OPTIMISATION OF THE TIGRIS RIVER HYDROPOWER SYSTEM OPERATIONS

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EMRAH YALÇIN

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submitted by EMRAH YALÇIN in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Civil Engineering Department, Middle East Technical University by,

Prof. Dr. Gülbin Dural Ünver
Dean, Graduate School of Natural and Applied Sciences

Prof. Dr. Ahmet Cevdet Yalçın
Head of Department, Civil Engineering

Assoc. Prof. Dr. Şahnaz Tiğrek
Supervisor, Civil Engineering Dept., Batman University

Examing Committee Members:

Prof. Dr. A. Melih Yanmaz
Civil Engineering Dept., METU

Assoc. Prof. Dr. Şahnaz Tiğrek
Civil Engineering Dept., Batman University

Assoc. Prof. Dr. Elçin Kentel
Civil Engineering Dept., METU

Asst. Prof. Dr. Önder Koçyiğit
Civil Engineering Dept., Gazi University

Asst. Prof. Dr. Aslı Numanoğlu Genç
Civil Engineering Dept., Atatürk University

Date: 22.05.2015
I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Emrah Yalçın

Signature: 
ABSTRACT

OPTIMISATION OF THE TIGRIS RIVER HYDROPOWER SYSTEM OPERATIONS

Yalçın, Emrah
Ph.D., Department of Civil Engineering
Supervisor: Assoc. Prof. Dr. Şahnaz Tiğrek

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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 OPTİMIZASYONU

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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).


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:
\[
\max_t \sum E_{i,t} - E_c^t \right]
\]

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 \( E_c^t \) = 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:

\[ E_{i,t} = \xi_T \xi_G \varphi_t P_{i,t} \]  

\[ P_{i,t} = g H_{i,t}^n \sum_j (\varepsilon_{i,j,t} \phi_t R_{i,j,t}^p) \]

where \( \xi_T \) = transformer efficiency, \( \xi_G \) = generator efficiency, \( \varphi_t \) = 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 \( t \), \( \phi_t \) = 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:

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

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:

\[ H_{i,t}^{n} = \lambda \left( H_{i,t}^{a} - tw_{i} \right) - \kappa_{i} \left( \phi_{t} \sum_{j} R_{i,j,t}^{p} \right)^{2} \]  

(5)

where \( \lambda = \) gross head reduction for local losses (95\% as default), \( H_{i,t}^{n} = \) 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 \( \kappa_{i} = \) friction loss constant for the penstocks and/or energy tunnels of the \( i^{th} \) reservoir in \( \text{m/(m}^{3}/\text{s})^{2} \).

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

\[ H_{i,t}^{a} = \frac{H_{i,t-1} + H_{i,t}}{2} \]  

(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:

\[ H_{i,t} = f_{2}(S_{i,t}) \]  

(7)

where \( S_{i,t} = \) ending storage in the \( i^{th} \) reservoir at the end of time period \( t \) in \( \text{m}^{3} \).

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:

\[ S_{i,t} = S_{i,t-1} + I_{i,t} + \sum_j R^p_{i-1,j,t} + R^s_{i-1,t} + R^{de}_{i-1,t} + r_{i-1} R^{di}_{i-1,t} - e_{i,t} A_{i,t-1} \]

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:

\[ A_{i,t-1} = f_3(S_{i,t-1}) \]

Turbine capacity:

\[ R^p_{i,j,t} \leq R^p_{i,\text{max}} \]
Spillway capacity:

\[ R_{l,t}^s \leq R_{l,\text{max}}^s \] (11)

where \( R_{l,\text{max}}^s \) = spillway capacity of the \( i^{th} \) reservoir in m\(^3\).

Minimum release:

\[ \sum_j R_{i,j,t}^p + R_{i,t}^s + R_{l,t}^{de} \geq R_{l,\text{min},t}^d \] (12)

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

Minimum energy production:

\[ \sum_t E_{i,t} \geq E_{t}^c \] (13)

Minimum and maximum storage values:

\[ S_{l,\text{min}} \leq S_{l,t} \leq S_{l,\text{max}} \] (14)

where \( S_{l,\text{min}} \) = minimum storage in the \( i^{th} \) reservoir in m\(^3\) and \( S_{l,\text{max}} \) = 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.

\[ \max \sum_{t} \sum_{i,t} E_{i,t} \]  

(15)
Real-time operation for the "ith" reservoir

Month $t$

NLP Model

ARIMA Model

Observed inflow values, $I_o$

Forecasted inflow values, $I_f$

$I_o < I_f$

Adjust $R^o$

$\Delta R^o = R^o - (I_f - I_o)$

Adjust $I$ for the $i+1$th reservoir

Month $t+1$

Adjust $R^o$

$S + (I_f - I_o) < S_{max}$

Month $t+1$

Adjust $I$ for the $i+1$th reservoir

Adjust $R^o$

$S - (I_f - I_o) > S_{min}$

Month $t+1$

Adjust $I$ for the $i+1$th reservoir

Adjust $R^o$

$R^o = R_{max}$

Month $t+1$

Adjust $R^o$

$R^o = R_{max}$

Figure 1 Real-Time Operations
\[ R_{i,j,t}^P = R_{i,j}^{pf} + R_{i,j,t}^{ps} \]  

where \( R_{i,j}^{pf} \) = firm power release through the \( j^{th} \) turbine of the \( i^{th} \) reservoir and \( R_{i,j,t}^{ps} \) = secondary power release through the \( j^{th} \) turbine of the \( i^{th} \) reservoir during time period \( t \) in \( \text{m}^3 \).

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.
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

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unit</th>
<th>Aysehatun</th>
<th>Kor</th>
<th>Garzan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td></td>
<td>Energy</td>
<td>Energy</td>
<td>Energy</td>
</tr>
<tr>
<td>Drainage Area</td>
<td>km²</td>
<td>405.0</td>
<td>942.2</td>
<td>1266.0</td>
</tr>
<tr>
<td>Thalweg Elevation</td>
<td>m</td>
<td>1180.0</td>
<td>895.0</td>
<td>675.5</td>
</tr>
<tr>
<td>Maximum Water Level</td>
<td>m</td>
<td>1250.0</td>
<td>956.0</td>
<td>788.3</td>
</tr>
<tr>
<td>Minimum Water Level</td>
<td>m</td>
<td>1230.0</td>
<td>930.0</td>
<td>757.7</td>
</tr>
<tr>
<td>Tailwater Level</td>
<td>m</td>
<td>950.0</td>
<td>830.0</td>
<td>676.0</td>
</tr>
<tr>
<td>Design Discharge</td>
<td>m³/s</td>
<td>13.36</td>
<td>26.54</td>
<td>43.60</td>
</tr>
<tr>
<td>Penstock: Number/Diameter/Length</td>
<td>/m/m</td>
<td>1/2.3/250</td>
<td>1/2.5/210</td>
<td>1/3.2/210</td>
</tr>
<tr>
<td>Energy Tunnel: Number/Diameter/Length</td>
<td>/m/m</td>
<td>1/3.5/8410</td>
<td>1/3.3/6370</td>
<td>1/4.0/382</td>
</tr>
<tr>
<td>Number of Units</td>
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<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Gross Head/Net Head</td>
<td>m/m</td>
<td>300.0/282.0</td>
<td>126.0/109.9</td>
<td>112.3/108.6</td>
</tr>
<tr>
<td>Turbine Type</td>
<td></td>
<td>Francis</td>
<td>Francis</td>
<td>Francis</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Station Id</th>
<th>Station Name</th>
<th>Opening Date</th>
<th>Closing Date</th>
<th>Drainage Area (km²)</th>
<th>Elevation (m)</th>
<th>Mean Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSI 26-57</td>
<td>Keyburan Brook Bogazonu</td>
<td>24.10.1981</td>
<td>-</td>
<td>425.0</td>
<td>1200</td>
<td>8.6</td>
</tr>
<tr>
<td>DSI 26-58</td>
<td>Garzan Creek Meydanonu</td>
<td>29.11.1981 08.01.1999</td>
<td>783.2</td>
<td>909</td>
<td>15.8</td>
<td></td>
</tr>
<tr>
<td>DSI 26-24</td>
<td>Pisyar Creek Kozluk</td>
<td>01.08.1970</td>
<td>-</td>
<td>1359.3</td>
<td>620</td>
<td>26.0</td>
</tr>
<tr>
<td>EIE 2634</td>
<td>Garzan Creek Kozluk</td>
<td>19.10.1999 30.09.2000</td>
<td>1407.7</td>
<td>630</td>
<td>23.0</td>
<td></td>
</tr>
<tr>
<td>EIE 2603</td>
<td>Garzan Creek Besiri</td>
<td>01.11.1945 30.09.2000</td>
<td>2450.4</td>
<td>545</td>
<td>49.0</td>
<td></td>
</tr>
</tbody>
</table>

