam and HEPP
S1(t), A1(t), WL1(t), Rt1_1t(t), Rt1_2t(t), Rs1(t), AvWL1(t),
NtH1(t), eff1_1t(t), eff1_2t(t), eng1(t),

*Kor Dam and HEPP
S2(t), A2(t), WL2(t), Rt2_1t(t), Rt2_2t(t), Rs2(t), AvWL2(t),
NtH2(t), eff2_1t(t), eff2_2t(t), eng2(t),

*Garzan Dam and HEPP
S3(t), A3(t), WL3(t), Rt3_1t(t), Rt3_2t(t), Rs3(t), AvWL3(t),
NtH3(t), eff3_1t(t), eff3_2t(t), eng3(t),

*Guzeldere Dam and HEPP
S4(t), A4(t), WL4(t), Rt4_1t(t), Rt4_2t(t), Rs4(t), AvWL4(t),
NtH4(t), eff4_1t(t), eff4_2t(t), eng4(t),

*Sirvan Dam and HEPP
S5(t), A5(t), WL5(t), Rt5_1t(t), Rt5_2t(t), Rs5(t), AvWL5(t),
NtH5(t), eff5_1t(t), eff5_2t(t), eng5(t),

*Basoren Dam and HEPP
S6(t), A6(t), WL6(t), Rt6_1t(t), Rt6_2t(t), Rs6(t), AvWL6(t),
NtH6(t), eff6_1t(t), eff6_2t(t), eng6(t),

*Narli Dam and HEPP
S7(t), A7(t), WL7(t), Rt7_1t(t), Rt7_2t(t), Rs7(t), AvWL7(t),
NtH7(t), eff7_1t(t), eff7_2t(t), eng7(t),

*Oran Dam and HEPP
S8(t), A8(t), WL8(t), Rt8_1t(t), Rt8_2t(t), Rs8(t), AvWL8(t),
NtH8(t), eff8_1t(t), eff8_2t(t), eng8(t),

*Keskin Dam and HEPP
S9(t), A9(t), WL9(t), Rt9_1t(t), Rt9_2t(t), Rt9_3t(t), Rs9(t),
AvWL9(t), NtH9(t), eff9_1t(t), eff9_2t(t), eff9_3t(t), eng9(t),
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*Pervari Dam and HEPP
S10(t), A10(t), WL10(t), Rt10_1t(t), Rt10_2t(t), Rt10_3t(t),
Rt10_4t(t), Rs10(t), AvWL10(t), NtH10(t), eff10_1t(t),
eff10_2t(t), eff10_3t(t), eff10_4t(t), eng10(t),

*Cetin Dam and HEPP
S11(t), A11(t), WL11(t), Rt11_1t(t), Rt11_2t(t), Rt11_3t(t),
Rt11_4t(t), Rt11_5t(t), Rs11(t), AvWL11(t), NtH11(t), eff11_1t(t),
eff11_2t(t), eff11_3t(t), eff11_4t(t), eff11_5t(t), eng11(t),

*Alkumru Dam and HEPP
S12(t), A12(t), WL12(t), Rt12_1t(t), Rt12_2t(t), Rt12_3t(t),
Rs12(t), AvWL12(t), NtH12(t), eff12_1t(t), eff12_2t(t),
eff12_3t(t), eng12(t),

*Eruh Dam and HEPP
S13(t), A13(t), WL13(t), Rt13_1t(t), Rt13_2t(t), Rs13(t),
AvWL13(t), NtH13(t), eff13_1t(t), eff13_2t(t), eng13(t),

*Anbar Dam
S14(t), A14(t), Rs14(t), TS14(t),

*Kurucay Dam
S15(t), A15(t), Rs15(t), TS15(t),

*Pamukcay Dam
S16(t), A16(t), Rs16(t), TS16(t),

*Baslar Dam
S17(t), A17(t), Rs17(t), TS17(t),

*Bulaklidere Dam
S18(t), A18(t), Rs18(t), TS18(t),

*Kibris Dam
S19(t), A19(t), Rs19(t), TS19(t),

*Karacalar Dam
S20(t), A20(t), Rs20(t), TS20(t),

*Silvan Dam and HEPP
S21(t), A21(t), WL21(t), Rt21_1t(t), Rt21_2t(t), Rt21_3t(t),
Rt21_4t(t), Rs21(t), AvWL21(t), NtH21(t), eff21_1t(t),
eff21_2t(t), eff21_3t(t), eff21_4t(t), eng21(t),

*Batman Dam and HEPP
S22(t), A22(t), WL22(t), Rt22_1t(t), Rt22_2t(t), Rt22_3t(t),
Rs22(t), AvWL22(t), NtH22(t), eff22_1t(t), eff22_2t(t),
eff22_3t(t), eng22(t),

*Ergani Dam
S23(t), A23(t), Rs23(t),

*Devegecidi Dam
S24(t), A24(t), Rs24(t),
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*Dipni Dam and HEPP
S25(t), A25(t), WL25(t), Rt25_1t(t), Rt25_2t(t), Rs25(t),
AvWL25(t), NtH25(t), eff25_1t(t), eff25_2t(t), eng25(t),

*Kralkizi Dam and HEPP
S26(t), A26(t), WL26(t), Rt26_1t(t), Rt26_2t(t), Rs26(t),
AvWL26(t), NtH26(t), eff26_1t(t), eff26_2t(t), eng26(t),

*Dicle Dam and HEPP
S27(t), A27(t), WL27(t), Rt27_1t(t), Rt27_2t(t), Rs27(t),
AvWL27(t), NtH27(t), eff27_1t(t), eff27_2t(t), eng27(t), TS27(t),

*Ilisu Dam and HEPP
S28(t), A28(t), WL28(t), Rt28_1t(t), Rt28_2t(t), Rt28_3t(t),
Rt28_4t(t), Rt28_5t(t), Rt28_6t(t), Rs28(t), AvWL28(t), NtH28(t),
eff28_1t(t), eff28_2t(t), eff28_3t(t), eff28_4t(t), eff28_5t(t),
eff28_6t(t), eng28(t);

S1.UP(t)=S1_max;
S1.LO(t)=S1_min;
S2.UP(t)=S2_max;
S2.LO(t)=S2_min;
S3.UP(t)=S3_max;
S3.LO(t)=S3_min;
S4.UP(t)=S4_max;
S4.LO(t)=S4_min;
S5.UP(t)=S5_max;
S5.LO(t)=S5_min;
S6.UP(t)=S6_max;
S6.LO(t)=S6_min;
S7.UP(t)=S7_max;
S7.LO(t)=S7_min;
S8.UP(t)=S8_max;
S8.LO(t)=S8_min;
S9.UP(t)=S9_max;
S9.LO(t)=S9_min;
S10.UP(t)=S10_max;
S10.LO(t)=S10_min;
S11.UP(t)=S11_max;
S11.LO(t)=S11_min;
S12.UP(t)=S12_max;
S12.LO(t)=S12_min;
S13.UP(t)=S13_max;
S13.LO(t)=S13_min;
S14.UP(t)=S14_max;
S14.LO(t)=S14_min;
S15.UP(t)=S15_max;
S15.LO(t)=S15_min;
S16.UP(t)=S16_max;
S16.LO(t)=S16_min;
S17.UP(t)=S17_max;
S17.LO(t)=S17_min;
S18.UP(t)=S18_max;
S18.LO(t)=S18_min;
S19.UP(t)=S19_max;
S19.LO(t)=S19_min;
S20.UP(t)=S20_max;
S20.LO(t)=S20_min;
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```
S21.UP(t)=S21_max;
S21.LO(t)=S21_min;
S22.UP(t)=S22_max;
S22.LO(t)=S22_min;
S23.UP(t)=S23_max;
S23.LO(t)=S23_min;
S24.UP(t)=S24_max;
S24.LO(t)=S24_min;
S25.UP(t)=S25_max;
S25.LO(t)=S25_min;
S26.UP(t)=S26_max;
S26.LO(t)=S26_min;
S27.UP(t)=S27_max;
S27.LO(t)=S27_min;
S28.UP(t)=S28_max;
S28.LO(t)=S28_min;

Rs1.UP(t)=Rs1_max;
Rs2.UP(t)=Rs2_max;
Rs3.UP(t)=Rs3_max;
Rs4.UP(t)=Rs4_max;
Rs5.UP(t)=Rs5_max;
Rs6.UP(t)=Rs6_max;
Rs7.UP(t)=Rs7_max;
Rs8.UP(t)=Rs8_max;
Rs9.UP(t)=Rs9_max;
Rs10.UP(t)=Rs10_max;
Rs11.UP(t)=Rs11_max;
Rs12.UP(t)=Rs12_max;
Rs13.UP(t)=Rs13_max;
Rs14.UP(t)=Rs14_max;
Rs15.UP(t)=Rs15_max;
Rs16.UP(t)=Rs16_max;
Rs17.UP(t)=Rs17_max;
Rs18.UP(t)=Rs18_max;
Rs19.UP(t)=Rs19_max;
Rs20.UP(t)=Rs20_max;
Rs21.UP(t)=Rs21_max;
Rs22.UP(t)=Rs22_max;
Rs23.UP(t)=Rs23_max;
Rs24.UP(t)=Rs24_max;
Rs25.UP(t)=Rs25_max;
Rs26.UP(t)=Rs26_max;
Rs27.UP(t)=Rs27_max;
Rs28.UP(t)=Rs28_max;

S1.UP('t12')=S1_min;
S2.UP('t12')=S2_min;
S3.UP('t12')=S3_min;
S4.UP('t12')=S4_min;
S5.UP('t12')=S5_min;
S6.UP('t12')=S6_min;
S7.UP('t12')=S7_min;
S8.UP('t12')=S8_min;
S9.UP('t12')=S9_min;
S10.UP('t12')=S10_min;
S11.UP('t12')=S11_min;
S12.UP('t12')=S12_min;
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```
S13.UP('t12')=S13_min;
S14.UP('t12')=S14_min;
S15.UP('t12')=S15_min;
S16.UP('t12')=S16_min;
S17.UP('t12')=S17_min;
S18.UP('t12')=S18_min;
S19.UP('t12')=S19_min;
S20.UP('t12')=S20_min;
S21.UP('t12')=S21_min;
S22.UP('t12')=S22_min;
S23.UP('t12')=S23_min;
S24.UP('t12')=S24_min;
S25.UP('t12')=S25_min;
S26.UP('t12')=S26_min;
S27.UP('t12')=S27_min;
S28.UP('t12')=S28_min;

Rt1_1t.UP(t)= Rt1_2t_max;
Rt1_2t.UP(t)= Rt1_2t_max;
Rt2_1t.UP(t)= Rt2_2t_max;
Rt2_2t.UP(t)= Rt2_2t_max;
Rt3_1t.UP(t)= Rt3_2t_max;
Rt3_2t.UP(t)= Rt3_2t_max;
Rt4_1t.UP(t)= Rt4_2t_max;
Rt4_2t.UP(t)= Rt4_2t_max;
Rt5_1t.UP(t)= Rt5_2t_max;
Rt5_2t.UP(t)= Rt5_2t_max;
Rt6_1t.UP(t)= Rt6_2t_max;
Rt6_2t.UP(t)= Rt6_2t_max;
Rt7_1t.UP(t)= Rt7_2t_max;
Rt7_2t.UP(t)= Rt7_2t_max;
Rt8_1t.UP(t)= Rt8_2t_max;
Rt8_2t.UP(t)= Rt8_2t_max;
Rt9_1t.UP(t)= Rt9_3t_max;
Rt9_2t.UP(t)= Rt9_3t_max;
Rt9_3t.UP(t)= Rt9_3t_max;
Rt10_1t.UP(t)= Rt10_4t_max;
Rt10_2t.UP(t)= Rt10_4t_max;
Rt10_3t.UP(t)= Rt10_4t_max;
Rt10_4t.UP(t)= Rt10_4t_max;
Rt11_1t.UP(t)= Rt11_5t_max;
Rt11_2t.UP(t)= Rt11_5t_max;
Rt11_3t.UP(t)= Rt11_5t_max;
Rt11_4t.UP(t)= Rt11_5t_max;
Rt11_5t.UP(t)= Rt11_5t_max;
Rt12_1t.UP(t)= Rt12_3t_max;
Rt12_2t.UP(t)= Rt12_3t_max;
Rt12_3t.UP(t)= Rt12_3t_max;
Rt13_1t.UP(t)= Rt13_2t_max;
Rt13_2t.UP(t)= Rt13_2t_max;
Rt21_1t.UP(t)= Rt21_4t_max;
Rt21_2t.UP(t)= Rt21_4t_max;
Rt21_3t.UP(t)= Rt21_4t_max;
Rt21_4t.UP(t)= Rt21_4t_max;
Rt22_1t.UP(t)= Rt22_3t_max;
Rt22_2t.UP(t)= Rt22_3t_max;
Rt22_3t.UP(t)= Rt22_3t_max;
Rt25_1t.UP(t)= Rt25_2t_max;
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Rt25_2t.UP(t)= Rt25_2t_max;
Rt26_1t.UP(t)= Rt26_2t_max;
Rt26_2t.UP(t)= Rt26_2t_max;
Rt27_1t.UP(t)= Rt27_2t_max;
Rt27_2t.UP(t)= Rt27_2t_max;
Rt28_1t.UP(t)= Rt28_6t_max;
Rt28_2t.UP(t)= Rt28_6t_max;
Rt28_3t.UP(t)= Rt28_6t_max;
Rt28_4t.UP(t)= Rt28_6t_max;
Rt28_5t.UP(t)= Rt28_6t_max;
Rt28_6t.UP(t)= Rt28_6t_max;

*starting points
Rt1_1t.L(t)= Rt1_2t_max;
Rt1_2t.L(t)= Rt1_2t_max;

Rt2_1t.L(t)= Rt2_2t_max;
Rt2_2t.L(t)= Rt2_2t_max;

Rt3_1t.L(t)= Rt3_2t_max;
Rt3_2t.L(t)= Rt3_2t_max;

Rt4_1t.L(t)= Rt4_2t_max;
Rt4_2t.L(t)= Rt4_2t_max;

Rt5_1t.L(t)= Rt5_2t_max;
Rt5_2t.L(t)= Rt5_2t_max;

Rt6_1t.L(t)= Rt6_2t_max;
Rt6_2t.L(t)= Rt6_2t_max;

Rt7_1t.L(t)= Rt7_2t_max;
Rt7_2t.L(t)= Rt7_2t_max;

Rt8_1t.L(t)= Rt8_2t_max;
Rt8_2t.L(t)= Rt8_2t_max;

Rt9_1t.L(t)= Rt9_3t_max;
Rt9_2t.L(t)= Rt9_3t_max;
Rt9_3t.L(t)= Rt9_3t_max;

Rt10_1t.L(t)= Rt10_4t_max;
Rt10_2t.L(t)= Rt10_4t_max;
Rt10_3t.L(t)= Rt10_4t_max;
Rt10_4t.L(t)= Rt10_4t_max;

Rt11_1t.L(t)= Rt11_5t_max;
Rt11_2t.L(t)= Rt11_5t_max;
Rt11_3t.L(t)= Rt11_5t_max;
Rt11_4t.L(t)= Rt11_5t_max;
Rt11_5t.L(t)= Rt11_5t_max;

Rt12_1t.L(t)= Rt12_3t_max;
Rt12_2t.L(t)= Rt12_3t_max;
Rt12_3t.L(t)= Rt12_3t_max;