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 m³/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

<table>
<thead>
<tr>
<th>Basin</th>
<th>Data set</th>
<th>Mean (hm³)</th>
<th>Standard deviation (hm³)</th>
<th>Skewness (hm³)</th>
<th>Minimum (hm³)</th>
<th>Maximum (hm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rainy period</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Aysehatun</td>
<td>Training</td>
<td>33.751</td>
<td>41.517</td>
<td>2.039</td>
<td>3.482</td>
<td>219.189</td>
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<tr>
<td></td>
<td>Testing</td>
<td>77.188</td>
<td>82.286</td>
<td>1.295</td>
<td>4.700</td>
<td>266.183</td>
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<tr>
<td></td>
<td>Entire</td>
<td>35.647</td>
<td>45.112</td>
<td>2.171</td>
<td>2.740</td>
<td>266.183</td>
</tr>
<tr>
<td>Kor</td>
<td>Training</td>
<td>51.844</td>
<td>64.168</td>
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<td>4.877</td>
<td>349.872</td>
</tr>
<tr>
<td></td>
<td>Testing</td>
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<td>Entire</td>
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<td>70.269</td>
<td>2.251</td>
<td>3.704</td>
<td>439.967</td>
</tr>
<tr>
<td>Garzan</td>
<td>Training</td>
<td>65.049</td>
<td>80.187</td>
<td>1.859</td>
<td>2.943</td>
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<td>143.700</td>
<td>147.366</td>
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</tr>
<tr>
<td></td>
<td>Entire</td>
<td>68.631</td>
<td>85.840</td>
<td>1.936</td>
<td>1.767</td>
<td>472.442</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dry period</td>
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<td></td>
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<td></td>
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<tr>
<td>Aysehatun</td>
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<td>266.183</td>
</tr>
<tr>
<td></td>
<td>Testing</td>
<td>13.370</td>
<td>12.364</td>
<td>1.706</td>
<td>2.740</td>
<td>44.800</td>
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<td>35.647</td>
<td>45.112</td>
<td>2.171</td>
<td>2.740</td>
<td>266.183</td>
</tr>
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<td>Kor</td>
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</tr>
<tr>
<td></td>
<td>Entire</td>
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<td>2.251</td>
<td>3.704</td>
<td>439.967</td>
</tr>
<tr>
<td>Garzan</td>
<td>Training</td>
<td>69.419</td>
<td>86.650</td>
<td>1.933</td>
<td>2.943</td>
<td>472.442</td>
</tr>
<tr>
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<td>24.857</td>
<td>26.259</td>
<td>1.642</td>
<td>1.767</td>
<td>90.823</td>
</tr>
<tr>
<td></td>
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<td>85.840</td>
<td>1.936</td>
<td>1.767</td>
<td>472.442</td>
</tr>
</tbody>
</table>

### 3.2.2.1 Fitting ARIMA Models

ARIMA models, as introduced by Box and Jenkins (1976), are represented by ARIMA \((p,d,q) \times (P,D,Q)_s\). 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 \(y^t = \{y_1, y_2, ..., y_n\}^T\) are expressed as follows:

\[
\phi(B) \Phi(B^s) (1 - B)^d (1 - B^s)^D y^t = \theta(B) \Theta(B^s) \epsilon_t
\]  

(17)
with

\[ \phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p \] (18)

\[ \theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q \] (19)

\[ \Phi(B^s) = 1 - \Phi_1 B^s - \Phi_2 B^{2s} - \cdots - \Phi_p B^{ps} \] (20)

\[ \Theta(B^s) = 1 - \Theta_1 B^s - \Theta_2 B^{2s} - \cdots - \Theta_q B^{qs} \] (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 \( \varepsilon_t \) 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.
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
Figure 7 (a) ACF-PACF and (b) ACF-PACF Residual of Streamflow Series at the Garzan Dam Location
Table 4 Selected ARIMA Models

<table>
<thead>
<tr>
<th>Run</th>
<th>Aysehatun</th>
<th>Kor</th>
<th>Garzan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainy period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run1</td>
<td>(0,0,1) (0,1,1)₁²</td>
<td>(0,0,1) (0,1,1)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
</tr>
<tr>
<td>Run2</td>
<td>(0,0,1) (0,1,1)₁²</td>
<td>(0,0,1) (0,1,1)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
</tr>
<tr>
<td>Run3</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,1)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
</tr>
<tr>
<td>Run4</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
</tr>
<tr>
<td>Run5</td>
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<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
</tr>
<tr>
<td>Run6</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
</tr>
<tr>
<td>Run7</td>
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<td>(0,0,2) (1,1,1)₁²</td>
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<tr>
<td>Run8</td>
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<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,2) (1,1,1)₁²</td>
</tr>
<tr>
<td>Run9</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,2) (1,1,1)₁²</td>
</tr>
<tr>
<td>Run10</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,2) (1,1,1)₁²</td>
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<tr>
<td>Run11</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
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<tr>
<td>Run12</td>
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<td></td>
<td>Dry period</td>
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<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
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<td>Run4</td>
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<td>(0,0,1) (0,1,0)₁²</td>
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<td>(1,0,0) (0,1,0)₁²</td>
<td>(1,0,0) (0,1,0)₁²</td>
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<tr>
<td>Run6</td>
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<td>(0,0,1) (0,1,1)₁²</td>
<td>(0,0,1) (0,1,0)₁²</td>
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<tr>
<td>Run7</td>
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<td>(0,0,1) (0,1,1)₁²</td>
<td>(1,0,0) (1,1,0)₁²</td>
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<tr>
<td>Run8</td>
<td>(0,0,1) (0,1,0)₁²</td>
<td>(0,0,1) (0,1,1)₁²</td>
<td>(1,0,1) (1,1,0)₁²</td>
</tr>
<tr>
<td>Run9</td>
<td>(1,0,0) (1,1,0)₁²</td>
<td>(1,0,0) (0,1,1)₁²</td>
<td>(0,0,2) (1,1,0)₁²</td>
</tr>
<tr>
<td>Run10</td>
<td>(1,0,0) (0,1,1)₁²</td>
<td>(2,0,1) (0,1,1)₁²</td>
<td>(0,0,2) (1,1,0)₁²</td>
</tr>
<tr>
<td>Run11</td>
<td>(1,0,0) (0,1,1)₁²</td>
<td>(2,0,1) (0,1,0)₁²</td>
<td>(0,0,2) (1,1,0)₁²</td>
</tr>
<tr>
<td>Run12</td>
<td>(1,0,0) (0,1,0)₁²</td>
<td>(1,0,0) (0,1,0)₁²</td>
<td>(1,0,0) (1,1,1)₁²</td>
</tr>
</tbody>
</table>

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/\(\bar{y}\) 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/\(\bar{y}\) 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.

\[
MAE = \frac{1}{n} \sum_{t=1}^{n} |y^o_t - y^f_t|
\]  

(22)

\[
RMSE = \sqrt{\frac{1}{n} \sum_{t=1}^{n} (y^o_t - y^f_t)^2}
\]  

(23)

\[
MBE = \frac{1}{n} \sum_{t=1}^{n} (y^o_t - y^f_t)
\]  

(24)

\[
NMBE = \frac{\frac{1}{n} \sum_{t=1}^{n} (y^f_t - y^o_t)}{\frac{1}{n} \sum_{t=1}^{n} y^o_t}
\]  

(25)

\[
R = \frac{\frac{1}{n} \sum_{t=1}^{n} (y^o_t - \bar{y}^o)(y^f_t - \bar{y}^f)}{\sqrt{\frac{1}{n} \sum_{t=1}^{n} (y^o_t - \bar{y}^o)^2} \sqrt{\frac{1}{n} \sum_{t=1}^{n} (y^f_t - \bar{y}^f)^2}}
\]  

(26)

\[
CE = 1 - \frac{\sum_{t=1}^{n} (y^o_t - y^f_t)^2}{\sum_{t=1}^{n} (y^o_t - \bar{y}^o)^2}
\]  

(27)

where \(y^o_t\) is the observed value and \(y^f_t\) 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

<table>
<thead>
<tr>
<th>Basin</th>
<th>Model</th>
<th>MAE</th>
<th>RMSE</th>
<th>NMBE</th>
<th>RMSE/³</th>
<th>MBE</th>
<th>R</th>
<th>CE</th>
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<tbody>
<tr>
<td></td>
<td>Rainy period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aysehatun</td>
<td>Mean</td>
<td>41.541</td>
<td>60.222</td>
<td>-0.538</td>
<td>0.780</td>
<td>41.541</td>
<td>0.966</td>
<td>0.416</td>
</tr>
<tr>
<td></td>
<td>ARIMA</td>
<td>23.116</td>
<td>39.558</td>
<td>-0.175</td>
<td>0.512</td>
<td>13.537</td>
<td>0.889</td>
<td>0.748</td>
</tr>
<tr>
<td>Kor</td>
<td>Mean</td>
<td>65.973</td>
<td>97.616</td>
<td>-0.546</td>
<td>0.808</td>
<td>65.973</td>
<td>0.971</td>
<td>0.409</td>
</tr>
<tr>
<td></td>
<td>ARIMA</td>
<td>34.151</td>
<td>57.459</td>
<td>-0.136</td>
<td>0.475</td>
<td>16.461</td>
<td>0.912</td>
<td>0.795</td>
</tr>
<tr>
<td>Garzan</td>
<td>Mean</td>
<td>75.069</td>
<td>104.992</td>
<td>-0.522</td>
<td>0.731</td>
<td>75.069</td>
<td>0.962</td>
<td>0.446</td>
</tr>
<tr>
<td></td>
<td>ARIMA</td>
<td>49.659</td>
<td>78.018</td>
<td>-0.049</td>
<td>0.543</td>
<td>7.015</td>
<td>0.876</td>
<td>0.694</td>
</tr>
<tr>
<td></td>
<td>Dry period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aysehatun</td>
<td>Mean</td>
<td>22.369</td>
<td>38.555</td>
<td>1.666</td>
<td>2.884</td>
<td>-22.277</td>
<td>0.630</td>
<td>-9.608</td>
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<tr>
<td></td>
<td>ARIMA</td>
<td>13.230</td>
<td>19.670</td>
<td>0.586</td>
<td>1.471</td>
<td>-7.838</td>
<td>0.468</td>
<td>-1.761</td>
</tr>
<tr>
<td>Kor</td>
<td>Mean</td>
<td>34.645</td>
<td>59.526</td>
<td>1.690</td>
<td>2.917</td>
<td>-34.494</td>
<td>0.632</td>
<td>-9.337</td>
</tr>
<tr>
<td></td>
<td>ARIMA</td>
<td>28.643</td>
<td>47.341</td>
<td>0.811</td>
<td>2.320</td>
<td>-16.554</td>
<td>0.382</td>
<td>-5.538</td>
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<tr>
<td>Garzan</td>
<td>Mean</td>
<td>44.069</td>
<td>74.337</td>
<td>1.761</td>
<td>2.991</td>
<td>-43.774</td>
<td>0.646</td>
<td>-7.742</td>
</tr>
<tr>
<td></td>
<td>ARIMA</td>
<td>35.134</td>
<td>52.321</td>
<td>0.787</td>
<td>2.105</td>
<td>-19.566</td>
<td>0.355</td>
<td>-3.331</td>
</tr>
</tbody>
</table>

### 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 (Prosem, 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](image-url)
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](image_url)

**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
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](Image)

**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

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

42
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).

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

<table>
<thead>
<tr>
<th>Projects</th>
<th>Stream Gauging Stations</th>
<th>Meteorological Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Planning</td>
<td>In Construction</td>
<td>In Operation</td>
</tr>
<tr>
<td>1 Aysehatun Dam and HEPP</td>
<td>1 DSI 26-57</td>
<td>1 Mutki</td>
</tr>
<tr>
<td>2 Mutki Derivation</td>
<td>2 DSI 26-58</td>
<td>2 Kozluk</td>
</tr>
<tr>
<td>3 Kor Dam and HEPP</td>
<td>3 DSI 26-24</td>
<td>3 Bitlis</td>
</tr>
<tr>
<td>4 Garzan Dam and HEPP</td>
<td>4 EIE 2634</td>
<td>4 Baykan</td>
</tr>
<tr>
<td>5 Kotum Derivation</td>
<td>5 EIE 2603</td>
<td>5 Pervari</td>
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<td>6 Guzeldere Dam and HEPP</td>
<td>6 DSI 25-14</td>
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<td>7 DSI 26-28</td>
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<td>17 DSI 26-18</td>
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<td>18 Kurucaay Dam</td>
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### Table 8 Irrigation Projects

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<td><strong>27233</strong></td>
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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.

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<th>Characteristics</th>
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<th>Kor</th>
<th>Garzan</th>
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<td>Energy</td>
<td>Energy</td>
<td>Energy</td>
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**Table 9 Characteristics of the Tigris Projects**

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<td>31.0/25.7</td>
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<td>100.0/99.2</td>
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<td>69.00/67.83</td>
<td>125.0/118.4</td>
</tr>
<tr>
<td>Francis</td>
<td>-</td>
<td>-</td>
<td>Francis</td>
<td>Francis</td>
<td>Francis</td>
<td>Francis</td>
</tr>
</tbody>
</table>
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**

<table>
<thead>
<tr>
<th>Project</th>
<th>Monthly Mean Temperature Data</th>
<th>Monthly Total Evaporation Data</th>
<th>Monthly Total Precipitation Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aysehatun Dam and HEPP</td>
<td>Bitlis MS</td>
<td>Bitlis MS</td>
<td>Mutki MS</td>
</tr>
<tr>
<td>Kor Dam and HEPP</td>
<td>Bitlis MS</td>
<td>Bitlis MS</td>
<td>Mutki MS</td>
</tr>
<tr>
<td>Garzan Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Kozluk MS</td>
</tr>
<tr>
<td>Guzeldere Dam and HEPP</td>
<td>Bitlis MS</td>
<td>Bitlis MS</td>
<td>Tatvan MS</td>
</tr>
<tr>
<td>Sirvan Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
</tr>
<tr>
<td>Basoren Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Baykan MS</td>
</tr>
<tr>
<td>Narli Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Pervari MS</td>
</tr>
<tr>
<td>Oran Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Pervari MS</td>
</tr>
<tr>
<td>Keskin Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Pervari MS</td>
</tr>
<tr>
<td>Pervari Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Pervari MS</td>
</tr>
<tr>
<td>Cetin Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
</tr>
<tr>
<td>Alkimru Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
</tr>
<tr>
<td>Eruh Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
</tr>
<tr>
<td>Anbar Dam</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
</tr>
<tr>
<td>Kurucay Dam</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
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<tr>
<td>Pamukcay Dam</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
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<tr>
<td>Baslar Dam</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
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<tr>
<td>Bulaklidere Dam</td>
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<td>Diyarbakir MS</td>
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<td>Silvan MS</td>
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<td>Karacalar Dam</td>
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<td>Diyarbakir MS</td>
<td>Silvan MS</td>
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<tr>
<td>Silvan Dam and HEPP</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Silvan MS</td>
</tr>
<tr>
<td>Batman Dam and HEPP</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Silvan MS</td>
</tr>
<tr>
<td>Ergani Dam</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Ergani MS</td>
</tr>
<tr>
<td>Devegecidi Dam</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
</tr>
<tr>
<td>Dipni Dam and HEPP</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Hani MS</td>
</tr>
<tr>
<td>Kralkizi Dam and HEPP</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Ergani MS</td>
</tr>
<tr>
<td>Dicle Dam and HEPP</td>
<td>Diyarbakir MS</td>
<td>Diyarbakir MS</td>
<td>Ergani MS</td>
</tr>
<tr>
<td>Ilisu Dam and HEPP</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
<td>Siirt MS</td>
</tr>
</tbody>
</table>
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, Bespınar, Kirkat (Gercus), Goksu irrigation schemes, the Tigris irrigation module is used (FPGA, 1968). The Batman-Sıivan 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