Rt13_1t.L(t)= Rt13_2t_max;
Rt13_2t.L(t)= Rt13_2t_max;
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Rt21_1t.L(t)= Rt21_4t_max;
Rt21_2t.L(t)= Rt21_4t_max;
Rt21_3t.L(t)= Rt21_4t_max;
Rt21_4t.L(t)= Rt21_4t_max;

Rt22_1t.L(t)= Rt22_3t_max;
Rt22_2t.L(t)= Rt22_3t_max;
Rt22_3t.L(t)= Rt22_3t_max;

Rt25_1t.L(t)= Rt25_2t_max;
Rt25_2t.L(t)= Rt25_2t_max;

Rt26_1t.L(t)= Rt26_2t_max;
Rt26_2t.L(t)= Rt26_2t_max;

Rt27_1t.L(t)= Rt27_2t_max;
Rt27_2t.L(t)= Rt27_2t_max;

Rt28_1t.L(t)= Rt28_6t_max;
Rt28_2t.L(t)= Rt28_6t_max;
Rt28_3t.L(t)= Rt28_6t_max;
Rt28_4t.L(t)= Rt28_6t_max;
Rt28_5t.L(t)= Rt28_6t_max;
Rt28_6t.L(t)= Rt28_6t_max;

VARIABLES
obj;

EQUATIONS
objective,

*Aysehatun Dam and HEPP
balance1(t), area1(t), level1(t), ave_level1(t), net_head1(t),
efficiency1_1t(t), efficiency1_2t(t), energy1(t),

*Kor Dam and HEPP
balance2(t), area2(t), level2(t), ave_level2(t), net_head2(t),
efficiency2_1t(t), efficiency2_2t(t), energy2(t),

*Garzan Dam and HEPP
balance3(t), min_release3(t), area3(t), level3(t), ave_level3(t),
net_head3(t), efficiency3_1t(t), efficiency3_2t(t), energy3(t),

*Guzeldere Dam and HEPP
balance4(t), area4(t), level4(t), ave_level4(t), net_head4(t),
efficiency4_1t(t), efficiency4_2t(t), energy4(t),

*Sirvan Dam and HEPP
balance5(t), area5(t), level5(t), ave_level5(t), net_head5(t),
efficiency5_1t(t), efficiency5_2t(t), energy5(t),

*Basoren Dam and HEPP
balance6(t), area6(t), level6(t), ave_level6(t), net_head6(t),
efficiency6_1t(t), efficiency6_2t(t), energy6(t),
min_releaseSWD(t),
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*Narli Dam and HEPP
balance7(t), area7(t), level7(t), ave_level7(t), net_head7(t),
efficiency7_1t(t), efficiency7_2t(t), energy7(t),

*Oran Dam and HEPP
balance8(t), area8(t), level8(t), ave_level8(t), net_head8(t),
efficiency8_1t(t), efficiency8_2t(t), energy8(t),

*Keskin Dam and HEPP
balance9(t), area9(t), level9(t), ave_level9(t), net_head9(t),
efficiency9_1t(t), efficiency9_2t(t), efficiency9_3t(t),
energy9(t),

*Pervari Dam and HEPP
balance10(t), area10(t), level10(t), ave_level10(t),
net_head10(t), efficiency10_1t(t), efficiency10_2t(t),
efficiency10_3t(t), efficiency10_4t(t), energy10(t),

*Cetin Dam and HEPP
balance11(t), area11(t), level11(t), ave_level11(t),
net_head11(t), efficiency11_1t(t), efficiency11_2t(t),
efficiency11_3t(t), efficiency11_4t(t), efficiency11_5t(t),
energy11(t),

*Alkumru Dam and HEPP
balance12(t), area12(t), level12(t), ave_level12(t),
net_head12(t), efficiency12_1t(t), efficiency12_2t(t),
efficiency12_3t(t), energy12(t),

*Eruh Dam and HEPP
balance13(t), area13(t), level13(t), ave_level13(t),
net_head13(t), efficiency13_1t(t), efficiency13_2t(t),
energy13(t),

*Anbar Dam
balance14(t), area14(t),

*Kurucay Dam
balance15(t), area15(t),

*Pamukcay Dam
balance16(t), area16(t),

*Baslar Dam
balance17(t), area17(t),

*Bulaklidere Dam
balance18(t), area18(t),

*Kibris Dam
balance19(t), area19(t),

*Karacalar Dam
balance20(t), area20(t),
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*Silvan Dam and HEPP
balance21(t), area21(t), level21(t), ave_level21(t),
net_head21(t), efficiency21_1t(t), efficiency21_2t(t),
efficiency21_3t(t), efficiency21_4t(t), energy21(t),

*Batman Dam and HEPP
balance22(t), area22(t), level22(t), ave_level22(t),
net_head22(t), efficiency22_1t(t), efficiency22_2t(t),
efficiency22_3t(t), energy22(t),

*Ergani Dam
balance23(t), area23(t),

*Devegecidi Dam
balance24(t), area24(t),

*Dipni Dam and HEPP
balance25(t), area25(t), level25(t), ave_level25(t),
net_head25(t), efficiency25_1t(t), efficiency25_2t(t),
energy25(t),

*Kralkizi Dam and HEPP
balance26(t), area26(t), level26(t), ave_level26(t),
net_head26(t), efficiency26_1t(t), efficiency26_2t(t),
energy26(t),

*Dicle Dam and HEPP
balance27(t), area27(t), level27(t), ave_level27(t),
net_head27(t), efficiency27_1t(t), efficiency27_2t(t),
energy27(t),

*Ilisu Dam and HEPP
balance28(t), area28(t), level28(t), ave_level28(t),
net_head28(t), efficiency28_1t(t), efficiency28_2t(t),
efficiency28_3t(t), efficiency28_4t(t), efficiency28_5t(t),
efficiency28_6t(t), energy28(t);

objective.. obj =E= SUM(t,(eng1(t) + eng2(t) + eng3(t) + eng4(t) +
eng5(t) + eng6(t) + eng7(t) + eng8(t) + eng9(t) + eng10(t) +
eng11(t) + eng12(t) + eng13(t) + eng21(t) + eng22(t) + eng25(t) +
eng26(t) + eng27(t) + eng28(t)));

*Aysehatun Dam and HEPP
balance1(t).. S1(t) =E= beg_S1$(ord(t) EQ 1) + S1(t-1)$(ord(t) GT
1) + Q1(t) - Rt1_1t(t)  - Rt1_2t(t) - Rs1(t) - D1(t) - E1(t) *
(beg_A1$(ord(t) EQ 1) + A1(t-1)$(ord(t) GT 1));

area1(t).. A1(t) =E= -0.000000000010405 * S1(t)**2 +
0.030310742571682 * S1(t) + 5311009.03784554;

level1(t).. WL1(t) =E= -0.00000000000000005026 * S1(t)**2 +
0.0000001047779418573 * S1(t) + 1208.56628735606;

ave_level1(t).. AvWL1(t) =E= ((beg_WL1 $(ord(t) EQ 1) + WL1(t-
1)$(ord(t) GT 1)) + WL1(t)) / 2;

net_head1(t).. NtH1(t)=E= (AvWL1(t) - twe1) * 0.95 - ((Rt1_1t(t) /
(24 * day(t) * 3600)) + (Rt1_2t(t) / (24 * day(t) * 3600))) *
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((Rt1_1t(t) / (24 * day(t) * 3600)) + (Rt1_2t(t) / (24 * day(t) *
3600))) * flK1;

efficiency1_1t(t).. eff1_1t(t) =E= - (1.4849 * ((Rt1_1t(t) /
Rt1_2t_max)**6)) + (7.4008 * ((Rt1_1t(t) / Rt1_2t_max)**5)) -
(16.7253 * ((Rt1_1t(t) / Rt1_2t_max)**4)) + (20.2156 * ((Rt1_1t(t)
/ Rt1_2t_max)**3)) - (13.6479 * ((Rt1_1t(t) / Rt1_2t_max)**2)) +
(5.1611 * (Rt1_1t(t) / Rt1_2t_max));

efficiency1_2t(t).. eff1_2t(t) =E= - (1.4849 * ((Rt1_2t(t) /
Rt1_2t_max)**6)) + (7.4008 * ((Rt1_2t(t) / Rt1_2t_max)**5)) -
(16.7253 * ((Rt1_2t(t) / Rt1_2t_max)**4)) + (20.2156 * ((Rt1_2t(t)
/ Rt1_2t_max)**3)) - (13.6479 * ((Rt1_2t(t) / Rt1_2t_max)**2)) +
(5.1611 * (Rt1_2t(t) / Rt1_2t_max));

energy1(t).. eng1(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH1(t) * ((eff1_1t(t) * (Rt1_1t(t) / (24 * day(t) * 3600))) +
(eff1_2t(t) * (Rt1_2t(t) / (24 * day(t) * 3600))));

*Kor Dam and HEPP
balance2(t).. S2(t) =E= beg_S2$(ord(t) EQ 1) + S2(t-1)$(ord(t) GT
1) + Q2(t) - Rt2_1t(t) - Rt2_2t(t) - Rs2(t) - D2(t) - E2(t) *
(beg_A2$(ord(t) EQ 1) + A2(t-1)$(ord(t) GT 1)) + Rt1_1t(t) +
Rt1_2t(t) + Rs1(t) + D1(t);

area2(t).. A2(t) =E= 0.000000000285871 * S2(t)**2 +
0.011932486521108 * S2(t) + 542187.347991712;

level2(t).. WL2(t) =E= -0.000000000000011 * S2(t)**2 +
0.000001523717615 * S2(t) + 913.753068954999;

ave_level2(t).. AvWL2(t) =E= ((beg_WL2 $(ord(t) EQ 1) + WL2(t-
1)$(ord(t) GT 1)) + WL2(t)) / 2;

net_head2(t).. NtH2(t) =E= (AvWL2(t) - twe2) * 0.95 - ((Rt2_1t(t)
/ (24 * day(t) * 3600)) + (Rt2_2t(t) / (24 * day(t) * 3600))) *
((Rt2_1t(t) / (24 * day(t) * 3600)) + (Rt2_2t(t) / (24 * day(t) *
3600))) * flK2;

efficiency2_1t(t).. eff2_1t(t) =E= - (1.4849 * ((Rt2_1t(t) /
Rt2_2t_max)**6)) + (7.4008 * ((Rt2_1t(t) / Rt2_2t_max)**5)) -
(16.7253 * ((Rt2_1t(t) / Rt2_2t_max)**4)) + (20.2156 * ((Rt2_1t(t)
/ Rt2_2t_max)**3)) - (13.6479 * ((Rt2_1t(t) / Rt2_2t_max)**2)) +
(5.1611 * (Rt2_1t(t) / Rt2_2t_max));

efficiency2_2t(t).. eff2_2t(t) =E= - (1.4849 * ((Rt2_2t(t) /
Rt2_2t_max)**6)) + (7.4008 * ((Rt2_2t(t) / Rt2_2t_max)**5)) -
(16.7253 * ((Rt2_2t(t) / Rt2_2t_max)**4)) + (20.2156 * ((Rt2_2t(t)
/ Rt2_2t_max)**3)) - (13.6479 * ((Rt2_2t(t) / Rt2_2t_max)**2)) +
(5.1611 * (Rt2_2t(t) / Rt2_2t_max));

energy2(t).. eng2(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH2(t) * ((eff2_1t(t) * (Rt2_1t(t) / (24 * day(t) * 3600))) +
(eff2_2t(t) * (Rt2_2t(t) / (24 * day(t) * 3600))));

*Garzan Dam and HEPP
balance3(t).. S3(t) =E= beg_S3$(ord(t) EQ 1) + S3(t-1)$(ord(t) GT
1) + Q3(t) - Rt3_1t(t) - Rt3_2t(t) - Rs3(t) - D3(t) - E3(t) *
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```
(beg_A3$(ord(t) EQ 1) + A3(t-1)$(ord(t) GT 1)) + Rt2_1t(t) +
Rt2_2t(t) + Rs2(t) + D2(t);

min_release3(t).. Rt3_1t(t) + Rt3_2t(t) + Rs3(t) + D3(t) =G=
R3_min(t);

area3(t).. A3(t) =E= -0.00000000004851553382 * S3(t)**2 +
0.0281158312067894 * S3(t) + 676446.867711646;

level3(t).. WL3(t) =E= -0.000000000000000100122 * S3(t)**2 +
0.00000054974910801169 * S3(t) + 721.461681514073;

ave_level3(t).. AvWL3(t) =E= ((beg_WL3 $(ord(t) EQ 1) + WL3(t-
1)$(ord(t) GT 1)) + WL3(t)) / 2;

net_head3(t).. NtH3(t) =E= (AvWL3(t) - twe3) * 0.95 - ((Rt3_1t(t)
/ (24 * day(t) * 3600)) + (Rt3_2t(t) / (24 * day(t) * 3600))) *
((Rt3_1t(t) / (24 * day(t) * 3600)) + (Rt3_2t(t) / (24 * day(t) *
3600))) * flK3;

efficiency3_1t(t).. eff3_1t(t) =E= - (1.4849 * ((Rt3_1t(t) /
Rt3_2t_max)**6)) + (7.4008 * ((Rt3_1t(t) / Rt3_2t_max)**5)) -
(16.7253 * ((Rt3_1t(t) / Rt3_2t_max)**4)) + (20.2156 * ((Rt3_1t(t)
/ Rt3_2t_max)**3)) - (13.6479 * ((Rt3_1t(t) / Rt3_2t_max)**2)) +
(5.1611 * (Rt3_1t(t) / Rt3_2t_max));

efficiency3_2t(t).. eff3_2t(t) =E= - (1.4849 * ((Rt3_2t(t) /
Rt3_2t_max)**6)) + (7.4008 * ((Rt3_2t(t) / Rt3_2t_max)**5)) -
(16.7253 * ((Rt3_2t(t) / Rt3_2t_max)**4)) + (20.2156 * ((Rt3_2t(t)
/ Rt3_2t_max)**3)) - (13.6479 * ((Rt3_2t(t) / Rt3_2t_max)**2)) +
(5.1611 * (Rt3_2t(t) / Rt3_2t_max));

energy3(t).. eng3(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH3(t) * ((eff3_1t(t) * (Rt3_1t(t) / (24 * day(t) * 3600))) +
(eff3_2t(t) * (Rt3_2t(t) / (24 * day(t) * 3600))));

*Guzeldere Dam and HEPP
balance4(t).. S4(t) =E= beg_S4$(ord(t) EQ 1) + S4(t-1)$(ord(t) GT
1) + Q4(t) - Rt4_1t(t) - Rt4_2t(t) - Rs4(t) - D4(t) - E4(t) *
(beg_A4$(ord(t) EQ 1) + A4(t-1)$(ord(t) GT 1));

area4(t).. A4(t) =E= 0.00000000070914938797* S4(t)**2 +
0.0283167682444349 * S4(t) + 866387.569904218;

level4(t).. WL4(t) =E= -0.0000000000000000926947* S4(t)**2 +
0.00000097016482745947* S4(t) + 1695.24403408668;

ave_level4(t).. AvWL4(t) =E= ((beg_WL4 $(ord(t) EQ 1) + WL4(t-
1)$(ord(t) GT 1)) + WL4(t)) / 2;

net_head4(t).. NtH4(t)=E= (AvWL4(t) - twe4) * 0.95 - ((Rt4_1t(t) /
(24 * day(t) * 3600)) + (Rt4_2t(t) / (24 * day(t) * 3600))) *
((Rt4_1t(t) / (24 * day(t) * 3600)) + (Rt4_2t(t) / (24 * day(t) *
3600))) * flK4;

efficiency4_1t(t).. eff4_1t(t) =E= - (1.4849 * ((Rt4_1t(t) /
Rt4_2t_max)**6)) + (7.4008 * ((Rt4_1t(t) / Rt4_2t_max)**5)) -
(16.7253 * ((Rt4_1t(t) / Rt4_2t_max)**4)) + (20.2156 * ((Rt4_1t(t)
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/ Rt4_2t_max)**3)) - (13.6479 * ((Rt4_1t(t) / Rt4_2t_max)**2)) +
(5.1611 * (Rt4_1t(t) / Rt4_2t_max));

efficiency4_2t(t).. eff4_2t(t) =E= - (1.4849 * ((Rt4_2t(t) /
Rt4_2t_max)**6)) + (7.4008 * ((Rt4_2t(t) / Rt4_2t_max)**5)) -
(16.7253 * ((Rt4_2t(t)/Rt4_2t_max)**4)) + (20.2156 * ((Rt4_2t(t) /
Rt4_2t_max)**3)) - (13.6479 * ((Rt4_2t(t) / Rt4_2t_max)**2)) +
(5.1611 * (Rt4_2t(t) / Rt4_2t_max));

energy4(t).. eng4(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH4(t) * ((eff4_1t(t) * (Rt4_1t(t) / (24 * day(t) * 3600))) +
(eff4_2t(t) * (Rt4_2t(t) / (24 * day(t) * 3600))));