<table>
<thead>
<tr>
<th>Station Id</th>
<th>Station Name</th>
<th>Opening Date</th>
<th>Closing Date</th>
<th>Drainage Area (km²)</th>
<th>Elevation (m)</th>
<th>Mean Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSI 26-57</td>
<td>Keyburan Brook Bogazonu</td>
<td>24.10.1981</td>
<td>-</td>
<td>425.0</td>
<td>1200</td>
<td>8.6</td>
</tr>
<tr>
<td>DSI 26-58</td>
<td>Garzan Creek Meydanonu</td>
<td>29.11.1981</td>
<td>08.01.1999</td>
<td>783.2</td>
<td>909</td>
<td>15.8</td>
</tr>
<tr>
<td>DSI 26-24</td>
<td>Pisyar Creek Kozluk</td>
<td>01.08.1970</td>
<td>-</td>
<td>1359.3</td>
<td>620</td>
<td>26.0</td>
</tr>
<tr>
<td>EIE 2634</td>
<td>Garzan Creek Kozluk</td>
<td>19.10.1999</td>
<td>30.09.2000</td>
<td>1407.7</td>
<td>630</td>
<td>23.0</td>
</tr>
<tr>
<td>EIE 2603</td>
<td>Garzan Creek Besiri</td>
<td>01.11.1945</td>
<td>30.09.2000</td>
<td>2450.4</td>
<td>545</td>
<td>49.0</td>
</tr>
<tr>
<td>DSI 25-14</td>
<td>Kotum Brook Kucuksu</td>
<td>01.10.1964</td>
<td>31.10.1972</td>
<td>78.9</td>
<td>1721.0</td>
<td>2.1</td>
</tr>
<tr>
<td>DSI 26-28</td>
<td>Guzeldere Kusukoyu</td>
<td>01.10.1973</td>
<td>08.01.1999</td>
<td>125.8</td>
<td>1594.0</td>
<td>3.9</td>
</tr>
<tr>
<td>EIE 2624</td>
<td>Kezer Creek Pinarca</td>
<td>01.10.1971</td>
<td>30.09.2000</td>
<td>1169.6</td>
<td>530.0</td>
<td>20.2</td>
</tr>
<tr>
<td>EIE 2610</td>
<td>Bitlis Creek Baykan</td>
<td>14.09.1954</td>
<td>30.09.2000</td>
<td>640.4</td>
<td>910.0</td>
<td>18.8</td>
</tr>
<tr>
<td>EIE 2609</td>
<td>Catak Brook Catak</td>
<td>12.09.1954</td>
<td>22.02.1972</td>
<td>2339.5</td>
<td>1625.0</td>
<td>27.5</td>
</tr>
<tr>
<td>EIE 2604/A</td>
<td>Botan Creek Billoris</td>
<td>31.07.1962</td>
<td>01.10.1970</td>
<td>8747.3</td>
<td>465.0</td>
<td>189.1</td>
</tr>
<tr>
<td>EIE 2626</td>
<td>Botan Creek Billoris</td>
<td>01.10.1970</td>
<td>03.10.1996</td>
<td>8761.2</td>
<td>457.0</td>
<td>156.8</td>
</tr>
<tr>
<td>EIE 2633</td>
<td>Botan Creek Billoris</td>
<td>03.10.1996</td>
<td>30.09.2000</td>
<td>8747.3</td>
<td>465.0</td>
<td>118.2</td>
</tr>
<tr>
<td>EIE 2615</td>
<td>Mukus Creek Begendik</td>
<td>11.08.1964</td>
<td>01.02.1973</td>
<td>505.6</td>
<td>1250.0</td>
<td>19.1</td>
</tr>
<tr>
<td>DSI 26-55</td>
<td>Catak Brook Dalbasti</td>
<td>01.10.1980</td>
<td>-</td>
<td>3069.0</td>
<td>1350.0</td>
<td>40.5</td>
</tr>
<tr>
<td>DSI 26-39</td>
<td>Anbar Creek Hani</td>
<td>01.06.1977</td>
<td>-</td>
<td>292.0</td>
<td>800.0</td>
<td>2.9</td>
</tr>
<tr>
<td>EIE 2618</td>
<td>Anbar Creek Koprubasi</td>
<td>01.11.1968</td>
<td>01.10.1998</td>
<td>976.0</td>
<td>595.0</td>
<td>7.7</td>
</tr>
<tr>
<td>DSI 26-14</td>
<td>Kurucay Yasince</td>
<td>19.08.1962</td>
<td>01.11.1986</td>
<td>240.0</td>
<td>520.0</td>
<td>1.2</td>
</tr>
<tr>
<td>DSI 26-32</td>
<td>Pamuk Creek Karahan Bridge</td>
<td>01.08.1974</td>
<td>-</td>
<td>305.0</td>
<td>738.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>
### Table 11 (cont’d)

<table>
<thead>
<tr>
<th>Station Id</th>
<th>Station Name</th>
<th>Opening Date</th>
<th>Closing Date</th>
<th>Drainage Area (km²)</th>
<th>Elevation (m)</th>
<th>Mean Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSI 26-12</td>
<td>Basnik Creek Salat</td>
<td>13.07.1960</td>
<td>-</td>
<td>1060.0</td>
<td>1085.0</td>
<td>3.4</td>
</tr>
<tr>
<td>DSI 26-60</td>
<td>Baskoy Creek Salikan</td>
<td>28.05.1985</td>
<td>-</td>
<td>118.5</td>
<td>620.0</td>
<td>0.5</td>
</tr>
<tr>
<td>EIE 2612</td>
<td>Batman Creek Malabadi Bridge</td>
<td>06.02.1957</td>
<td>30.09.2000</td>
<td>4105.2</td>
<td>597.0</td>
<td>124.0</td>
</tr>
<tr>
<td>DSI 26-62</td>
<td>Sallar Creek Yolkopru</td>
<td>17.02.1998</td>
<td>-</td>
<td>51.6</td>
<td>850.0</td>
<td>0.8</td>
</tr>
<tr>
<td>DSI 26-09</td>
<td>Furtaksa Brook DDY Bridge</td>
<td>01.12.1959</td>
<td>01.10.1965</td>
<td>1607.0</td>
<td>705.0</td>
<td>8.8</td>
</tr>
<tr>
<td>EIE 2632</td>
<td>Berkilin Creek Cayustu</td>
<td>16.09.1988</td>
<td>13.01.1998</td>
<td>1503.6</td>
<td>689.0</td>
<td>28.2</td>
</tr>
<tr>
<td>EIE 2617</td>
<td>Tigris River Cayonu</td>
<td>01.11.1968</td>
<td>01.12.1997</td>
<td>1186.0</td>
<td>695.0</td>
<td>24.3</td>
</tr>
<tr>
<td>EIE 2605</td>
<td>Tigris River Diyarbakir</td>
<td>13.11.1945</td>
<td>30.09.2000</td>
<td>5655.2</td>
<td>570.0</td>
<td>68.4</td>
</tr>
<tr>
<td>EIE 2604</td>
<td>Botan Creek Billoris</td>
<td>07.11.1945</td>
<td>31.07.1962</td>
<td>7857.3</td>
<td>473.0</td>
<td>122.5</td>
</tr>
<tr>
<td>EIE 2606</td>
<td>Tigris River Cizre</td>
<td>27.11.1945</td>
<td>01.09.2000</td>
<td>38280.7</td>
<td>370.0</td>
<td>517.8</td>
</tr>
<tr>
<td>EIE 2611</td>
<td>Tigris River Rezuk</td>
<td>01.03.1955</td>
<td>07.03.1975</td>
<td>34493.1</td>
<td>427.0</td>
<td>424.9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Station</th>
<th>Valuable Years</th>
<th>Naturalised due to</th>
<th>Extended by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Correlation → EIE 2603</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>• Correlation → EIE 2603</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Correlation → EIE 2603</td>
</tr>
<tr>
<td>EIE 2634</td>
<td>2000</td>
<td>-</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Area ratio → EIE 2634</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Kozluk Irrigation Gross: 3973 ha Net: 3362 ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Commissioning Date: 1996</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Garzan - Kozluk Irrigation Module</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Rate of return: 20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Monthly means of observations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Correlation → EIE 2610</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Correlation → EIE 2624</td>
</tr>
<tr>
<td>EIE 2624</td>
<td>1972-2000</td>
<td>-</td>
<td>1971</td>
</tr>
<tr>
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<td></td>
<td>• Correlation → EIE 2610</td>
</tr>
<tr>
<td>EIE 2610</td>
<td>1955-2000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EIE 2609</td>
<td>1961-1971</td>
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<tr>
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</tr>
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<td>EIE 2626</td>
<td>1972-1996</td>
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<td>• EIE 2604/A</td>
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<td></td>
<td></td>
<td>1971</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Correlation → EIE 2609</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1972-1996</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Area ratio → EIE 2626</td>
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<td></td>
<td>• Correlation → EIE 2633</td>
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<td>Naturalised due to</td>
<td>Extended by</td>
</tr>
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Table 12 (cont’d)

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<th>Station</th>
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<th>Extended by</th>
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<tr>
<td></td>
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<td>Extended monthly means of observations</td>
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<td></td>
<td><strong>Kahlara Irrigation</strong></td>
<td>1972-1988</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gross: 380 ha</td>
<td>1995</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Net: 380 ha</td>
<td><strong>Correlation → EIE 2617</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Commissioning Date: 1965</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>June</strong>: + 0.35 hm$^3$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>July</strong>: + 0.33 hm$^3$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>August</strong>: + 0.32 hm$^3$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>September</strong>: + 0.27 hm$^3$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Correlation → EIE 2605</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1998-2000</td>
</tr>
<tr>
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<td></td>
<td><strong>Extended monthly means of observations</strong></td>
</tr>
<tr>
<td>EIE 2632</td>
<td>1989-1997</td>
<td>-</td>
<td>1971</td>
</tr>
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<td><strong>Extended monthly means of observations</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1972-1988</td>
</tr>
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<td><strong>Correlation → EIE 2617</strong></td>
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<td>1998-2000</td>
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<td><strong>Extended monthly means of observations</strong></td>
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<td>EIE 2617</td>
<td>1972-1997</td>
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<td>1971</td>
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<td>1998-2000</td>
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<td><strong>Extended monthly means of observations</strong></td>
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<td>1955-2000</td>
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<td><strong>Extended monthly means of observations</strong></td>
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<tr>
<td></td>
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<td><strong>Devegecidi Irrigation</strong></td>
<td>1946-1952</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gross: 10600 ha</td>
<td><strong>Drainage area 5655.2 km$^2$</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Net: 5800 ha</td>
<td>1955-1963</td>
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<td></td>
<td>Commissioning Date: 1972</td>
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<td><strong>Gozegol Irrigation</strong></td>
<td>1955-1963</td>
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<tr>
<td></td>
<td></td>
<td>Gross: 650 ha</td>
<td><strong>Drainage area 6675.6 km$^2$</strong></td>
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<tr>
<td></td>
<td></td>
<td>Net: 550 ha</td>
<td>1964-1969</td>
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<td>Commissioning Date: 1974</td>
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<tr>
<td></td>
<td></td>
<td><strong>Tigris Irrigation Module</strong></td>
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<td></td>
<td><strong>Rate of return: 20%</strong></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td><strong>Drainage area 6298.4 km$^2$</strong></td>
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<td></td>
<td>1970-2000</td>
<td><strong>Kralkizi Dam</strong></td>
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<td></td>
<td></td>
<td><strong>Drainage area 5655.2 km$^2$</strong></td>
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<tr>
<td></td>
<td></td>
<td><strong>Commissioning</strong></td>
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<td>Date: October 1997</td>
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<td><strong>Dicke Dam</strong></td>
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<td><strong>Commissioning</strong></td>
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EIE 2604 | 1946-1962      | -                  | -           |

60
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</tbody>
</table>

- **Silvan Irrigation**
  - Gross: 8790 ha
  - Net: 7590 ha
  - Commissioning Date: 1972
- **Kabaklı 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
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<tr>
<th>Station</th>
<th>Valuable Years</th>
<th>Naturalised due to</th>
<th>Extended by</th>
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</table>
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 12 (cont’d)

<table>
<thead>
<tr>
<th>Station</th>
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<th>Extended by</th>
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<tr>
<td>EIE 2611</td>
<td></td>
<td>• Gozegol Irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Gross: 650 ha</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Net: 550 ha</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Commissioning</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Date: 1974</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Tigris Irrigation Module</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rate of return: 20%</td>
<td></td>
</tr>
<tr>
<td>Project</td>
<td>Equation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mutki Derivation</td>
<td>( Q_{\text{Mutki}} = \frac{(Q_{26-58} - Q_{26-57})}{A_{26-58} - A_{26-57}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aysehatun Dam and HEPP</td>
<td>( Q_{\text{Aysehatun}} = \frac{A_{\text{Aysehatun}}}{A_{26-57}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kor Dam and HEPP</td>
<td>( Q_{\text{Kor}} = \frac{A_{\text{Kor}}}{A_{26-58}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garzan Dam and HEPP</td>
<td>( Q_{\text{Garzan}} = \frac{A_{\text{Garzan}}}{A_{26-24}} )</td>
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<td></td>
</tr>
<tr>
<td>Kotum Derivation</td>
<td>( Q_{\text{Kotum}} = Q_{25-14} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guzeldere Dam and HEPP</td>
<td>( Q_{\text{Guzeldere}} = \frac{A_{\text{Guzeldere}}}{A_{26-28}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sirvan Dam and HEPP</td>
<td>( Q_{\text{Sirvan}} = \frac{A_{\text{Sirvan}}}{A_{2624}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basoren Dam and HEPP</td>
<td>( Q_{\text{Basoren}} = \frac{A_{\text{Basoren}}}{A_{2610}} )</td>
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<td></td>
</tr>
<tr>
<td>Narli Dam and HEPP</td>
<td>( Q_{\text{Narli}} = \frac{A_{\text{Narli}} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oran Dam and HEPP</td>
<td>( Q_{\text{Oran}} = \frac{A_{\text{Oran}} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}} )</td>
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</tr>
<tr>
<td>Keskin Dam and HEPP</td>
<td>( Q_{\text{Keskin}} = \frac{A_{\text{Keskin}} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}} )</td>
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</tr>
<tr>
<td>Mukus Derivation</td>
<td>( Q_{\text{Mukus}} = Q_{2615} )</td>
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</tr>
<tr>
<td>Pervari Dam and HEPP</td>
<td>( Q_{\text{Pervari}} = \frac{A_{\text{Pervari}} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}} )</td>
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<td></td>
</tr>
<tr>
<td>Cetin Dam and HEPP</td>
<td>( Q_{\text{Cetin}} = \frac{A_{\text{Cetin}} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}} )</td>
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</tr>
<tr>
<td>Alkumru Dam and HEPP</td>
<td>( Q_{\text{Alkumru}} = \frac{A_{\text{Alkumru}} - A_{26-55}}{A_{2633} - A_{2615} - A_{26-55}} )</td>
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</tr>
<tr>
<td>Eruh Dam and HEPP</td>
<td>( Q_{\text{Eruh}} = \frac{A_{\text{Eruh}}}{A_{2633}} )</td>
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</tr>
<tr>
<td>Anbar Dam</td>
<td>( Q_{\text{Anbar}} = \frac{A_{\text{Anbar}} - A_{26-39}}{A_{2633} - A_{2618} - A_{26-39}} )</td>
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</tr>
<tr>
<td>Kurucay Dam</td>
<td>( Q_{\text{Kurucay}} = \frac{A_{\text{Kurucay}}}{A_{26-14}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pamukcay Dam</td>
<td>( Q_{\text{Pamukcay}} = \frac{A_{\text{Pamukcay}}}{A_{26-32}} )</td>
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<td></td>
</tr>
<tr>
<td>Baslar Dam</td>
<td>( Q_{\text{Baslar}} = \frac{A_{\text{Baslar}}}{A_{26-12}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project</td>
<td>Equation</td>
<td></td>
<td></td>
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<tr>
<td>-------------------------------</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Bulaklidere Dam</td>
<td>( Q_{Bulaklidere} = \frac{A_{Bulaklidere}}{A_{26-12}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kibris Dam</td>
<td>( Q_{Kibris} = \frac{A_{Kibris}}{A_{26-60}} )</td>
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<td></td>
</tr>
<tr>
<td>Karacalar Dam</td>
<td>( Q_{Karacalar} = \frac{A_{Karacalar}}{A_{26-60}} )</td>
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<td></td>
</tr>
<tr>
<td>Silvan Dam and HEPP</td>
<td>( Q_{Silvan} = \frac{A_{Silvan}}{A_{2612}} )</td>
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</tr>
<tr>
<td>Batman Dam and HEPP</td>
<td>( Q_{Batman} = \frac{A_{Batman}}{A_{2612}} )</td>
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</tr>
<tr>
<td>Ergani Dam</td>
<td>( Q_{Ergani} = \frac{A_{Ergani}}{A_{26-62}} )</td>
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</tr>
<tr>
<td>Devegecidi Dam</td>
<td>( Q_{Devegecidi} = \frac{A_{Devegecidi}}{A_{26-09}} )</td>
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<tr>
<td>Dipni Dam and HEPP</td>
<td>( Q_{Dipni} = \frac{A_{Dipni}}{A_{2632}} )</td>
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<tr>
<td>Kralkizi Dam and HEPP</td>
<td>( Q_{Kralkizi} = \frac{A_{Kralkizi}}{A_{2617}} )</td>
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</tr>
<tr>
<td>Dicle Dam and HEPP</td>
<td>( Q_{Dicle} = Q_{2617} + Q_{2632} + (Q_{2605} - Q_{26-09} - Q_{2632} - Q_{2617}) )</td>
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</tr>
<tr>
<td>Ilisu Dam and HEPP</td>
<td>( Q_{Ilisu} = \frac{A_{Ilisu}}{A_{2611}} )</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Project</th>
<th>Upstream</th>
<th>Reservoir</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aysehatun Dam and HEPP</td>
<td>-</td>
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</tr>
<tr>
<td>Kor Dam and HEPP</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Garzan Dam and HEPP</td>
<td>-</td>
<td>-</td>
<td>Garzan Irrigation Module</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Net: 60000 ha</td>
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<td></td>
<td>Rate of return: 20%</td>
</tr>
<tr>
<td>Guzeldere Dam and HEPP</td>
<td>-</td>
<td>Tatvan Water Supply</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Demand: 0.35 m³/s</td>
<td></td>
</tr>
<tr>
<td>Sirvan Dam and HEPP</td>
<td>-</td>
<td>-</td>
<td>Siirt Water Supply Module</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Demand: 0.60 m³/s</td>
</tr>
<tr>
<td>Basoren Dam and HEPP</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Narlı Dam and HEPP</td>
<td>-</td>
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<tr>
<td>Oran Dam and HEPP</td>
<td>-</td>
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</tr>
<tr>
<td>Keskin Dam and HEPP</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Pervari Dam and HEPP</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Çetin Dam and HEPP</td>
<td>-</td>
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<tr>
<td>Alkumru Dam and HEPP</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Erhu Dam and HEPP</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Anbar Dam</td>
<td></td>
<td></td>
<td>Anbar Irrigation Module</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Batman - Silvan Irrigation Module</td>
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<td></td>
<td></td>
<td></td>
<td>Rate of return: 15%</td>
</tr>
<tr>
<td>Kurucay Dam</td>
<td></td>
<td></td>
<td>Kurucay Irrigation Module</td>
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<td></td>
<td></td>
<td>Batman - Silvan Irrigation Module</td>
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<tr>
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<td>Rate of return: 15%</td>
</tr>
<tr>
<td>Pamukcay Dam</td>
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<td>Pamukcay Irrigation Module</td>
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<td>Batman - Silvan Irrigation Module</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Rate of return: 15%</td>
</tr>
</tbody>
</table>