*Sirvan Dam and HEPP
balance5(t).. S5(t) =E= beg_S5$(ord(t) EQ 1) + S5(t-1)$(ord(t) GT
1) + Q5(t) - Rt5_1t(t) - Rt5_2t(t) - Rs5(t) - D5(t) - E5(t) *
(beg_A5$(ord(t) EQ 1) + A5(t-1)$(ord(t) GT 1)) + Rt4_1t(t) +
Rt4_2t(t) + Rs4(t) + D4(t) - TWD(t);

area5(t).. A5(t) =E= 0.00000000000000000003944434 * S5(t)**3 -
0.000000000360237356920209 * S5(t)**2 + 0.125888887152403 * S5(t)
- 5238775.78928351;

level5(t).. WL5(t) =E= -0.00000000000000011664 * S5(t)**2 +
0.000000161353058740052 * S5(t) + 640.703682061252;

ave_level5(t).. AvWL5(t) =E= ((beg_WL5 $(ord(t) EQ 1) + WL5(t-
1)$(ord(t) GT 1)) + WL5(t)) / 2;

net_head5(t).. NtH5(t) =E= (AvWL5(t) - twe5) * 0.95 - ((Rt5_1t(t)
/ (24 * day(t) * 3600)) + (Rt5_2t(t) / (24 * day(t) * 3600))) *
((Rt5_1t(t) / (24 * day(t) * 3600)) + (Rt5_2t(t) / (24 * day(t) *
3600))) * flK5;

efficiency5_1t(t).. eff5_1t(t) =E= - (1.4849 * ((Rt5_1t(t) /
Rt5_2t_max)**6)) + (7.4008 * ((Rt5_1t(t) / Rt5_2t_max)**5)) -
(16.7253 * ((Rt5_1t(t) / Rt5_2t_max)**4)) + (20.2156 * ((Rt5_1t(t)
/ Rt5_2t_max)**3)) - (13.6479 * ((Rt5_1t(t) / Rt5_2t_max)**2)) +
(5.1611 * (Rt5_1t(t) / Rt5_2t_max));

efficiency5_2t(t).. eff5_2t(t) =E= - (1.4849 * ((Rt5_2t(t) /
Rt5_2t_max)**6)) + (7.4008 * ((Rt5_2t(t) / Rt5_2t_max)**5)) -
(16.7253 * ((Rt5_2t(t) / Rt5_2t_max)**4)) + (20.2156 * ((Rt5_2t(t)
/ Rt5_2t_max)**3)) - (13.6479 * ((Rt5_2t(t) / Rt5_2t_max)**2)) +
(5.1611 * (Rt5_2t(t) / Rt5_2t_max));

energy5(t).. eng5(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH5(t) * ((eff5_1t(t) * (Rt5_1t(t) / (24 * day(t) * 3600))) +
(eff5_2t(t) * (Rt5_2t(t) / (24 * day(t) * 3600))));

*Basoren Dam and HEPP
balance6(t).. S6(t) =E= beg_S6$(ord(t) EQ 1) + S6(t-1)$(ord(t) GT
1) + Q6(t) - Rt6_1t(t) - Rt6_2t(t) - Rs6(t) - D6(t) - E6(t) *
(beg_A6$(ord(t) EQ 1) + A6(t-1)$(ord(t) GT 1));

area6(t).. A6(t) =E= -0.00000000068773641326 * S6(t)**2 +
0.0844113737854904 * S6(t) + 517393.052747439;
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level6(t).. WL6(t) =E= -0.0000000000000878115 * S6(t)**2 +
0.00000094615022471932 * S6(t) + 546.067806517902;

ave_level6(t).. AvWL6(t) =E= ((beg_WL6 $(ord(t) EQ 1) + WL6(t-
1)$(ord(t) GT 1)) + WL6(t)) / 2;

net_head6(t).. NtH6(t)=E= (AvWL6(t) - twe6) * 0.95 - ((Rt6_1t(t) /
(24 * day(t) * 3600)) + (Rt6_2t(t) / (24 * day(t) * 3600))) *
((Rt6_1t(t) / (24 * day(t) * 3600)) + (Rt6_2t(t) / (24 * day(t) *
3600))) * flK6;

efficiency6_1t(t).. eff6_1t(t) =E= - (1.4849 * ((Rt6_1t(t) /
Rt6_2t_max)**6)) + (7.4008 * ((Rt6_1t(t) / Rt6_2t_max)**5)) -
(16.7253 * ((Rt6_1t(t) / Rt6_2t_max)**4)) + (20.2156 * ((Rt6_1t(t)
/ Rt6_2t_max)**3)) - (13.6479 * ((Rt6_1t(t) / Rt6_2t_max)**2)) +
(5.1611 * (Rt6_1t(t) / Rt6_2t_max));

efficiency6_2t(t).. eff6_2t(t) =E= - (1.4849 * ((Rt6_2t(t) /
Rt6_2t_max)**6)) + (7.4008 * ((Rt6_2t(t) / Rt6_2t_max)**5)) -
(16.7253 * ((Rt6_2t(t) / Rt6_2t_max)**4)) + (20.2156 * ((Rt6_2t(t)
/ Rt6_2t_max)**3)) - (13.6479 * ((Rt6_2t(t) / Rt6_2t_max)**2)) +
(5.1611 * (Rt6_2t(t) / Rt6_2t_max));

energy6(t).. eng6(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH6(t) * ((eff6_1t(t) * (Rt6_1t(t) / (24 * day(t) * 3600))) +
(eff6_2t(t) * (Rt6_2t(t) / (24 * day(t) * 3600))));

min_releaseSWD(t).. Rt5_1t(t) + Rt5_2t(t) + Rs5(t) + D5(t) +
Rt6_1t(t) + Rt6_2t(t) + Rs6(t) + D6(t) =G= SWD(t);

*Narli Dam and HEPP
balance7(t).. S7(t) =E= beg_S7$(ord(t) EQ 1) + S7(t-1)$(ord(t) GT
1) + Q7(t) - Rt7_1t(t) - Rt7_2t(t) - Rs7(t) - D7(t) - E7(t) *
(beg_A7$(ord(t) EQ 1) + A7(t-1)$(ord(t) GT 1));

area7(t).. A7(t) =E= -0.00000000014752816534 * S7(t)**2 +
0.03813514196672350000 * S7(t) + 194569.54853835;

level7(t).. WL7(t) =E= -0.0000000000000575896 * S7(t)**2 +
0.00000117382450668088 * S7(t) + 1317.33250628358;

ave_level7(t).. AvWL7(t) =E= ((beg_WL7 $(ord(t) EQ 1) + WL7(t-
1)$(ord(t) GT 1)) + WL7(t)) / 2;

net_head7(t).. NtH7(t)=E= (AvWL7(t) - twe7) * 0.95 - ((Rt7_1t(t) /
(24 * day(t) * 3600)) + (Rt7_2t(t) / (24 * day(t) * 3600))) *
((Rt7_1t(t) / (24 * day(t) * 3600)) + (Rt7_2t(t) / (24 * day(t) *
3600))) * flK7;

efficiency7_1t(t).. eff7_1t(t) =E= - (1.4849 * ((Rt7_1t(t) /
Rt7_2t_max)**6)) + (7.4008 * ((Rt7_1t(t) / Rt7_2t_max)**5)) -
(16.7253 * ((Rt7_1t(t) / Rt7_2t_max)**4)) + (20.2156 * ((Rt7_1t(t)
/ Rt7_2t_max)**3)) - (13.6479 * ((Rt7_1t(t) / Rt7_2t_max)**2)) +
(5.1611 * (Rt7_1t(t) / Rt7_2t_max));

efficiency7_2t(t).. eff7_2t(t) =E= - (1.4849 * ((Rt7_2t(t) /
Rt7_2t_max)**6)) + (7.4008 * ((Rt7_2t(t) / Rt7_2t_max)**5)) -
(16.7253 * ((Rt7_2t(t) / Rt7_2t_max)**4)) + (20.2156 *
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((Rt7_2t(t)/ Rt7_2t_max)**3)) - (13.6479 * ((Rt7_2t(t) /
Rt7_2t_max)**2)) + (5.1611 * (Rt7_2t(t) / Rt7_2t_max));

energy7(t).. eng7(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH7(t) * ((eff7_1t(t) * (Rt7_1t(t) / (24 * day(t) * 3600))) +
(eff7_2t(t) * (Rt7_2t(t) / (24 * day(t) * 3600))));

*Oran Dam and HEPP
balance8(t).. S8(t) =E= beg_S8$(ord(t) EQ 1) + S8(t-1)$(ord(t) GT
1) + Q8(t) - Rt8_1t(t) - Rt8_2t(t) - Rs8(t) - D8(t) - E8(t) *
(beg_A8$(ord(t) EQ 1) + A8(t-1)$(ord(t) GT 1)) + Rt7_1t(t) +
Rt7_2t(t) + Rs7(t) + D7(t);

area8(t).. A8(t) =E= -0.000000000000912024038 * S8(t)**2 +
0.0298598482442959 * S8(t) + 224018.558801985;

level8(t).. WL8(t) =E= -0.000000000000000734449 * S8(t)**2 +
0.00000133510205382715 * S8(t) + 1224.87380144661;

ave_level8(t).. AvWL8(t) =E= ((beg_WL8 $(ord(t) EQ 1) + WL8(t-
1)$(ord(t) GT 1)) + WL8(t)) / 2;

net_head8(t).. NtH8(t) =E= (AvWL8(t) - twe8) * 0.95 - ((Rt8_1t(t)
/ (24 * day(t) * 3600)) + (Rt8_2t(t) / (24 * day(t) * 3600))) *
((Rt8_1t(t) / (24 * day(t) * 3600)) + (Rt8_2t(t) / (24 * day(t) *
3600))) * flK8;

efficiency8_1t(t).. eff8_1t(t) =E= - (1.4849 * ((Rt8_1t(t) /
Rt8_2t_max)**6)) + (7.4008 * ((Rt8_1t(t) / Rt8_2t_max)**5)) -
(16.7253 * ((Rt8_1t(t) / Rt8_2t_max)**4)) + (20.2156 * ((Rt8_1t(t)
/ Rt8_2t_max)**3)) - (13.6479 * ((Rt8_1t(t) / Rt8_2t_max)**2)) +
(5.1611 * (Rt8_1t(t) / Rt8_2t_max));

efficiency8_2t(t).. eff8_2t(t) =E= - (1.4849 * ((Rt8_2t(t) /
Rt8_2t_max)**6)) + (7.4008 * ((Rt8_2t(t) / Rt8_2t_max)**5)) -
(16.7253 * ((Rt8_2t(t) / Rt8_2t_max)**4)) + (20.2156 * ((Rt8_2t(t)
/ Rt8_2t_max)**3)) - (13.6479 * ((Rt8_2t(t) / Rt8_2t_max)**2)) +
(5.1611 * (Rt8_2t(t) / Rt8_2t_max));

energy8(t).. eng8(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH8(t) * ((eff8_1t(t) * (Rt8_1t(t) / (24 * day(t) * 3600))) +
(eff8_2t(t) * (Rt8_2t(t) / (24 * day(t) * 3600))));

*Keskin Dam and HEPP
balance9(t).. S9(t) =E= beg_S9$(ord(t) EQ 1) + S9(t-1)$(ord(t) GT
1) + Q9(t) - Rt9_1t(t) - Rt9_2t(t) - Rt9_3t(t) - Rs9(t) - D9(t) -
E9(t) * (beg_A9$(ord(t) EQ 1) + A9(t-1)$(ord(t) GT 1)) + Rt8_1t(t)
+ Rt8_2t(t) + Rs8(t) + D8(t);

area9(t).. A9(t) =E= -0.000000000002464184466 * S9(t)**2 +
0.0296284465913661 * S9(t) - 1103325.02966546;

level9(t).. WL9(t) =E= -0.000000000000000043103 * S9(t)**2 +
0.00000043915579660186 * S9(t) + 1077.74944598635;

ave_level9(t).. AvWL9(t) =E= ((beg_WL9 $(ord(t) EQ 1) + WL9(t-
1)$(ord(t) GT 1)) + WL9(t)) / 2;
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net_head9(t).. NtH9(t) =E= (AvWL9(t) - twe9) * 0.95 - ((Rt9_1t(t)
/ (24 * day(t) * 3600)) + (Rt9_2t(t) / (24 * day(t) * 3600)) +
(Rt9_3t(t) / (24 * day(t) * 3600))) * ((Rt9_1t(t) / (24 * day(t) *
3600)) + (Rt9_2t(t) / (24 * day(t) * 3600)) + (Rt9_3t(t) / (24 *
day(t) * 3600))) * flK9;

efficiency9_1t(t).. eff9_1t(t) =E= - (1.4849 * ((Rt9_1t(t) /
Rt9_3t_max)**6)) + (7.4008 * ((Rt9_1t(t) / Rt9_3t_max)**5)) -
(16.7253 * ((Rt9_1t(t) / Rt9_3t_max)**4)) + (20.2156 * ((Rt9_1t(t)
/ Rt9_3t_max)**3)) - (13.6479 * ((Rt9_1t(t) / Rt9_3t_max)**2)) +
(5.1611 * (Rt9_1t(t) / Rt9_3t_max));

efficiency9_2t(t).. eff9_2t(t) =E= - (1.4849 * ((Rt9_2t(t) /
Rt9_3t_max)**6)) + (7.4008 * ((Rt9_2t(t) / Rt9_3t_max)**5)) -
(16.7253 * ((Rt9_2t(t) / Rt9_3t_max)**4)) + (20.2156 * ((Rt9_2t(t)
/ Rt9_3t_max)**3)) - (13.6479 * ((Rt9_2t(t) / Rt9_3t_max)**2)) +
(5.1611 * (Rt9_2t(t) / Rt9_3t_max));

efficiency9_3t(t).. eff9_3t(t) =E= - (1.4849 * ((Rt9_3t(t) /
Rt9_3t_max)**6)) + (7.4008 * ((Rt9_3t(t) / Rt9_3t_max)**5)) -
(16.7253 * ((Rt9_3t(t) / Rt9_3t_max)**4)) + (20.2156 * ((Rt9_3t(t)
/ Rt9_3t_max)**3)) - (13.6479 * ((Rt9_3t(t) / Rt9_3t_max)**2)) +
(5.1611 * (Rt9_3t(t) / Rt9_3t_max));

energy9(t).. eng9(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH9(t) * ((eff9_1t(t) * (Rt9_1t(t) / (24 * day(t) * 3600))) +
(eff9_2t(t) * (Rt9_2t(t) / (24 * day(t) * 3600))) + (eff9_3t(t) *
(Rt9_3t(t) / (24 * day(t) * 3600))));