- **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%**
Table 14 (cont’d)

<table>
<thead>
<tr>
<th>Project</th>
<th>Upstream</th>
<th>Reservoir</th>
<th>Downstream</th>
</tr>
</thead>
</table>
| 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)

<table>
<thead>
<tr>
<th>Project</th>
<th>Upstream</th>
<th>Reservoir</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silvan Dam and HEPP</td>
<td>-</td>
<td>• Silvan Irrigation&lt;br&gt;Gravity - Fed&lt;br&gt;Gross: 171284 ha&lt;br&gt;Net: 149531 ha</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pumping - Fed&lt;br&gt;Gross: 31022 ha&lt;br&gt;Net: 27082 ha</td>
<td>-</td>
</tr>
<tr>
<td>Batman Dam and HEPP</td>
<td>-</td>
<td>• Batman Irrigation&lt;br&gt;Gravity - Fed&lt;br&gt;Gross: 37744 ha&lt;br&gt;Net: 32951 ha</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Batman - Silvan Irrigation Module&lt;br&gt;Rate of return: 15%</td>
<td>-</td>
</tr>
<tr>
<td>Ergani Dam</td>
<td>-</td>
<td>• Ergani Irrigation&lt;br&gt;Gross: 1861 ha&lt;br&gt;Net: 1861 ha</td>
<td>-</td>
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<td>Return flows of Kirkat (Gercus) Irrigation Gross: 350 ha Net: 348 ha</td>
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#### 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).
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, \( D_{\text{Siirt}} \).

\[
\sum_j R_{\text{Basoren},j,t}^p + R_{\text{Basoren},t}^s + R_{\text{Basoren},t}^{de} + \sum_j R_{\text{Sirvan},j,t}^p + R_{\text{Sirvan},t}^s + R_{\text{Sirvan},t}^{de} \geq D_{\text{Siirt}}
\]  

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, $D_{\text{Cizre},t}$.

$$\sum_{j} R_{\text{Ilisu},j,t} + R_{\text{Ilisu},t} \geq D_{\text{Cizre},t} \quad (31)$$

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.
### Operation Results of the Tigris Power Plants

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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Efficiency of turbine 4</td>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Efficiency of turbine 5</td>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Efficiency of turbine 6</td>
<td></td>
<td>0.67</td>
<td>0.92</td>
<td>0.92</td>
<td>0.92</td>
<td>0.92</td>
<td>0.92</td>
</tr>
<tr>
<td>Net head</td>
<td>m</td>
<td>81.13</td>
<td>81.12</td>
<td>81.12</td>
<td>81.10</td>
<td>81.11</td>
<td>81.09</td>
</tr>
<tr>
<td>Spillway release</td>
<td>hm³</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Storage ratio</td>
<td>%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Produced energy</td>
<td>GWh</td>
<td>18.99</td>
<td>110.31</td>
<td>127.92</td>
<td>220.55</td>
<td>159.96</td>
<td>229.95</td>
</tr>
</tbody>
</table>

System: **7371.82** GWh
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.
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/km² and the submerged specific weight is 1.31 t/m³. 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 m³/year/km². The total area controlled by the upstream projects is 23016.8 km². By subtracting this area from the total drainage area of the Ilisu Reservoir, a region of 13391.2 km² 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 hm³ (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

<table>
<thead>
<tr>
<th><strong>EIE 2606 Dicle River - Cizre</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Net drainage area</strong> : 30774.7 km²</td>
</tr>
</tbody>
</table>
| **Degree of dispersion** : Clay + Silt 49.7%  
  Sand 50.3% |
| **Submerged specific weight** : 1.31 t/m³ |
| **Sediment amount** : 22557064 t/year  
  17219133 m³/year |
| **Sediment yield** : 733 t/year/km²  
  560 m³/year/km² |
| **Suspended sediment load** : 733 t/year/km² |
| **Bed load** : 183 ton/year/km² |
| **Total sediment load** : 916 ton/year/km²  
  699 m³/year/km² |

<table>
<thead>
<tr>
<th><strong>Ilisu Dam</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drainage area</strong> : 36408.0 km²</td>
</tr>
<tr>
<td><strong>Net drainage area</strong> : 13391.2 km²</td>
</tr>
</tbody>
</table>

**Upstream Projects**  
**Catchment Area (km²)**

<table>
<thead>
<tr>
<th>Project</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkumru Dam</td>
<td>7562.5</td>
</tr>
<tr>
<td>Batman Dam</td>
<td>4105.0</td>
</tr>
<tr>
<td>Dicle Dam</td>
<td>3216.0</td>
</tr>
<tr>
<td>Devegecidi Dam</td>
<td>1576.0</td>
</tr>
<tr>
<td>Garzan Dam</td>
<td>1266.0</td>
</tr>
<tr>
<td>Sirvan Dam</td>
<td>1010.0</td>
</tr>
<tr>
<td>Basoren Dam</td>
<td>737.3</td>
</tr>
<tr>
<td>Bespinar Pond</td>
<td>733.0</td>
</tr>
<tr>
<td>Goksu Dam</td>
<td>672.0</td>
</tr>
<tr>
<td>Eruh Dam</td>
<td>600.0</td>
</tr>
<tr>
<td>Anbar Dam</td>
<td>480.0</td>
</tr>
<tr>
<td>Pamukcay Dam</td>
<td>312.5</td>
</tr>
<tr>
<td>Gozegol Pond</td>
<td>156.2</td>
</tr>
<tr>
<td>Kibris Dam</td>
<td>150.0</td>
</tr>
<tr>
<td>Baslar Dam</td>
<td>136.0</td>
</tr>
<tr>
<td>Kuruçay Dam</td>
<td>122.0</td>
</tr>
<tr>
<td>Bulaklidere Dam</td>
<td>88.0</td>
</tr>
<tr>
<td>Kirkat Pond</td>
<td>40.3</td>
</tr>
<tr>
<td>Karacalar Dam</td>
<td>32.5</td>
</tr>
<tr>
<td>Kabakli Pond</td>
<td>21.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>23016.8</strong></td>
</tr>
</tbody>
</table>

| **Economic lifetime period** : 50 year |
| **Total sediment amount** : 468.31 hm³ |
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