*Pervari Dam and HEPP
balance10(t).. S10(t) =E= beg_S10$(ord(t) EQ 1) + S10(t-1)$(ord(t)
GT 1) + Q10(t) - Rt10_1t(t) - Rt10_2t(t) - Rt10_3t(t) - Rt10_4t(t)
- Rs10(t) - D10(t) - E10(t) * (beg_A10$(ord(t) EQ 1) + A10(t-
1)$(ord(t) GT 1)) + Rt9_1t(t) + Rt9_2t(t) + Rt9_3t(t) + Rs9(t) +
D9(t);

area10(t).. A10(t) =E= -0.00000000001954957843 * S10(t)**2 +
0.0176108160825508 * S10(t) + 623348.351988801;

level10(t).. WL10(t) =E= -0.000000000000000066174 * S10(t)**2 +
0.00000056213290537088 * S10(t) + 883.685020854896;

ave_level10(t).. AvWL10(t) =E= ((beg_WL10 $(ord(t) EQ 1) + WL10(t-
1)$(ord(t) GT 1)) + WL10(t)) / 2;

net_head10(t).. NtH10(t) =E= (AvWL10(t) - twe10) * 0.95 -
((Rt10_1t(t) / (24 * day(t) * 3600)) + (Rt10_2t(t) / (24 * day(t)
* 3600)) + (Rt10_3t(t) / (24 * day(t) * 3600)) + (Rt10_4t(t) / (24
* day(t) * 3600))) * ((Rt10_1t(t) /  (24 * day(t) * 3600)) +
(Rt10_2t(t) /  (24 * day(t) * 3600)) + (Rt10_3t(t) / (24 * day(t)
* 3600)) + (Rt10_4t(t) / (24 * day(t) * 3600))) * flK10;

efficiency10_1t(t).. eff10_1t(t) =E= - (1.4849 * ((Rt10_1t(t) /
Rt10_4t_max)**6)) + (7.4008 * ((Rt10_1t(t) / Rt10_4t_max)**5)) -
(16.7253 * ((Rt10_1t(t) / Rt10_4t_max)**4)) + (20.2156 *
((Rt10_1t(t) / Rt10_4t_max)**3)) - (13.6479 * ((Rt10_1t(t) /
Rt10_4t_max)**2)) + (5.1611 * (Rt10_1t(t) / Rt10_4t_max));
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efficiency10_2t(t).. eff10_2t(t) =E= - (1.4849 * ((Rt10_2t(t) /
Rt10_4t_max)**6)) + (7.4008 * ((Rt10_2t(t) / Rt10_4t_max)**5)) -
(16.7253 * ((Rt10_2t(t) / Rt10_4t_max)**4)) + (20.2156 *
((Rt10_2t(t) / Rt10_4t_max)**3)) - (13.6479 * ((Rt10_2t(t) /
Rt10_4t_max)**2)) + (5.1611 * (Rt10_2t(t) / Rt10_4t_max));

efficiency10_3t(t).. eff10_3t(t) =E= - (1.4849 * ((Rt10_3t(t) /
Rt10_4t_max)**6)) + (7.4008 * ((Rt10_3t(t) / Rt10_4t_max)**5)) -
(16.7253 * ((Rt10_3t(t) / Rt10_4t_max)**4)) + (20.2156 *
((Rt10_3t(t) / Rt10_4t_max)**3)) - (13.6479 * ((Rt10_3t(t) /
Rt10_4t_max)**2)) + (5.1611 * (Rt10_3t(t) / Rt10_4t_max));

efficiency10_4t(t).. eff10_4t(t) =E= - (1.4849 * ((Rt10_4t(t) /
Rt10_4t_max)**6)) + (7.4008 * ((Rt10_4t(t) / Rt10_4t_max)**5)) -
(16.7253 * ((Rt10_4t(t) / Rt10_4t_max)**4)) + (20.2156 *
((Rt10_4t(t) / Rt10_4t_max)**3)) - (13.6479 * ((Rt10_4t(t) /
Rt10_4t_max)**2)) + (5.1611 * (Rt10_4t(t) / Rt10_4t_max));

energy10(t).. eng10(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH10(t) * ((eff10_1t(t) * (Rt10_1t(t) / (24 * day(t) * 3600))) +
(eff10_2t(t) * (Rt10_2t(t) / (24 * day(t) * 3600))) + (eff10_3t(t)
* (Rt10_3t(t) / (24 * day(t) * 3600))) + (eff10_4t(t) *
(Rt10_4t(t) / (24 * day(t) * 3600))));

*Cetin Dam and HEPP
balance11(t).. S11(t) =E= beg_S11$(ord(t) EQ 1) + S11(t-1)$(ord(t)
GT 1) + Q11(t) - Rt11_1t(t) - Rt11_2t(t) - Rt11_3t(t) - Rt11_4t(t)
- Rt11_5t(t) - Rs11(t) - D11(t) - E11(t) * (beg_A11$(ord(t) EQ 1)
+ A11(t-1)$(ord(t) GT 1)) + Rt10_1t(t) + Rt10_2t(t) + Rt10_3t(t) +
Rt10_4t(t) + Rs10(t) + D10(t);

area11(t).. A11(t) =E= -0.00000000000530205205 * S11(t)**2 +
0.0184167689036022 * S11(t) + 1672445.27802706;

level11(t).. WL11(t) =E= -0.00000000000000011103 * S11(t)**2 +
0.00000021985326948785 * S11(t) + 729.56326722873;

ave_level11(t).. AvWL11(t) =E= ((beg_WL11 $(ord(t) EQ 1) + WL11(t-
1)$(ord(t) GT 1)) + WL11(t)) / 2;

net_head11(t).. NtH11(t) =E= (AvWL11(t) - twe11) * 0.95 -
((Rt11_1t(t) / (24 * day(t) * 3600)) + (Rt11_2t(t) / (24 * day(t)
* 3600)) + (Rt11_3t(t) / (24 * day(t) * 3600)) + (Rt11_4t(t) / (24
* day(t) * 3600)) + (Rt11_5t(t) / (24 * day(t) * 3600))) *
((Rt11_1t(t) /  (24 * day(t) * 3600)) + (Rt11_2t(t) /  (24 *
day(t) * 3600)) + (Rt11_3t(t) /  (24 * day(t) * 3600)) +
(Rt11_4t(t) / (24 * day(t) * 3600)) + (Rt11_5t(t) / (24 * day(t) *
3600))) * flK11;

efficiency11_1t(t).. eff11_1t(t) =E= - (1.4849 * ((Rt11_1t(t) /
Rt11_5t_max)**6)) + (7.4008 * ((Rt11_1t(t) / Rt11_5t_max)**5)) -
(16.7253 * ((Rt11_1t(t) / Rt11_5t_max)**4)) + (20.2156 *
((Rt11_1t(t) / Rt11_5t_max)**3)) - (13.6479 * ((Rt11_1t(t) /
Rt11_5t_max)**2)) + (5.1611 * (Rt11_1t(t) / Rt11_5t_max));

efficiency11_2t(t).. eff11_2t(t) =E= - (1.4849 * ((Rt11_2t(t) /
Rt11_5t_max)**6)) + (7.4008 * ((Rt11_2t(t) / Rt11_5t_max)**5)) -
(16.7253 * ((Rt11_2t(t) / Rt11_5t_max)**4)) + (20.2156 *
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((Rt11_2t(t) / Rt11_5t_max)**3)) - (13.6479 * ((Rt11_2t(t) /
Rt11_5t_max)**2)) + (5.1611 * (Rt11_2t(t) / Rt11_5t_max));

efficiency11_3t(t).. eff11_3t(t) =E= - (1.4849 * ((Rt11_3t(t) /
Rt11_5t_max)**6)) + (7.4008 * ((Rt11_3t(t) / Rt11_5t_max)**5)) -
(16.7253 * ((Rt11_3t(t) / Rt11_5t_max)**4)) + (20.2156 *
((Rt11_3t(t) / Rt11_5t_max)**3)) - (13.6479 * ((Rt11_3t(t) /
Rt11_5t_max)**2)) + (5.1611 * (Rt11_3t(t) / Rt11_5t_max));

efficiency11_4t(t).. eff11_4t(t) =E= - (1.4849 * ((Rt11_4t(t) /
Rt11_5t_max)**6)) + (7.4008 * ((Rt11_4t(t) / Rt11_5t_max)**5)) -
(16.7253 * ((Rt11_4t(t) / Rt11_5t_max)**4)) + (20.2156 *
((Rt11_4t(t) / Rt11_5t_max)**3)) - (13.6479 * ((Rt11_4t(t) /
Rt11_5t_max)**2)) + (5.1611 * (Rt11_4t(t) / Rt11_5t_max));

efficiency11_5t(t).. eff11_5t(t) =E= - (1.4849 * ((Rt11_5t(t) /
Rt11_5t_max)**6)) + (7.4008 * ((Rt11_5t(t) / Rt11_5t_max)**5)) -
(16.7253 * ((Rt11_5t(t) / Rt11_5t_max)**4)) + (20.2156 *
((Rt11_5t(t) / Rt11_5t_max)**3)) - (13.6479 * ((Rt11_5t(t) /
Rt11_5t_max)**2)) + (5.1611 * (Rt11_5t(t) / Rt11_5t_max));

energy11(t).. eng11(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH11(t) * ((eff11_1t(t) * (Rt11_1t(t) / (24 * day(t) * 3600))) +
(eff11_2t(t) * (Rt11_2t(t) / (24 * day(t) * 3600))) + (eff11_3t(t)
* (Rt11_3t(t) / (24 * day(t) * 3600))) + (eff11_4t(t) *
(Rt11_4t(t) / (24 * day(t) * 3600))) + (eff11_5t(t) * (Rt11_5t(t)
/ (24 * day(t) * 3600))));

*Alkumru Dam and HEPP
balance12(t).. S12(t) =E= beg_S12$(ord(t) EQ 1) + S12(t-1)$(ord(t)
GT 1) + Q12(t) - Rt12_1t(t) - Rt12_2t(t) - Rt12_3t(t) - Rs12(t) -
D12(t) - E12(t) * (beg_A12$(ord(t) EQ 1) + A12(t-1)$(ord(t) GT 1))
+ Rt11_1t(t) + Rt11_2t(t) + Rt11_3t(t) + Rt11_4t(t) + Rt11_5t(t) +
Rs11(t) + D11(t);

area12(t).. A12(t) =E= -0.00000000001559512673 * S12(t)**2 +
0.029354038716462 * S12(t) + 1200473.54745129;

level12(t).. WL12(t) =E= -0.00000000000000014861 * S12(t)**2 +
0.00000021219969217737 * S12(t) + 583.116482562263;

ave_level12(t).. AvWL12(t) =E= ((beg_WL12 $(ord(t) EQ 1) + WL12(t-
1)$(ord(t) GT 1)) + WL12(t)) / 2;

net_head12(t).. NtH12(t) =E= (AvWL12(t) - twe12) * 0.95 -
((Rt12_1t(t) / (24 * day(t) * 3600)) + (RT12_2t(t) / (24 * day(t)
* 3600)) + (Rt12_3t(t) / (24 * day(t) * 3600))) * ((Rt12_1t(t) /
(24 * day(t) * 3600)) + (Rt12_2t(t) / (24 * day(t) * 3600)) +
(Rt12_3t(t) / (24 * day(t) * 3600))) * flK12;

efficiency12_1t(t).. eff12_1t(t) =E= - (1.4849 * ((Rt12_1t(t) /
Rt12_3t_max)**6)) + (7.4008 * ((Rt12_1t(t) / Rt12_3t_max)**5)) -
(16.7253 * ((Rt12_1t(t) / Rt12_3t_max)**4)) + (20.2156 *
((Rt12_1t(t) / Rt12_3t_max)**3)) - (13.6479 * ((Rt12_1t(t) /
Rt12_3t_max)**2)) + (5.1611 * (Rt12_1t(t) / Rt12_3t_max));

efficiency12_2t(t).. eff12_2t(t) =E= - (1.4849 * ((Rt12_2t(t) /
Rt12_3t_max)**6)) + (7.4008 * ((Rt12_2t(t) / Rt12_3t_max)**5)) -
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(16.7253 * ((Rt12_2t(t) / Rt12_3t_max)**4)) + (20.2156 *
((Rt12_2t(t) / Rt12_3t_max)**3)) - (13.6479 * ((Rt12_2t(t) /
Rt12_3t_max)**2)) + (5.1611 * (Rt12_2t(t) / Rt12_3t_max));

efficiency12_3t(t).. eff12_3t(t) =E= - (1.4849 * ((Rt12_3t(t) /
Rt12_3t_max)**6)) + (7.4008 * ((Rt12_3t(t) / Rt12_3t_max)**5)) -
(16.7253 * ((Rt12_3t(t) / Rt12_3t_max)**4)) + (20.2156 *
((Rt12_3t(t) / Rt12_3t_max)**3)) - (13.6479 * ((Rt12_3t(t) /
Rt12_3t_max)**2)) + (5.1611 * (Rt12_3t(t) / Rt12_3t_max));

energy12(t).. eng12(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH12(t) * ((eff12_1t(t) * (Rt12_1t(t) / (24 * day(t) * 3600))) +
(eff12_2t(t) * (Rt12_2t(t) / (24 * day(t) * 3600))) + (eff12_3t(t)
* (Rt12_3t(t) / (24 * day(t) * 3600))));

*Eruh Dam and HEPP
balance13(t).. S13(t) =E= beg_S13$(ord(t) EQ 1) + S13(t-1)$(ord(t)
GT 1) + Q13(t) - Rt13_1t(t) - Rt13_2t(t) - Rs13(t) - D13(t) -
E13(t) * (beg_A13$(ord(t) EQ 1) + A13(t-1)$(ord(t) GT 1));

area13(t).. A13(t) =E= -0.00000000000000000031 * S13(t)**3 +
0.00000000006257948004 * S13(t)**2 + 0.0256815810607943 * S13(t) +
904149.720943853;

level13(t).. WL13(t) =E= 0.000000000000000000000000072 * S13(t)**3 -
0.0000000000000000036771574947 * S13(t)**2 + 0.000000792104901537661
* S13(t) + 699.494705801062;

ave_level13(t).. AvWL13(t) =E= ((beg_WL13 $(ord(t) EQ 1) + WL13(t-
1)$(ord(t) GT 1)) + WL13(t)) / 2;

net_head13(t).. NtH13(t)=E= (AvWL13(t) - twe13) * 0.95 -
((Rt13_1t(t) / (24 * day(t) * 3600)) + (Rt13_2t(t) / (24 * day(t)
* 3600))) * ((Rt13_1t(t) / (24 * day(t) * 3600)) + (Rt13_2t(t) /
(24 * day(t) * 3600))) * flK13;

efficiency13_1t(t).. eff13_1t(t) =E= - (1.4849 * ((Rt13_1t(t) /
Rt13_2t_max)**6)) + (7.4008 * ((Rt13_1t(t) / Rt13_2t_max)**5)) -
(16.7253 * ((Rt13_1t(t) / Rt13_2t_max)**4)) + (20.2156 *
((Rt13_1t(t) / Rt13_2t_max)**3)) - (13.6479 * ((Rt13_1t(t) /
Rt13_2t_max)**2)) + (5.1611 * (Rt13_1t(t) / Rt13_2t_max));

efficiency13_2t(t).. eff13_2t(t) =E= - (1.4849 * ((Rt13_2t(t) /
Rt13_2t_max)**6)) + (7.4008 * ((Rt13_2t(t) / Rt13_2t_max)**5)) -
(16.7253 * ((Rt13_2t(t) / Rt13_2t_max)**4)) + (20.2156 *
((Rt13_2t(t) / Rt13_2t_max)**3)) - (13.6479 * ((Rt13_2t(t) /
Rt13_2t_max)**2)) + (5.1611 * (Rt13_2t(t) / Rt13_2t_max));

energy13(t).. eng13(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH13(t) * ((eff13_1t(t) * (Rt13_1t(t) / (24 * day(t) * 3600))) +
(eff13_2t(t) * (Rt13_2t(t) / (24 * day(t) * 3600))));

*Anbar Dam
balance14(t).. S14(t) =E= beg_S14$(ord(t) EQ 1) + S14(t-1)$(ord(t)
GT 1) + Q14(t) + TS14(t) - Rs14(t) - D14(t) -E14(t) *
(beg_A14$(ord(t) EQ 1) + A14(t-1)$(ord(t) GT 1));
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area14(t).. A14(t) =E= 0.0560843838435812 * S14(t) +
1730692.05042449;

*Kurucay Dam
balance15(t).. S15(t) =E= beg_S15$(ord(t) EQ 1) + S15(t-1)$(ord(t)
GT 1) + Q15(t) + TS15(t) - Rs15(t) - D15(t) -E15(t) *
(beg_A15$(ord(t) EQ 1) + A15(t-1)$(ord(t) GT 1));

area15(t).. A15(t) =E= 0.0759275237273512 * S15(t) +
714616.048317515;

*Pamukcay Dam
balance16(t).. S16(t) =E= beg_S16$(ord(t) EQ 1) + S16(t-1)$(ord(t)
GT 1) + Q16(t) + TS16(t) - Rs16(t) - D16(t) - E16(t) *
(beg_A16$(ord(t) EQ 1) + A16(t-1)$(ord(t) GT 1));

area16(t).. A16(t) =E= 0.0786407766990291 * S16(t) +
553106.796116505;

*Baslar Dam
balance17(t).. S17(t) =E= beg_S17$(ord(t) EQ 1) + S17(t-1)$(ord(t)
GT 1) + Q17(t) + TS17(t) - Rs17(t) - D17(t) - E17(t) *
(beg_A17$(ord(t) EQ 1) + A17(t-1)$(ord(t) GT 1));

area17(t).. A17(t) =E= 0.0753392606457651 * S17(t) +
584955.545156761;

*Bulaklidere Dam
balance18(t).. S18(t) =E= beg_S18$(ord(t) EQ 1) + S18(t-1)$(ord(t)
GT 1) + Q18(t) + TS18(t) - Rs18(t) - D18(t) -E18(t) *
(beg_A18$(ord(t) EQ 1) + A18(t-1)$(ord(t) GT 1));

area18(t).. A18(t) =E= 0.0780885780885781 * S18(t) +
222587.412587413;

*Kibris Dam
balance19(t).. S19(t) =E= beg_S19$(ord(t) EQ 1) + S19(t-1)$(ord(t)
GT 1) + Q19(t) + TS19(t) - Rs19(t) - D19(t) - E19(t) *
(beg_A19$(ord(t) EQ 1) + A19(t-1)$(ord(t) GT 1));

area19(t).. A19(t) =E= 0.0927021696252465 * S19(t) +
199921.104536489;

*Karacalar Dam
balance20(t).. S20(t) =E= beg_S20$(ord(t) EQ 1) + S20(t-1)$(ord(t)
GT 1) + Q20(t) + TS20(t) - Rs20(t) - D20(t) -E20(t) *
(beg_A20$(ord(t) EQ 1) + A20(t-1)$(ord(t) GT 1));

area20(t).. A20(t) =E= 0.0609756097560976 * S20(t) +
236707.317073171;

*Silvan Dam and HEPP
balance21(t).. S21(t) =E= beg_S21$(ord(t) EQ 1) + S21(t-1)$(ord(t)
GT 1) + Q21(t) - Rt21_1t(t) - Rt21_2t(t) - Rt21_3t(t) -Rt21_4t(t)
- Rs21(t) - D21(t) - E21(t) * (beg_A21$(ord(t) EQ 1) + A21(t-
1)$(ord(t) GT 1)) - TS14(t) - TS15(t) - TS16(t) - TS17(t) -
TS18(t) - TS19(t) - TS20(t);
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area21(t).. A21(t) =E= -0.00000000000208879061 * S21(t)**2 +
0.0406598244727645 * S21(t) - 2947877.26530275;

level21(t).. WL21(t) =E= -0.0000000000000000045 * S21(t)**2 +
0.00000001169908645675 * S21(t) + 761.016155118528;

ave_level21(t).. AvWL21(t) =E= ((beg_WL21 $(ord(t) EQ 1) + WL21(t-
1)$(ord(t) GT 1)) + WL21(t)) / 2;

net_head21(t).. NtH21(t) =E= (AvWL21(t) - twe21) * 0.95 -
((Rt21_1t(t) / (24 * day(t) * 3600)) + (Rt21_2t(t) / (24 * day(t)
* 3600)) + (Rt21_3t(t) / (24 * day(t) * 3600)) + (Rt21_4t(t) / (24
* day(t) * 3600))) * ((Rt21_1t(t) /  (24 * day(t) * 3600)) +
(Rt21_2t(t) /  (24 * day(t) * 3600)) + (Rt21_3t(t) / (24 * day(t)
* 3600)) + (Rt21_4t(t) / (24 * day(t) * 3600))) * flK21;

efficiency21_1t(t).. eff21_1t(t) =E= - (1.4849 * ((Rt21_1t(t) /
Rt21_4t_max)**6)) + (7.4008 * ((Rt21_1t(t) / Rt21_4t_max)**5)) -
(16.7253 * ((Rt21_1t(t) / Rt21_4t_max)**4)) + (20.2156 *
((Rt21_1t(t) / Rt21_4t_max)**3)) - (13.6479 * ((Rt21_1t(t) /
Rt21_4t_max)**2)) + (5.1611 * (Rt21_1t(t) / Rt21_4t_max));

efficiency21_2t(t).. eff21_2t(t) =E= - (1.4849 * ((Rt21_2t(t) /
Rt21_4t_max)**6)) + (7.4008 * ((Rt21_2t(t) / Rt21_4t_max)**5)) -
(16.7253 * ((Rt21_2t(t) / Rt21_4t_max)**4)) + (20.2156 *
((Rt21_2t(t) / Rt21_4t_max)**3)) - (13.6479 * ((Rt21_2t(t) /
Rt21_4t_max)**2)) + (5.1611 * (Rt21_2t(t) / Rt21_4t_max));

efficiency21_3t(t).. eff21_3t(t) =E= - (1.4849 * ((Rt21_3t(t) /
Rt21_4t_max)**6)) + (7.4008 * ((Rt21_3t(t) / Rt21_4t_max)**5)) -
(16.7253 * ((Rt21_3t(t) / Rt21_4t_max)**4)) + (20.2156 *
((Rt21_3t(t) / Rt21_4t_max)**3)) - (13.6479 * ((Rt21_3t(t) /
Rt21_4t_max)**2)) + (5.1611 * (Rt21_3t(t) / Rt21_4t_max));

efficiency21_4t(t).. eff21_4t(t) =E= - (1.4849 * ((Rt21_4t(t) /
Rt21_4t_max)**6)) + (7.4008 * ((Rt21_4t(t) / Rt21_4t_max)**5)) -
(16.7253 * ((Rt21_4t(t) / Rt21_4t_max)**4)) + (20.2156 *
((Rt21_4t(t) / Rt21_4t_max)**3)) - (13.6479 * ((Rt21_4t(t) /
Rt21_4t_max)**2)) + (5.1611 * (Rt21_4t(t) / Rt21_4t_max));

energy21(t).. eng21(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH21(t) * ((eff21_1t(t) * (Rt21_1t(t) / (24 * day(t) * 3600))) +
(eff21_2t(t) * (Rt21_2t(t) / (24 * day(t) * 3600))) + (eff21_3t(t)
* (Rt21_3t(t) / (24 * day(t) * 3600))) + (eff21_4t(t) *
(Rt21_4t(t) / (24 * day(t) * 3600))));

*Batman Dam and HEPP
balance22(t).. S22(t) =E= beg_S22$(ord(t) EQ 1) + S22(t-1)$(ord(t)
GT 1) + Q22(t) - Rt22_1t(t) - Rt22_2t(t) - Rt22_3t(t) - Rs22(t) -
D22(t) - E22(t)*(beg_A22$(ord(t) EQ 1) + A22(t-1)$(ord(t) GT 1)) +
Rt21_1t(t) + Rt21_2t(t) + Rt21_3t(t) + Rt21_4t(t) +  Rs21(t);

area22(t).. A22(t) =E= -0.00000000001312912859 * S22(t)**2 +
0.0453475791841959 * S22(t) + 8442134.15596033;

level22(t).. WL22(t) =E= -0.0000000000000000864 * S22(t)**2 +
0.00000004315742428013 * S22(t) + 626.593036867525;
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ave_level22(t).. AvWL22(t) =E= ((beg_WL22 $(ord(t) EQ 1) + WL22(t-1)$(ord(t) GT 1)) + WL22(t)) / 2;

net_head22(t).. NtH22(t) =E= (AvWL22(t) - twe22) * 0.95 - ((Rt22_1t(t) / (24 * day(t) * 3600)) + (Rt22_2t(t) / (24 * day(t) * 3600)) + (Rt22_3t(t) / (24 * day(t) * 3600))) * ((Rt22_1t(t) / (24 * day(t) * 3600)) + (Rt22_2t(t) / (24 * day(t) * 3600)) + (Rt22_3t(t) / (24 * day(t) * 3600))) * flK22;

efficiency22_1t(t).. eff22_1t(t) =E= - (1.4849 * ((Rt22_1t(t) / Rt22_3t_max)**6)) + (7.4008 * ((Rt22_1t(t) / Rt22_3t_max)**5)) - (16.7253 * ((Rt22_1t(t) / Rt22_3t_max)**4)) + (20.2156 * ((Rt22_1t(t) / Rt22_3t_max)**3)) - (13.6479 * ((Rt22_1t(t) / Rt22_3t_max)**2)) + (5.1611 * (Rt22_1t(t) / Rt22_3t_max));

efficiency22_2t(t).. eff22_2t(t) =E= - (1.4849 * ((Rt22_2t(t) / Rt22_3t_max)**6)) + (7.4008 * ((Rt22_2t(t) / Rt22_3t_max)**5)) - (16.7253 * ((Rt22_2t(t) / Rt22_3t_max)**4)) + (20.2156 * ((Rt22_2t(t) / Rt22_3t_max)**3)) - (13.6479 * ((Rt22_2t(t) / Rt22_3t_max)**2)) + (5.1611 * (Rt22_2t(t) / Rt22_3t_max));

efficiency22_3t(t).. eff22_3t(t) =E= - (1.4849 * ((Rt22_3t(t) / Rt22_3t_max)**6)) + (7.4008 * ((Rt22_3t(t) / Rt22_3t_max)**5)) - (16.7253 * ((Rt22_3t(t) / Rt22_3t_max)**4)) + (20.2156 * ((Rt22_3t(t) / Rt22_3t_max)**3)) - (13.6479 * ((Rt22_3t(t) / Rt22_3t_max)**2)) + (5.1611 * (Rt22_3t(t) / Rt22_3t_max));

energy22(t).. eng22(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 * NtH22(t) * ((eff22_1t(t) * (Rt22_1t(t) / (24 * day(t) * 3600))) + (eff22_2t(t) * (Rt22_2t(t) / (24 * day(t) * 3600))) + (eff22_3t(t) * (Rt22_3t(t) / (24 * day(t) * 3600))));

*Ergani Dam
balance23(t).. S23(t) =E= beg_S23$(ord(t) EQ 1) + S23(t-1)$(ord(t) GT 1) + Q23(t) - Rs23(t) - D23(t) - E23(t) * (beg_A23$(ord(t) EQ 1) + A23(t-1)$(ord(t) GT 1));

area23(t).. A23(t) =E= -0.00000000185648984544 * S23(t)**2 + 0.0782686613259762 * S23(t) + 124704.070389418;

*Devegecidi Dam
balance24(t).. S24(t) =E= beg_S24$(ord(t) EQ 1) + S24(t-1)$(ord(t) GT 1) + Q24(t) - Rs24(t) - D24(t) - E24(t) * (beg_A23$(ord(t) EQ 1) + A24(t-1)$(ord(t) GT 1)) + Rs23(t) + D23(t) - EIRR(t);

area24(t).. A24(t) =E= 0.00000000000000000314 * S24(t)**3  - 0.00000000103957183719 * S24(t)**2 + 0.209440282696998 * S24(t) + 741696.440081436;

*Dipni Dam and HEPP
balance25(t).. S25(t) =E= beg_S25$(ord(t) EQ 1) + S25(t-1)$(ord(t) GT 1) + Q25(t) - Rt25_1t(t) - Rt25_2t(t) - Rs25(t) - D25(t) - E25(t) * (beg_A25$(ord(t) EQ 1) + A25(t-1)$(ord(t) GT 1));

area25(t).. A25(t) =E= 0.0000000000021857543 * S25(t)**2 + 0.00377189223608465 * S25(t) + 519327.912317403;
```

```
level25(t).. WL25(t) =E= -0.000000000000000003612 * S25(t)**2 +
0.0000000816067470211 9 * S25(t) + 804.974838099189;

ave_level25(t).. AvWL25(t) =E= ((beg_WL25 $(ord(t) EQ 1) + WL25(t-
1)$(ord(t) GT 1)) + WL25(t)) / 2;

net_head25(t).. NtH25(t)=E= (AvWL25(t) - twe25) * 0.95 -
((Rt25_1t(t) / (24 * day(t) * 3600)) + (Rt25_2t(t) / (24 * day(t)
* 3600))) * ((Rt25_1t(t) / (24 * day(t) * 3600)) + (Rt25_2t(t) /
(24 * day(t) * 3600))) * flK25;

efficiency25_1t(t).. eff25_1t(t) =E= - (1.4849 * ((Rt25_1t(t) /
Rt25_2t_max)**6)) + (7.4008 * ((Rt25_1t(t) / Rt25_2t_max)**5)) -
(16.7253 * ((Rt25_1t(t) / Rt25_2t_max)**4)) + (20.2156 *
((Rt25_1t(t) / Rt25_2t_max)**3)) - (13.6479 * ((Rt25_1t(t) /
Rt25_2t_max)**2)) + (5.1611 * (Rt25_1t(t) / Rt25_2t_max));

efficiency25_2t(t).. eff25_2t(t) =E= - (1.4849 * ((Rt25_2t(t) /
Rt25_2t_max)**6)) + (7.4008 * ((Rt25_2t(t) / Rt25_2t_max)**5)) -
(16.7253 * ((Rt25_2t(t) / Rt25_2t_max)**4)) + (20.2156 *
((Rt25_2t(t) / Rt25_2t_max)**3)) - (13.6479 * ((Rt25_2t(t) /
Rt25_2t_max)**2)) + (5.1611 * (Rt25_2t(t) / Rt25_2t_max));

energy25(t).. eng25(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH25(t) * ((eff25_1t(t) * (Rt25_1t(t) / (24 * day(t) * 3600))) +
(eff25_2t(t) * (Rt25_2t(t) / (24 * day(t) * 3600))));