<table>
<thead>
<tr>
<th>Produced Energy (GWh)</th>
<th>Months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>without constraint on Silopi and Nusaybin-Idil-Cizre Irrigations</td>
<td>63.6</td>
</tr>
<tr>
<td>with constraint on Silopi and Nusaybin-Idil-Cizre Irrigations</td>
<td>55.8</td>
</tr>
<tr>
<td>with constraint on Silopi and Nusaybin-Idil-Cizre Irrigations &amp; reduced storage of the Ilisu Reservoir</td>
<td>57.6</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Optimised Operation System</th>
<th>Inflow Values</th>
<th>Special Case</th>
<th>Produced Energy (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tigris</td>
<td>Mean</td>
<td>-</td>
<td>Aysehatun</td>
</tr>
<tr>
<td>1-year</td>
<td></td>
<td>with constraint on Silopi and Nusaybin-Idil-Cizre Irrigations &amp; reduced storage of the Ilisu Reservoir</td>
<td>170.80</td>
</tr>
<tr>
<td>Tigris</td>
<td>Mean</td>
<td>-</td>
<td>Aysehatun</td>
</tr>
<tr>
<td>1-year</td>
<td></td>
<td>-</td>
<td>186.52</td>
</tr>
<tr>
<td>Garzan</td>
<td>Mean</td>
<td>-</td>
<td>Aysehatun</td>
</tr>
<tr>
<td>1-year</td>
<td></td>
<td>-</td>
<td>212.98</td>
</tr>
<tr>
<td>Garzan</td>
<td>30-year</td>
<td>Historical</td>
<td>Aysehatun</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>211.41</td>
</tr>
</tbody>
</table>

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).
REFERENCES


APPENDIX A

NLP MODEL OF THE GARZAN HYDROPOWER SYSTEM

$Title$ 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_j(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 R1_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 R2_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 R3_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), R1_1t(t), R1_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), R2_1t(t), R2_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), R3_1t(t), R3_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;

*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= -0.0000000000010405 * S1(t)**2
+ 0.030310742571682 * S1(t) + 5311009.03784554;
level1(t). WL1(t) =E= -0.0000000000000005026 * S1(t)**2 + 0.000000104779418573 * 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))) * f1K1;

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). incl(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= 0.0000000000285871 * S2(t)**2 + 0.011932386521108 * S2(t) + 542187.347991712;

level2(t). WL2(t) =E= -0.0000000000000011 * S2(t)**2 + 0.000001523716715 * 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))) * f1K2;

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) = E= ep(t) * 0.985 * 0.975 * 24 * day(t) * 9.81 * NhH2(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) = 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) = G= Rt3_1t(t) + Rt3_2t(t) + Rs3(t) + D3(t) =

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

level3(t) = E= -0.0000000000000100122 * S3(t)**2 + 
0.00000054974910801169 * S3(t) + 721.461681514073;

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

net_head3(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) = 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) = 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) = E= ep(t) * 0.985 * 0.975 * 24 * day(t) * 9.81 * NhH3(t) * ((eff3_1t(t) * (Rt3_1t(t) / (24 * day(t) * 3600))) + (eff3_2t(t) * (Rt3_2t(t) / (24 * day(t) * 3600))));

OPTION ITERLIM= 1000000000;
OPTION OPTCR= 0.000000000000000000000001;
OPTION LIMROW= 12;
OPTION nlp = minos5;

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

PARAMETER
pwr1(t), pwr2(t), pwr3(t);
\[
pwr_1(t) = 9.81 \times N_{tH1.t}(t) \times ((\text{eff}_{1_1t}(t) \times (R_{t1_1t}(t) / (24 \times \text{day}(t) \times 3600))) + (\text{eff}_{1_2t}(t) \times (R_{t1_2t}(t) / (24 \times \text{day}(t) \times 3600))));
\]

\[
pwr_2(t) = 9.81 \times N_{tH2.t}(t) \times ((\text{eff}_{2_1t}(t) \times (R_{t2_1t}(t) / (24 \times \text{day}(t) \times 3600))) + (\text{eff}_{2_2t}(t) \times (R_{t2_2t}(t) / (24 \times \text{day}(t) \times 3600))));
\]

\[
pwr_3(t) = 9.81 \times N_{tH3.t}(t) \times ((\text{eff}_{3_1t}(t) \times (R_{t3_1t}(t) / (24 \times \text{day}(t) \times 3600))) + (\text{eff}_{3_2t}(t) \times (R_{t3_2t}(t) / (24 \times \text{day}(t) \times 3600))));
\]
APPENDIX B

NLP MODEL OF THE TIGRIS HYDROPOWER SYSTEM

$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
Rs_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 /0.3099/;
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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<td>Oran Dam and HEPP</td>
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<td>$S_7$ min</td>
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<td>$R_{s10, max}$</td>
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107
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 /2473056000/;
SCALAR beg_S12 /151177877.36/;
SCALAR beg_A12 /5281732.08/;
SCALAR beg_WL12 /611.8/;
SCALAR twe12 /541.8/;
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SCALAR Rs12_max /16097184000/;

*Eruh Dam and HEPP
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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/;
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SCALAR Rs14_max /4282761600/;

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

*Pamukcay Dam
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SCALAR S16_min /17000000/;
SCALAR beg_S16 /17000000/;
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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/;
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/;
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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 f1K21 /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 f1K22 /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/;
SCALAR beg_S25 /209000000/;
SCALAR beg_A25 /1317200.98/;
SCALAR beg_WL25 /820.45/;
SCALAR twe25 /715/;
SCALAR fK25 /0.0087/;
SCALAR Rs25_max /10962691200/;

*Kalkizi Dam and HEPP
SCALAR S25_max /1919600000/;
SCALAR S25_min /208000000/;
SCALAR Rt25_2t_max /192844800/;
SCALAR beg_S25 /208000000/;
SCALAR beg_A25 /8621336.50/;
SCALAR beg_WL25 /763.10/;
SCALAR twe26 /708/;
SCALAR fK26 /0.0001/;
SCALAR Rs26_max /838392000/;

*Dicle 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 fK26 /0.0001/;
SCALAR Rs26_max /838392000/;

*Ilisu Dam and HEPP
SCALAR S27_max /10926322092.69/;
SCALAR S27_min /3078721306.26/;
SCALAR Rt28_6t_max /565142400/;
SCALAR beg_S27 /3078721306.26/;
SCALAR beg_A27 /112440535.39/;
SCALAR beg_WL28 /485.40/;
SCALAR twe28 /400/;
SCALAR fK28 /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
$include 13_Eruh.inc
$include 14_Anbar.inc
$include 15_Kurucay.inc
$include 16_Famukcay.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),
*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),
*Dipni Dam and HEPP
S25(t), A25(t), WL25(t), Rt25_1t(t), Rt25_2t(t), Rs25(t),
AvWL25(t), NCH25(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), NCH26(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), NCH27(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;
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;
Rs1.LO(t)=Rs1_min;
Rs2.UP(t)=Rs2_max;
Rs2.LO(t)=Rs2_min;
Rs3.UP(t)=Rs3_max;
Rs3.LO(t)=Rs3_min;
Rs4.UP(t)=Rs4_max;
Rs4.LO(t)=Rs4_min;
Rs5.UP(t)=Rs5_max;
Rs5.LO(t)=Rs5_min;
Rs6.UP(t)=Rs6_max;
Rs6.LO(t)=Rs6_min;
Rs7.UP(t)=Rs7_max;
Rs7.LO(t)=Rs7_min;
Rs8.UP(t)=Rs8_max;
Rs8.LO(t)=Rs8_min;
Rs9.UP(t)=Rs9_max;
Rs9.LO(t)=Rs9_min;
Rs10.UP(t)=Rs10_max;
Rs10.LO(t)=Rs10_min;
Rs11.UP(t)=Rs11_max;
Rs11.LO(t)=Rs11_min;
Rs12.UP(t)=Rs12_max;
Rs12.LO(t)=Rs12_min;
Rs13.UP(t)=Rs13_max;
Rs13.LO(t)=Rs13_min;
Rs14.UP(t)=Rs14_max;
Rs14.LO(t)=Rs14_min;
Rs15.UP(t)=Rs15_max;
Rs15.LO(t)=Rs15_min;
Rs16.UP(t)=Rs16_max;
Rs16.LO(t)=Rs16_min;
Rs17.UP(t)=Rs17_max;
Rs17.LO(t)=Rs17_min;
Rs18.UP(t)=Rs18_max;
Rs18.LO(t)=Rs18_min;
Rs19.UP(t)=Rs19_max;
Rs19.LO(t)=Rs19_min;
Rs20.UP(t)=Rs20_max;
Rs20.LO(t)=Rs20_min;
Rs21.UP(t)=Rs21_max;
Rs21.LO(t)=Rs21_min;
Rs22.UP(t)=Rs22_max;
Rs22.LO(t)=Rs22_min;
Rs23.UP(t)=Rs23_max;
Rs23.LO(t)=Rs23_min;
Rs24.UP(t)=Rs24_max;
Rs24.LO(t)=Rs24_min;
Rs25.UP(t)=Rs25_max;
Rs25.LO(t)=Rs25_min;
Rs26.UP(t)=Rs26_max;
Rs26.LO(t)=Rs26_min;
Rs27.UP(t)=Rs27_max;
Rs27.LO(t)=Rs27_min;
Rs28.UP(t)=Rs28_max;
Rs28.LO(t)=Rs28_min;