*Kralkizi Dam and HEPP
balance26(t).. S26(t) =E= beg_S26$(ord(t) EQ 1) + S26(t-1)$(ord(t)
GT 1) + Q26(t) - Rt26_1t(t) - Rt26_2t(t) - Rs26(t) - D26(t) -
E26(t) * (beg_A26$(ord(t) EQ 1) + A26(t-1)$(ord(t) GT 1)) -
TS27(t);

area26(t).. A26(t) =E= -0.00000000001008501383 * S26(t)**2 +
0.0499258396986249 * S26(t) - 1326920.12221243;

level26(t).. WL26(t) =E= -0.000000000000000001175 * S26(t)**2 +
0.0000000555476256921 * S26(t) + 752.055480469782;

ave_level26(t).. AvWL26(t) =E= ((beg_WL26 $(ord(t) EQ 1) + WL26(t-
1)$(ord(t) GT 1)) + WL26(t)) / 2;

net_head26(t).. NtH26(t)=E= (AvWL26(t) - twe26) * 0.95 -
((Rt26_1t(t) / (24 * day(t) * 3600)) + (Rt26_2t(t) / (24 * day(t)
* 3600))) * ((Rt26_1t(t) / (24 * day(t) * 3600)) + (Rt26_2t(t) /
(24 * day(t) * 3600))) * flK26;

efficiency26_1t(t).. eff26_1t(t) =E= - (1.4849 * ((Rt26_1t(t) /
Rt26_2t_max)**6)) + (7.4008 * ((Rt26_1t(t) / Rt26_2t_max)**5)) -
(16.7253 * ((Rt26_1t(t) / Rt26_2t_max)**4)) + (20.2156 *
((Rt26_1t(t) / Rt26_2t_max)**3)) - (13.6479 * ((Rt26_1t(t) /
Rt26_2t_max)**2)) + (5.1611 * (Rt26_1t(t) / Rt26_2t_max));

efficiency26_2t(t).. eff26_2t(t) =E= - (1.4849 * ((Rt26_2t(t) /
Rt26_2t_max)**6)) + (7.4008 * ((Rt26_2t(t) / Rt26_2t_max)**5)) -
(16.7253 * ((Rt26_2t(t) / Rt26_2t_max)**4)) + (20.2156 *
((Rt26_2t(t) / Rt26_2t_max)**3)) - (13.6479 * ((Rt26_2t(t) /
Rt26_2t_max)**2)) + (5.1611 * (Rt26_2t(t) / Rt26_2t_max));
```

```
energy26(t).. eng26(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH26(t) * ((eff26_1t(t) * (Rt26_1t(t) / (24 * day(t) * 3600))) +
(eff26_2t(t) * (Rt26_2t(t) / (24 * day(t) * 3600))));

*Dicle Dam and HEPP
balance27(t).. S27(t) =E= beg_S27$(ord(t) EQ 1) + S27(t-1)$(ord(t)
GT 1) + Q27(t) - Rt27_1t(t) - Rt27_2t(t) - Rs27(t) - D27(t) -
E27(t) * (beg_A27$(ord(t) EQ 1) + A27(t-1)$(ord(t) GT 1)) +
Rt25_1t(t) + Rt25_2t(t) + Rs25(t) + D25(t) + Rt26_1t(t) +
Rt26_2t(t) + Rs26(t) + D26(t) + TS27(t);

area27(t).. A27(t) =E= 0.0257848272380862 * S27(t) +
8658027.79333876;

level27(t).. WL27(t) =E= 0.00000002941176470588 * S27(t) + 692.5;

ave_level27(t).. AvWL27(t) =E= ((beg_WL27 $(ord(t) EQ 1) + WL27(t-
1)$(ord(t) GT 1)) + WL27(t)) / 2;

net_head27(t).. NtH27(t)=E= (AvWL27(t) - twe27) * 0.95 -
((Rt27_1t(t) / (24 * day(t) * 3600)) + (Rt27_2t(t) / (24 * day(t)
* 3600))) * ((Rt27_1t(t) / (24 * day(t) * 3600)) + (Rt27_2t(t) /
(24 * day(t) * 3600))) * flK27;

efficiency27_1t(t).. eff27_1t(t) =E= - (1.4849 * ((Rt27_1t(t) /
Rt27_2t_max)**6)) + (7.4008 * ((Rt27_1t(t) / Rt27_2t_max)**5)) -
(16.7253 * ((Rt27_1t(t) / Rt27_2t_max)**4)) + (20.2156 *
((Rt27_1t(t) / Rt27_2t_max)**3)) - (13.6479 * ((Rt27_1t(t) /
Rt27_2t_max)**2)) + (5.1611 * (Rt27_1t(t) / Rt27_2t_max));

efficiency27_2t(t).. eff27_2t(t) =E= - (1.4849 * ((Rt27_2t(t) /
Rt27_2t_max)**6)) + (7.4008 * ((Rt27_2t(t) / Rt27_2t_max)**5)) -
(16.7253 * ((Rt27_2t(t) / Rt27_2t_max)**4)) + (20.2156 *
((Rt27_2t(t) / Rt27_2t_max)**3)) - (13.6479 * ((Rt27_2t(t) /
Rt27_2t_max)**2)) + (5.1611 * (Rt27_2t(t) / Rt27_2t_max));

energy27(t).. eng27(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH27(t) * ((eff27_1t(t) * (Rt27_1t(t) / (24 * day(t) * 3600))) +
(eff27_2t(t) * (Rt27_2t(t) / (24 * day(t) * 3600))));

*Ilisu Dam and HEPP
balance28(t).. S28(t) =E= beg_S28$(ord(t) EQ 1) + S28(t-1)$(ord(t)
GT 1) + Q28(t) - Rt28_1t(t) - Rt28_2t(t) - Rt28_3t(t) - Rt28_4t(t)
- Rt28_5t(t) - Rt28_6t(t) - Rs28(t) - D28(t) - E28(t) *
(beg_A28$(ord(t) EQ 1) + A28(t-1)$(ord(t) GT 1)) + Rt3_1t(t) +
Rt3_2t(t) + Rs3(t) + D3(t) + Rt5_1t(t) + Rt5_2t(t) + Rs5(t) +
D5(t) + Rt6_1t(t) + Rt6_2t(t) + Rs6(t) + D6(t) + Rt12_1t(t) +
Rt12_2t(t) + Rt12_3t(t) + Rs12(t) + D12(t) + Rt13_1t(t) +
Rt13_2t(t) + Rs13(t) + D13(t) + Rs14(t) + D14(t) + Rs15(t) +
D15(t) + Rs16(t) + D16(t) + Rs17(t) + D17(t) + Rs18(t) + D18(t) +
Rs19(t) + D19(t) + Rs20(t) + D20(t) + Rt22_1t(t) + Rt22_2t(t) +
Rt22_3t(t) + Rs22(t) + D22(t) + D21(t) + Rs24(t) + D24(t) +
Rt27_1t(t) + Rt27_2t(t) + Rs27(t) + D27(t) - AHC(t);

area28(t).. A28(t) =E= 0.0000000000042621031 * S28(t)**2 +
0.020553538372832 * S28(t) + 45122073.8522646;
```

```
level28(t).. WL28(t) =E= -0.00000000000000000036 * S28(t)**2 +
0.00000001000685284339 * S28(t) + 458.007628499163;

ave_level28(t).. AvWL28(t) =E= ((beg_WL28 $(ord(t) EQ 1) + WL28(t-
1)$(ord(t) GT 1)) + WL28(t)) / 2;

net_head28(t).. NtH28(t) =E= (AvWL28(t) - twe28) * 0.95 -
((Rt28_1t(t) / (24 * day(t) * 3600)) + (Rt28_2t (t) / (24 * day(t)
* 3600)) + (Rt28_3t(t) / (24 * day(t) * 3600)) + (Rt28_4t(t) / (24
* day(t) * 3600)) + (Rt28_5t(t) / (24 * day(t) * 3600)) +
(Rt28_6t(t) / (24 * day(t) * 3600))) * ((Rt28_1t(t) /  (24 *
day(t) * 3600)) + (Rt28_2t(t) /  (24 * day(t) * 3600)) +
(Rt28_3t(t) /  (24 * day(t) * 3600)) + (Rt28_4t(t) / (24 * day(t)
* 3600)) + (Rt28_5t(t) / (24 * day(t) * 3600)) + (Rt28_6t(t) / (24
* day(t) * 3600))) * flK28;

efficiency28_1t(t).. eff28_1t(t) =E= - (1.4849 * ((Rt28_1t(t) /
Rt28_6t_max)**6)) + (7.4008 * ((Rt28_1t(t) / Rt28_6t_max)**5)) -
(16.7253 * ((Rt28_1t(t) / Rt28_6t_max)**4)) + (20.2156 *
((Rt28_1t(t) / Rt28_6t_max)**3)) - (13.6479 * ((Rt28_1t(t) /
Rt28_6t_max)**2)) + (5.1611 * (Rt28_1t(t) / Rt28_6t_max));

efficiency28_2t(t).. eff28_2t(t) =E= - (1.4849 * ((Rt28_2t(t) /
Rt28_6t_max)**6)) + (7.4008 * ((Rt28_2t(t) / Rt28_6t_max)**5)) -
(16.7253 * ((Rt28_2t(t) / Rt28_6t_max)**4)) + (20.2156 *
((Rt28_2t(t) / Rt28_6t_max)**3)) - (13.6479 * ((Rt28_2t(t) /
Rt28_6t_max)**2)) + (5.1611 * (Rt28_2t(t) / Rt28_6t_max));

efficiency28_3t(t).. eff28_3t(t) =E= - (1.4849 * ((Rt28_3t(t) /
Rt28_6t_max)**6)) + (7.4008 * ((Rt28_3t(t) / Rt28_6t_max)**5)) -
(16.7253 * ((Rt28_3t(t) / Rt28_6t_max)**4)) + (20.2156 *
((Rt28_3t(t) / Rt28_6t_max)**3)) - (13.6479 * ((Rt28_3t(t) /
Rt28_6t_max)**2)) + (5.1611 * (Rt28_3t(t) / Rt28_6t_max));

efficiency28_4t(t).. eff28_4t(t) =E= - (1.4849 * ((Rt28_4t(t) /
Rt28_6t_max)**6)) + (7.4008 * ((Rt28_4t(t) / Rt28_6t_max)**5)) -
(16.7253 * ((Rt28_4t(t) / Rt28_6t_max)**4)) + (20.2156 *
((Rt28_4t(t) / Rt28_6t_max)**3)) - (13.6479 * ((Rt28_4t(t) /
Rt28_6t_max)**2)) + (5.1611 * (Rt28_4t(t) / Rt28_6t_max));

efficiency28_5t(t).. eff28_5t(t) =E= - (1.4849 * ((Rt28_5t(t) /
Rt28_6t_max)**6)) + (7.4008 * ((Rt28_5t(t) / Rt28_6t_max)**5)) -
(16.7253 * ((Rt28_5t(t) / Rt28_6t_max)**4)) + (20.2156 *
((Rt28_5t(t) / Rt28_6t_max)**3)) - (13.6479 * ((Rt28_5t(t) /
Rt28_6t_max)**2)) + (5.1611 * (Rt28_5t(t) / Rt28_6t_max));

efficiency28_6t(t).. eff28_6t(t) =E= - (1.4849 * ((Rt28_6t(t) /
Rt28_6t_max)**6)) + (7.4008 * ((Rt28_6t(t) / Rt28_6t_max)**5)) -
(16.7253 * ((Rt28_6t(t) / Rt28_6t_max)**4)) + (20.2156 *
((Rt28_6t(t) / Rt28_6t_max)**3)) - (13.6479 * ((Rt28_6t(t) /
Rt28_6t_max)**2)) + (5.1611 * (Rt28_6t(t) / Rt28_6t_max));

energy28(t).. eng28(t) =E= 0.985 * 0.975 * 24 * day(t) * 9.81 *
NtH28(t) * ((eff28_1t(t) * (Rt28_1t(t) / (24 * day(t) * 3600))) +
(eff28_2t(t) * (Rt28_2t(t) / (24 * day(t) * 3600))) + (eff28_3t(t)
* (Rt28_3t(t) / (24 * day(t) * 3600))) + (eff28_4t(t) *
(Rt28_4t(t) / (24 * day(t) * 3600))) + (eff28_5t(t) * (Rt28_5t(t)
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/ (24 * day(t) * 3600))) + (eff28_6t(t) * (Rt28_6t(t) / (24 *
day(t) * 3600))));

OPTION ITERLIM= 100000000;
OPTION OPTCR= 0.0000000000000000000000001;
OPTION LIMROW= 12;
OPTION nlp = minos5;

MODEL Tigris_ES / ALL /;
SOLVE Tigris_ES USING NLP MAXIMIZING obj;

PARAMETER
pwr1(t), pwr2(t), pwr3(t), pwr4(t), pwr5(t), pwr6(t), pwr7(t),
pwr8(t), pwr9(t), pwr10(t), pwr11(t), pwr12(t), pwr13(t),
pwr21(t), pwr22(t), pwr25(t), pwr26(t), pwr27(t), pwr28(t);

pwr1(t) = 9.81 * NtH1.L(t) * ((eff1_1t.L(t) * (Rt1_1t.L(t) / (24 *
day(t) * 3600))) + (eff1_2t.L(t) * (Rt1_2t.L(t) / (24 * day(t) *
3600))));

pwr2(t) = 9.81 * NtH2.L(t) * ((eff2_1t.L(t) * (Rt2_1t.L(t) / (24 *
day(t) * 3600))) + (eff2_2t.L(t) * (Rt2_2t.L(t) / (24 * day(t) *
3600))));

pwr3(t) = 9.81 * NtH3.L(t) * ((eff3_1t.L(t) * (Rt3_1t.L(t) / (24 *
day(t) * 3600))) + (eff3_2t.L(t) * (Rt3_2t.L(t) / (24 * day(t) *
3600))));

pwr4(t) = 9.81 * NtH4.L(t) * ((eff4_1t.L(t) * (Rt4_1t.L(t) / (24 *
day(t) * 3600))) + (eff4_2t.L(t) * (Rt4_2t.L(t) / (24 * day(t) *
3600))));

pwr5(t) = 9.81 * NtH5.L(t) * ((eff5_1t.L(t) * (Rt5_1t.L(t) / (24 *
day(t) * 3600))) + (eff5_2t.L(t) * (Rt5_2t.L(t) / (24 * day(t) *
3600))));

pwr6(t) = 9.81 * NtH6.L(t) * ((eff6_1t.L(t) * (Rt6_1t.L(t) / (24 *
day(t) * 3600))) + (eff6_2t.L(t) * (Rt6_2t.L(t) / (24 * day(t) *
3600))));

pwr7(t) = 9.81 * NtH7.L(t) * ((eff7_1t.L(t) * (Rt7_1t.L(t) / (24 *
day(t) * 3600))) + (eff7_2t.L(t) * (Rt7_2t.L(t) / (24 * day(t) *
3600))));

pwr8(t) = 9.81 * NtH8.L(t) * ((eff8_1t.L(t) * (Rt8_1t.L(t) / (24 *
day(t) * 3600))) + (eff8_2t.L(t) * (Rt8_2t.L(t) / (24 * day(t) *
3600))));

pwr9(t) = 9.81 * NtH9.L(t) * ((eff9_1t.L(t) * (Rt9_1t.L(t) / (24 *
day(t) * 3600))) + (eff9_2t.L(t) * (Rt9_2t.L(t) / (24 * day(t) *
3600))) + (eff9_3t.L(t) * (Rt9_3t.L(t) / (24 * day(t) * 3600))));

pwr10(t) = 9.81 * NtH10.L(t) * ((eff10_1t.L(t) * (Rt10_1t.L(t) /
(24 * day(t) * 3600))) + (eff10_2t.L(t) * (Rt10_2t.L(t) / (24 *
day(t) * 3600))) + (eff10_3t.L(t) * (Rt10_3t.L(t) / (24 * day(t) *
3600))) + (eff10_4t.L(t) * (Rt10_4t.L(t) / (24 * day(t) *
3600))));
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pwr11(t) = 9.81 * NtH11.L(t) * ((eff11_1t.L(t) * (Rt11_1t.L(t) /
(24 * day(t) * 3600))) + (eff11_2t.L(t) * (Rt11_2t.L(t) / (24 *
day(t) * 3600))) + (eff11_3t.L(t) * (Rt11_3t.L(t) / (24 * day(t) *
3600))) + (eff11_4t.L(t) * (Rt11_4t.L(t) / (24 * day(t) * 3600)))
+ (eff11_5t.L(t) * (Rt11_5t.L(t) / (24 * day(t) * 3600))));

pwr12(t) = 9.81 * NtH12.L(t) * ((eff12_1t.L(t) * (Rt12_1t.L(t) /
(24 * day(t) * 3600))) + (eff12_2t.L(t) * (Rt12_2t.L(t) / (24 *
day(t) * 3600))) + (eff12_3t.L(t) * (Rt12_3t.L(t) / (24 * day(t) *
3600))));

pwr13(t) = 9.81 * NtH13.L(t) * ((eff13_1t.L(t) * (Rt13_1t.L(t) /
(24 * day(t) * 3600))) + (eff13_2t.L(t) * (Rt13_2t.L(t) / (24 *
day(t) * 3600))));

pwr21(t) = 9.81 * NtH21.L(t) * ((eff21_1t.L(t) * (Rt21_1t.L(t) /
(24 * day(t) * 3600))) + (eff21_2t.L(t) * (Rt21_2t.L(t) / (24 *
day(t) * 3600))) + (eff21_3t.L(t) * (Rt21_3t.L(t) / (24 * day(t) *
3600))) + (eff21_4t.L(t) * (Rt21_4t.L(t) / (24 * day(t) *
3600))));

pwr22(t) = 9.81 * NtH22.L(t) * ((eff22_1t.L(t) * (Rt22_1t.L(t) /
(24 * day(t) * 3600))) + (eff22_2t.L(t) * (Rt22_2t.L(t) / (24 *
day(t) * 3600))) + (eff22_3t.L(t) * (Rt22_3t.L(t) / (24 * day(t) *
3600))));

pwr25(t) = 9.81 * NtH25.L(t) * ((eff25_1t.L(t) * (Rt25_1t.L(t) /
(24 * day(t) * 3600))) + (eff25_2t.L(t) * (Rt25_2t.L(t) / (24 *
day(t) * 3600))));

pwr26(t) = 9.81 * NtH26.L(t) * ((eff26_1t.L(t) * (Rt26_1t.L(t) /
(24 * day(t) * 3600))) + (eff26_2t.L(t) * (Rt26_2t.L(t) / (24 *
day(t) * 3600))));

pwr27(t) = 9.81 * NtH27.L(t) * ((eff27_1t.L(t) * (Rt27_1t.L(t) /
(24 * day(t) * 3600))) + (eff27_2t.L(t) * (Rt27_2t.L(t) / (24 *
day(t) * 3600))));

pwr28(t) = 9.81 * NtH28.L(t) * ((eff28_1t.L(t) * (Rt28_1t.L(t) /
(24 * day(t) * 3600))) + (eff28_2t.L(t) * (Rt28_2t.L(t) / (24 *
day(t) * 3600))) + (eff28_3t.L(t) * (Rt28_3t.L(t) / (24 * day(t) *
3600))) + (eff28_4t.L(t) * (Rt28_4t.L(t) / (24 * day(t) * 3600)))
+ (eff28_5t.L(t) * (Rt28_5t.L(t) / (24 * day(t) * 3600))) +
(eff28_6t.L(t) * (Rt28_6t.L(t) / (24 * day(t) * 3600))));

FILE res /TigrisES.txt/;
PUT res

PUT "Aysehatun Dam and HEPP"/;
PUT " t    day(t)    S1(t)    A1(t)    WL1(t)    Q1(t)    D1(t)    E1(t)
Rt1_1t(t)    Rt1_2t(t)    Rs1(t)    AvWL1(t)    NtH1(t)    eff1_1t(t)
eff1_2t(t)    pwr1(t)    eng1(t)"/;
PUT "t0","     --   ", beg_S1, beg_A1, beg_WL1/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S1.L(t):13.2, A1.L(t):13.2,
WL1.L(t):13.2, Q1(t):13.2, D1(t):13.2, E1(t):13.2,
Rt1_1t.L(t):13.2, Rt1_2t.L(t):13.2, Rs1.L(t):13.2,
AvWL1.L(t):13.2, NtH1.L(t):13.2, eff1_1t.L(t):13.2,
eff1_2t.L(t):13.2, pwr1(t):13.2, eng1.L(t):13.2/;);
```

```
PUT "         "/;

PUT "Kor Dam and HEPP"/;
PUT " t   day(t)   S2(t)   A2(t)   WL2(t)   Q2(t)   D2(t)   E2(t)
Rt2_1t(t)   Rt2_2t(t)   Rs2(t)   AvWL2(t)   NtH2(t)   eff2_1t(t)
eff2_2t(t)   pwr2(t)   eng2(t)"/;
PUT "t0","      --   ", beg_S2, beg_A2, beg_WL2/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S2.L(t):13.2, A2.L(t):13.2,
WL2.L(t):13.2, Q2(t):13.2, D2(t):13.2, E2(t):13.2,
Rt2_1t.L(t):13.2, Rt2_2t.L(t):13.2, Rs2.L(t):13.2,
AvWL2.L(t):13.2, NtH2.L(t):13.2, eff2_1t.L(t):13.2,
eff2_2t.L(t):13.2, pwr2(t):13.2, eng2.L(t):13.2/;);

PUT "         "/;

PUT "Garzan Dam and HEPP"/;
PUT " t   day(t)   S3(t)   A3(t)   WL3(t)   Q3(t)   D3(t)   E3(t)
Rt3_1t(t)   Rt3_2t(t)   Rs3(t)   AvWL3(t)   NtH3(t)   eff3_1t(t)
eff3_2t(t)   pwr3(t)   eng3(t)"/;
PUT "t0","      --   ", beg_S3, beg_A3, beg_WL3/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S3.L(t):13.2, A3.L(t):13.2,
WL3.L(t):13.2, Q3(t):13.2, D3(t):13.2, E3(t):13.2,
Rt3_1t.L(t):13.2, Rt3_2t.L(t):13.2, Rs3.L(t):13.2,
AvWL3.L(t):13.2, NtH3.L(t):13.2, eff3_1t.L(t):13.2,
eff3_2t.L(t):13.2, pwr3(t):13.2, eng3.L(t):13.2/;);

PUT "         "/;

PUT "Guzeldere Dam and HEPP"/;
PUT " t   day(t)   S4(t)   A4(t)   WL4(t)   Q4(t)   D4(t)   E4(t)
Rt4_1t(t)   Rt4_2t(t)   Rs4(t)   AvWL4(t)   NtH4(t)   eff4_1t(t)
eff4_2t(t)   pwr4(t)   eng4(t)"/;
PUT "t0","      --   ", beg_S4, beg_A4, beg_WL4/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S4.L(t):13.2, A4.L(t):13.2,
WL4.L(t):13.2, Q4(t):13.2, D4(t):13.2, E4(t):13.2,
Rt4_1t.L(t):13.2, Rt4_2t.L(t):13.2, Rs4.L(t):13.2,
AvWL4.L(t):13.2, NtH4.L(t):13.2, eff4_1t.L(t):13.2,
eff4_2t.L(t):13.2, pwr4(t):13.2, eng4.L(t):13.2/;);

PUT "         "/;

PUT "Sirvan Dam and HEPP"/;
PUT " t   day(t)   S5(t)   A5(t)   WL5(t)   Q5(t)   D5(t)   E5(t)
Rt5_1t(t)   Rt5_2t(t)   Rs5(t)   AvWL5(t)   NtH5(t)   eff5_1t(t)
eff5_2t(t)   pwr5(t)   eng5(t)"/;
PUT "t0","      --   ", beg_S5, beg_A5, beg_WL5/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S5.L(t):13.2, A5.L(t):13.2,
WL5.L(t):13.2, Q5(t):13.2, D5(t):13.2, E5(t):13.2,
Rt5_1t.L(t):13.2, Rt5_2t.L(t):13.2, Rs5.L(t):13.2,
AvWL5.L(t):13.2, NtH5.L(t):13.2, eff5_1t.L(t):13.2,
eff5_2t.L(t):13.2, pwr5(t):13.2, eng5.L(t):13.2/;);

PUT "         "/;

PUT "Basoren Dam and HEPP"/;
PUT " t   day(t)   S6(t)   A6(t)   WL6(t)   Q6(t)   D6(t)   E6(t)
Rt6_1t(t)   Rt6_2t(t)   Rs6(t)   AvWL6(t)   NtH6(t)   eff6_1t(t)
eff6_2t(t)   pwr6(t)   eng6(t)"/;
```

```
PUT "t0","      --  ", beg_S6, beg_A6, beg_WL6/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S6.L(t):13.2, A6.L(t):13.2,
WL6.L(t):13.2, Q6(t):13.2, D6(t):13.2, E6(t):13.2,
Rt6_1t.L(t):13.2, Rt6_2t.L(t):13.2, Rs6.L(t):13.2,
AvWL6.L(t):13.2, NtH6.L(t):13.2, eff6_1t.L(t):13.2,
eff6_2t.L(t):13.2, pwr6(t):13.2, eng6.L(t):13.2/;);

PUT "        "/;

PUT "Narli Dam and HEPP"/;
PUT " t   day(t)   S7(t)   A7(t)   WL7(t)   Q7(t)   D7(t)   E7(t)
Rt7_1t(t)   Rt7_2t(t)   Rs7(t)   AvWL7(t)   NtH7(t)   eff7_1t(t)
eff7_2t(t)   pwr7(t)   eng7(t)"/;
PUT "t0","      --  ", beg_S7, beg_A7, beg_WL7/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S7.L(t):13.2, A7.L(t):13.2,
WL7.L(t):13.2, Q7(t):13.2, D7(t):13.2, E7(t):13.2,
Rt7_1t.L(t):13.2, Rt7_2t.L(t):13.2, Rs7.L(t):13.2,
AvWL7.L(t):13.2, NtH7.L(t):13.2, eff7_1t.L(t):13.2,
eff7_2t.L(t):13.2, pwr7(t):13.2, eng7.L(t):13.2/;);

PUT "        "/;

PUT "Oran Dam and HEPP"/;
PUT " t   day(t)   S8(t)   A8(t)   WL8(t)   Q8(t)   D8(t)   E8(t)
Rt8_1t(t)   Rt8_2t(t)   Rs8(t)   AvWL8(t)   NtH8(t)   eff8_1t(t)
eff8_2t(t)   pwr8(t)   eng8(t)"/;
PUT "t0","      --  ", beg_S8, beg_A8, beg_WL8/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S8.L(t):13.2, A8.L(t):13.2,
WL8.L(t):13.2, Q8(t):13.2, D8(t):13.2, E8(t):13.2,
Rt8_1t.L(t):13.2, Rt8_2t.L(t):13.2, Rs8.L(t):13.2,
AvWL8.L(t):13.2, NtH8.L(t):13.2, eff8_1t.L(t):13.2,
eff8_2t.L(t):13.2, pwr8(t):13.2, eng8.L(t):13.2/;);

PUT "        "/;

PUT "Keskin Dam and HEPP (a)"/;
PUT " t   day(t)   S9(t)   A9(t)   WL9(t)   Q9(t)   D9(t)   E9(t)
Rt9_1t(t)   Rt9_2t(t)   Rt9_3t(t)   Rs9(t)"/;
PUT "t0","      --  ", beg_S9, beg_A9, beg_WL9/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S9.L(t):13.2, A9.L(t):13.2,
WL9.L(t):13.2, Q9(t):13.2, D9(t):13.2, E9(t):13.2,
Rt9_1t.L(t):13.2, Rt9_2t.L(t):13.2, Rt9_3t.L(t):13.2,
Rs9.L(t):13.2/;);

PUT "        "/;

PUT "Keskin Dam and HEPP (b)"/;
PUT " t   AvWL9(t)   NtH9(t)   eff9_1t(t)   eff9_2t(t)
eff9_3t(t)   pwr9(t)   eng9(t)"/;
LOOP(t,PUT t.TL:5, AvWL9.L(t):13.2, NtH9.L(t):13.2,
eff9_1t.L(t):13.2, eff9_2t.L(t):13.2, eff9_3t.L(t):13.2,
pwr9(t):13.2, eng9.L(t):13.2/;);

PUT "        "/;

PUT "Pervari Dam and HEPP (a)"/;
PUT " t   day(t)   S10(t)   A10(t)   WL10(t)   Q10(t)   D10(t)
E10(t)   Rt10_1t(t)   Rt10_2t(t)   Rt10_3t(t)   Rt10_4t(t)"/;
```

```
PUT "t0","      --  ", beg_S10, beg_A10, beg_WL10/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S10.L(t):13.2, A10.L(t):13.2,
WL10.L(t):13.2, Q10(t):13.2, D10(t):13.2, E10(t):13.2,
Rt10_1t.L(t):13.2, Rt10_2t.L(t):13.2, Rt10_3t.L(t):13.2,
Rt10_4t.L(t):13.2/;);

PUT "        "/;

PUT "Pervari Dam and HEPP (b)"/;
PUT " t   Rs10(t)   AvWL10(t)   NtH10(t)   eff10_1t(t)
eff10_2t(t)   eff10_3t(t)   eff10_4t(t)   pwr10(t)   eng10(t)"/;
LOOP(t,PUT t.TL:5,  Rs10.L(t):13.2, AvWL10.L(t):13.2,
NtH10.L(t):13.2, eff10_1t.L(t):13.2, eff10_2t.L(t):13.2,
eff10_3t.L(t):13.2, eff10_4t.L(t):13.2, pwr10(t):13.2,
eng10.L(t):13.2/;);

PUT "        "/;

PUT "Cetin Dam and HEPP (a)"/;
PUT " t   day(t)   S11(t)   A11(t)   WL11(t)   Q11(t)   D11(t)
E11(t)   Rt11_1t(t)   Rt11_2t(t)   Rt11_3t(t)   Rt11_4t(t)
Rt11_5t(t)"/;
PUT "t0","      --  ", beg_S11, beg_A11, beg_WL11/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S11.L(t):13.2, A11.L(t):13.2,
WL11.L(t):13.2, Q11(t):13.2, D11(t):13.2, E11(t):13.2,
Rt11_1t.L(t):13.2, Rt11_2t.L(t):13.2, Rt11_3t.L(t):13.2,
Rt11_4t.L(t):13.2, Rt11_5t.L(t):13.2/;);

PUT "        "/;

PUT "Cetin Dam and HEPP (b)"/;
PUT " t   Rs11(t)   AvWL11(t)   NtH11(t)   eff11_1t(t)
eff11_2t(t)   eff11_3t(t)   eff11_4t(t)   eff11_5t(t)   pwr11(t)
eng11(t)"/;
LOOP(t,PUT t.TL:5, Rs11.L(t):13.2, AvWL11.L(t):13.2,
NtH11.L(t):13.2, eff11_1t.L(t):13.2, eff11_2t.L(t):13.2,
eff11_3t.L(t):13.2, eff11_4t.L(t):13.2, eff11_5t.L(t):13.2,
pwr11(t):13.2, eng11.L(t):13.2/;);

PUT "        "/;

PUT "Alkumru Dam and HEPP (a)"/;
PUT " t   day(t)   S12(t)   A12(t)   WL12(t)   Q12(t)   D12(t)
E12(t)   Rt12_1t(t)   Rt12_2t(t)   Rt12_3t(t)"/;
PUT "t0","      --  ", beg_S12, beg_A12, beg_WL12/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S12.L(t):13.2, A12.L(t):13.2,
WL12.L(t):13.2, Q12(t):13.2, D12(t):13.2, E12(t):13.2,
Rt12_1t.L(t):13.2, Rt12_2t.L(t):13.2, Rt12_3t.L(t):13.2/;);

PUT "        "/;

PUT "Alkumru Dam and HEPP (b)"/;
PUT " t   Rs12(t)   AvWL12(t)   NtH12(t)   eff12_1t(t)
eff12_2t(t)   eff12_3t(t)   pwr12(t)   eng12(t)"/;
LOOP(t,PUT t.TL:5, Rs12.L(t):13.2, AvWL12.L(t):13.2,
NtH12.L(t):13.2, eff12_1t.L(t):13.2, eff12_2t.L(t):13.2,
eff12_3t.L(t):13.2, pwr12(t):13.2, eng12.L(t):13.2/;);
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```
PUT "          "/;

PUT "Eruh Dam and HEPP"/;
PUT " t    day(t)    S13(t)    A13(t)    WL13(t)    Q13(t)    D13(t)
E13(t)    Rt13_1t(t)    Rt13_2t(t)    Rs13(t)    AvWL13(t)    NtH13(t)
eff13_1t(t)    eff13_2t(t)    pwr13(t)    eng13(t)"/;
PUT "t0","      --   ", beg_S13, beg_A13, beg_WL13/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S13.L(t):13.2, A13.L(t):13.2,
WL13.L(t):13.2, Q13(t):13.2, D13(t):13.2, E13(t):13.2,
Rt13_1t.L(t):13.2, Rt13_2t.L(t):13.2, Rs13.L(t):13.2,
AvWL13.L(t):13.2, NtH13.L(t):13.2, eff13_1t.L(t):13.2,
eff13_2t.L(t):13.2, pwr13(t):13.2, eng13.L(t):13.2/;);

PUT "          "/;

PUT "Anbar Dam"/;
PUT " t    day(t)    S14(t)    A14(t)    Q14(t)    D14(t)   E14(t)
Rs14(t)    TS14(t)"/;
PUT "t0","      --   ", beg_S14, beg_A14/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S14.L(t):13.2, A14.L(t):13.2,
Q14(t):13.2, D14(t):13.2, E14(t):13.2, Rs14.L(t):13.2,
TS14.L(t):13.2/;);

PUT "          "/;

PUT "Kurucay Dam"/;
PUT " t    day(t)    S15(t)    A15(t)    Q15(t)    D15(t)   E15(t)
Rs15(t)    TS15(t)"/;
PUT "t0","      --   ", beg_S15, beg_A15/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S15.L(t):13.2, A15.L(t):13.2,
Q15(t):13.2, D15(t):13.2, E15(t):13.2, Rs15.L(t):13.2,
TS15.L(t):13.2/;);

PUT "          "/;

PUT "Pamukcay Dam"/;
PUT " t    day(t)    S16(t)    A16(t)    Q16(t)    D16(t)   E16(t)
Rs16(t)    TS16(t)"/;
PUT "t0","      --   ", beg_S16, beg_A16/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S16.L(t):13.2, A16.L(t):13.2,
Q16(t):13.2, D16(t):13.2, E16(t):13.2, Rs16.L(t):13.2,
TS16.L(t):13.2/;);

PUT "          "/;

PUT "Baslar Dam"/;
PUT " t    day(t)    S17(t)    A17(t)    Q17(t)    D17(t)   E17(t)
Rs17(t)    TS17(t)"/;
PUT "t0","      --   ", beg_S17, beg_A17/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S17.L(t):13.2, A17.L(t):13.2,
Q17(t):13.2, D17(t):13.2, E17(t):13.2, Rs17.L(t):13.2,
TS17.L(t):13.2/;);

PUT "          "/;

PUT "Bulaklidere Dam"/;
PUT " t    day(t)    S18(t)    A18(t)    Q18(t)    D18(t)   E18(t)
Rs18(t)    TS18(t)"/;
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```
PUT "t0","      --   ", beg_S18, beg_A18/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S18.L(t):13.2, A18.L(t):13.2,
Q18(t):13.2, D18(t):13.2, E18(t):13.2, Rs18.L(t):13.2,
TS18.L(t):13.2/;);

PUT "        "/;

PUT "Kibris Dam"/;
PUT " t   day(t)   S19(t)   A19(t)   Q19(t)   D19(t)  E19(t)
Rs19(t)   TS19(t)"/;
PUT "t0","      --   ", beg_S19, beg_A19/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S19.L(t):13.2, A19.L(t):13.2,
Q19(t):13.2, D19(t):13.2, E19(t):13.2, Rs19.L(t):13.2,
TS19.L(t):13.2/;);

PUT "        "/;

PUT "Karacalar Dam"/;
PUT " t   day(t)   S20(t)   A29(t)   Q20(t)   D20(t)  E20(t)
Rs20(t)   TS20(t)"/;
PUT "t0","      --   ", beg_S20, beg_A20/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S20.L(t):13.2, A20.L(t):13.2,
Q20(t):13.2, D20(t):13.2, E20(t):13.2, Rs20.L(t):13.2,
TS20.L(t):13.2/;);

PUT "        "/;

PUT "Silvan Dam and HEPP (a)"/;
PUT " t   day(t)   S21(t)   A21(t)   WL21(t)   Q21(t)   D21(t)
E21(t)   Rt21_1t(t)   Rt21_2t(t)   Rt21_3t(t)   Rt21_4t(t)"/;
PUT "t0","      --   ", beg_S21, beg_A21, beg_WL21/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S21.L(t):13.2, A21.L(t):13.2,
WL21.L(t):13.2, Q21(t):13.2, D21(t):13.2, E21(t):13.2,
Rt21_1t.L(t):13.2, Rt21_2t.L(t):13.2, Rt21_3t.L(t):13.2,
Rt21_4t.L(t):13.2/;);

PUT "        "/;

PUT "Silvan Dam and HEPP (b)"/;
PUT " t   Rs21(t)   AvWL21(t)   NtH21(t)   eff21_1t(t)
eff21_2t(t)   eff21_3t(t)   eff21_4t(t)   pwr21(t)   eng21(t)"/;
LOOP(t,PUT t.TL:5, Rs21.L(t):13.2, AvWL21.L(t):13.2,
NtH21.L(t):13.2, eff21_1t.L(t):13.2, eff21_2t.L(t):13.2,
eff21_3t.L(t):13.2, eff21_4t.L(t):13.2, pwr21(t):13.2,
eng21.L(t):13.2/;);

PUT "        "/;

PUT "Batman Dam and HEPP (a)"/;
PUT " t   day(t)   S22(t)   A22(t)   WL22(t)   Q22(t)   D22(t)
E22(t)   Rt22_1t(t)   Rt22_2t(t)   Rt22_3t(t)"/;
PUT "t0","      --   ", beg_S22, beg_A22, beg_WL22/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S22.L(t):13.2, A22.L(t):13.2,
WL22.L(t):13.2, Q22(t):13.2, D22(t):13.2, E22(t):13.2,
Rt22_1t.L(t):13.2, Rt22_2t.L(t):13.2, Rt22_3t.L(t):13.2/;);

PUT "        "/;
```

```
PUT "Batman Dam and HEPP (b)"/;
PUT " t   Rs22(t)    AvWL22(t)    NtH22(t)    eff22_1t(t)
eff22_2t(t)    eff22_3t(t)    pwr22(t)     eng22(t)"/;
LOOP(t,PUT t.TL:5, Rs22.L(t):13.2, AvWL22.L(t):13.2,
NtH22.L(t):13.2, eff22_1t.L(t):13.2, eff22_2t.L(t):13.2,
eff22_3t.L(t):13.2, pwr22(t):13.2, eng22.L(t):13.2/;);

PUT "         "/;

PUT "Ergani Dam"/;
PUT " t   day(t)    S23(t)    A23(t)    Q23(t)    D23(t)    E23(t)
Rs23(t)"/;
PUT "t0","     --   ", beg_S23, beg_A23/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S23.L(t):13.2, A23.L(t):13.2,
Q23(t):13.2, D23(t):13.2, E23(t):13.2, Rs23.L(t):13.2/;);

PUT "         "/;

PUT "Devegecidi Dam"/;
PUT " t   day(t)    S24(t)    A24(t)    Q24(t)    D24(t)    E24(t)
Rs24(t)"/;
PUT "t0","     --   ", beg_S24, beg_A24/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S24.L(t):13.2, A24.L(t):13.2,
Q24(t):13.2, D24(t):13.2, E24(t):13.2, Rs24.L(t):13.2/;);

PUT "         "/;

PUT "Dipni Dam and HEPP"/;
PUT " t   day(t)    S25(t)    A25(t)    WL25(t)    Q25(t)    D25(t)
E25(t)    Rt25_1t(t)    Rt25_2t(t)    Rs25(t)    AvWL25(t)    NtH25(t)
eff25_1t(t)    eff25_2t(t)    pwr25(t)    eng25(t)"/;
PUT "t0","     --   ", beg_S25, beg_A25, beg_WL25/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S25.L(t):13.2, A25.L(t):13.2,
WL25.L(t):13.2, Q25(t):13.2, D25(t):13.2, E25(t):13.2,
Rt25_1t.L(t):13.2, Rt25_2t.L(t):13.2, Rs25.L(t):13.2,
AvWL25.L(t):13.2, NtH25.L(t):13.2, eff25_1t.L(t):13.2,
eff25_2t.L(t):13.2, pwr25(t):13.2, eng25.L(t):13.2/;);

PUT "         "/;

PUT "Kralkizi Dam and HEPP"/;
PUT " t   day(t)    S26(t)    A26(t)    WL26(t)    Q26(t)    D26(t)
E26(t)    Rt26_1t(t)    Rt26_2t(t)    Rs26(t)    AvWL26(t)    NtH26(t)
eff26_1t(t)    eff26_2t(t)    pwr26(t)    eng26(t)"/;
PUT "t0","     --   ", beg_S26, beg_A26, beg_WL26/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S26.L(t):13.2, A26.L(t):13.2,
WL26.L(t):13.2, Q26(t):13.2, D26(t):13.2, E26(t):13.2,
Rt26_1t.L(t):13.2, Rt26_2t.L(t):13.2, Rs26.L(t):13.2,
AvWL26.L(t):13.2, NtH26.L(t):13.2, eff26_1t.L(t):13.2,
eff26_2t.L(t):13.2, pwr26(t):13.2, eng26.L(t):13.2/;);

PUT "         "/;

PUT "Dicle Dam and HEPP"/;
PUT " t   day(t)    S27(t)    A27(t)    WL27(t)    Q27(t)    D27(t)
E27(t)    Rt27_1t(t)    Rt27_2t(t)    Rs27(t)    AvWL27(t)    NtH27(t)
eff27_1t(t)    eff27_2t(t)    pwr27(t)    eng27(t)    TS27(t)"/;
PUT "t0","     --   ", beg_S27, beg_A27, beg_WL27/;
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LOOP(t,PUT t.TL:5,  day(t):5.2, S27.L(t):13.2, A27.L(t):13.2,
WL27.L(t):13.2, Q27(t):13.2, D27(t):13.2, E27(t):13.2,
Rt27_1t.L(t):13.2, Rt27_2t.L(t):13.2, Rs27.L(t):13.2,
AvWL27.L(t):13.2, NtH27.L(t):13.2, eff27_1t.L(t):13.2,
eff27_2t.L(t):13.2, pwr27(t):13.2, eng27.L(t):13.2,
TS27.L(t):13.2/;);

PUT "        "/;

PUT "Ilisu Dam and HEPP (a)"/;
PUT " t   day(t)   S28(t)   A28(t)   WL28(t)   Q28(t)   D28(t)
E28(t)   Rt28_1t(t)   Rt28_2t(t)   Rt28_3t(t)   Rt28_4t(t)
Rt28_5t(t)   Rt28_6t(t)"/;
PUT "t0","     --  ", beg_S28, beg_A28, beg_WL28/;
LOOP(t,PUT t.TL:5,  day(t):5.2, S28.L(t):20.2, A28.L(t):13.2,
WL28.L(t):13.2, Q28(t):13.2, D28(t):13.2, E28(t):13.2,
Rt28_1t.L(t):13.2, Rt28_2t.L(t):13.2, Rt28_3t.L(t):13.2,
Rt28_4t.L(t):13.2, Rt28_5t.L(t):13.2, Rt28_6t.L(t):13.2/;);

PUT "        "/;

PUT "Ilisu Dam and HEPP (b)"/;
PUT " t   Rs28(t)   AvWL28(t)   NtH28(t)   eff28_1t(t)
eff28_2t(t)   eff28_3t(t)   eff28_4t(t)   eff28_5t(t)
eff28_6t(t)   pwr28(t)   eng28(t)"/;
LOOP(t,PUT t.TL:5, Rs28.L(t):13.2, AvWL28.L(t):13.2,
NtH28.L(t):13.2, eff28_1t.L(t):13.2, eff28_2t.L(t):13.2,
eff28_3t.L(t):13.2, eff28_4t.L(t):13.2, eff28_5t.L(t):13.2,
eff28_6t.L(t):13.2,  pwr28(t):13.2, eng28.L(t):13.2/;);

PUT "        "/;

PUT "System Energy:", Obj.L:25.2/;
```

CURRICULUM VITAE

PERSONAL INFORMATION

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EDUCATION

Degree	**Institution**	**Year of Graduation**
MS	METU Civil Engineering	2010
BS	METU Civil Engineering	2008
High School	Ankara Atatürk High School	2003

WORK EXPERIENCE

Year	**Place**	**Enrolment**
2011 January - Present	EIN Construction	Company Manager
2008 July - October	PROSEM Engineering	Design Engineer
2007 July	VE-NA Construction	Intern Engineering Student
2006 July	VE-NA Construction	Intern Engineering Student

FOREIGN LANGUAGES

Advanced English

PUBLICATIONS

1. Yalcin, E., & Tigrek, S. (2010, July). *Investigation of alternative solutions to Ilisu Dam and HEPP*. Paper presented at the meeting of the 2nd International Conference on Nuclear and Renewable Energy Resources, Ankara.

2. Yalcin, E., & Tigrek, S. (2015). Hydropower production without sacrificing environment: a case study of Ilisu Dam and Hasankeyf. *International Journal of Water Resources Development*. doi: 10.1080/07900627.2015.1031210

3. Yalcin, E., & Tigrek, S. (2015, May). *Ilisu Dam and HEPP, investigation of alternative solutions*. Poster session presented at the meeting of the 15th World Water Congress, Edinburgh.

4. Yalcin, E., & Tigrek, S. (2015, May). *Integrated operation optimisation of cascade hydropower projects*. Poster session presented at the meeting of the 15th World Water Congress, Edinburgh.