S1.UP('t12')=S1_min;
S1.LO('t12')=S1_min;
S2.UP('t12')=S2_min;
S2.LO('t12')=S2_min;
S3.UP('t12')=S3_min;
S3.LO('t12')=S3_min;
S4.UP('t12')=S4_min;
S4.LO('t12')=S4_min;
S5.UP('t12')=S5_min;
S5.LO('t12')=S5_min;
S6.UP('t12')=S6_min;
S6.LO('t12')=S6_min;
S7.UP('t12')=S7_min;
S7.LO('t12')=S7_min;
S8.UP('t12')=S8_min;
S8.LO('t12')=S8_min;
S9.UP('t12')=S9_min;
S9.LO('t12')=S9_min;
S10.UP('t12')=S10_min;
S10.LO('t12')=S10_min;
S11.UP('t12')=S11_min;
S11.LO('t12')=S11_min;
S12.UP('t12')=S12_min;
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;
Rt9_4t.UP(t) = Rt9_4t_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;
Rt14_1t.UP(t) = Rt14_4t_max;
Rt14_2t.UP(t) = Rt14_4t_max;
Rt15_3t.UP(t) = Rt15_4t_max;
Rt15_4t.UP(t) = Rt15_4t_max;
Rt15_5t.UP(t) = Rt15_4t_max;
Rt20_1t.UP(t) = Rt20_3t_max;
Rt20_2t.UP(t) = Rt20_3t_max;
Rt20_3t.UP(t) = Rt20_3t_max;
Rt20_4t.UP(t) = Rt20_3t_max;
Rt20_5t.UP(t) = Rt20_3t_max;
Rt25_1t.UP(t) = Rt25_2t_max;
\text{Rt25}_2t.U(t) = \text{Rt25}_2t_{\text{max}}; \\
\text{Rt26}_1t.U(t) = \text{Rt26}_2t_{\text{max}}; \\
\text{Rt26}_2t.U(t) = \text{Rt26}_2t_{\text{max}}; \\
\text{Rt27}_1t.U(t) = \text{Rt27}_2t_{\text{max}}; \\
\text{Rt27}_2t.U(t) = \text{Rt27}_2t_{\text{max}}; \\
\text{Rt28}_1t.U(t) = \text{Rt28}_6t_{\text{max}}; \\
\text{Rt28}_2t.U(t) = \text{Rt28}_6t_{\text{max}}; \\
\text{Rt28}_3t.U(t) = \text{Rt28}_6t_{\text{max}}; \\
\text{Rt28}_4t.U(t) = \text{Rt28}_6t_{\text{max}}; \\
\text{Rt28}_5t.U(t) = \text{Rt28}_6t_{\text{max}}; \\
\text{Rt28}_6t.U(t) = \text{Rt28}_6t_{\text{max}}; \\

*starting points* \\
\text{Rt1}_1t.L(t) = \text{Rt1}_2t_{\text{max}}; \\
\text{Rt1}_2t.L(t) = \text{Rt1}_2t_{\text{max}}; \\
\text{Rt2}_1t.L(t) = \text{Rt2}_2t_{\text{max}}; \\
\text{Rt2}_2t.L(t) = \text{Rt2}_2t_{\text{max}}; \\
\text{Rt3}_1t.L(t) = \text{Rt3}_2t_{\text{max}}; \\
\text{Rt3}_2t.L(t) = \text{Rt3}_2t_{\text{max}}; \\
\text{Rt4}_1t.L(t) = \text{Rt4}_2t_{\text{max}}; \\
\text{Rt4}_2t.L(t) = \text{Rt4}_2t_{\text{max}}; \\
\text{Rt5}_1t.L(t) = \text{Rt5}_2t_{\text{max}}; \\
\text{Rt5}_2t.L(t) = \text{Rt5}_2t_{\text{max}}; \\
\text{Rt6}_1t.L(t) = \text{Rt6}_2t_{\text{max}}; \\
\text{Rt6}_2t.L(t) = \text{Rt6}_2t_{\text{max}}; \\
\text{Rt7}_1t.L(t) = \text{Rt7}_2t_{\text{max}}; \\
\text{Rt7}_2t.L(t) = \text{Rt7}_2t_{\text{max}}; \\
\text{Rt8}_1t.L(t) = \text{Rt8}_2t_{\text{max}}; \\
\text{Rt8}_2t.L(t) = \text{Rt8}_2t_{\text{max}}; \\
\text{Rt9}_1t.L(t) = \text{Rt9}_3t_{\text{max}}; \\
\text{Rt9}_2t.L(t) = \text{Rt9}_3t_{\text{max}}; \\
\text{Rt9}_3t.L(t) = \text{Rt9}_3t_{\text{max}}; \\
\text{Rt10}_1t.L(t) = \text{Rt10}_4t_{\text{max}}; \\
\text{Rt10}_2t.L(t) = \text{Rt10}_4t_{\text{max}}; \\
\text{Rt10}_3t.L(t) = \text{Rt10}_4t_{\text{max}}; \\
\text{Rt10}_4t.L(t) = \text{Rt10}_4t_{\text{max}}; \\
\text{Rt11}_1t.L(t) = \text{Rt11}_5t_{\text{max}}; \\
\text{Rt11}_2t.L(t) = \text{Rt11}_5t_{\text{max}}; \\
\text{Rt11}_3t.L(t) = \text{Rt11}_5t_{\text{max}}; \\
\text{Rt11}_4t.L(t) = \text{Rt11}_5t_{\text{max}}; \\
\text{Rt11}_5t.L(t) = \text{Rt11}_5t_{\text{max}}; \\
\text{Rt12}_1t.L(t) = \text{Rt12}_3t_{\text{max}}; \\
\text{Rt12}_2t.L(t) = \text{Rt12}_3t_{\text{max}}; \\
\text{Rt12}_3t.L(t) = \text{Rt12}_3t_{\text{max}}; \\
\text{Rt13}_1t.L(t) = \text{Rt13}_2t_{\text{max}}; \\
\text{Rt13}_2t.L(t) = \text{Rt13}_2t_{\text{max}};
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),
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),

*Devegeci 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),
efficiency25_3t(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),
efficiency26_3t(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),
efficiency27_3t(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$(ord(t) EQ 1) + S1(t-1)$S(ord(t) GT 1) + Q1(t) - Rt1_1t(t) - Rt1_2t(t) - Rs1(t) - D1(t) - E1(t) *
beg_A1$(ord(t) EQ 1) + A1(t-1)$S(ord(t) GT 1));
area1(t).. A1(t) =E= -0.0000000000010405 * S1(t)**2 + 0.030310742571682 * S1(t) + 5311009.03784554;
level1(t).. WL1(t) =E= -0.000000000000000005026 * S1(t)**2 + 0.000000104779418573 * S1(t) + 1208.56628735606;
ave_level1(t).. AvWL1(t) =E= ((beg_WL1 $(ord(t) EQ 1) + WL1(t-1)$S(ord(t) GT 1)) + WL1(t)) / 2;
net_head1(t).. NtH1(t) =E= (AvWL1(t) - twel) * 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))) * fK1;

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)) + 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))) + (eff2_1t(t) * (Rt2_1t(t) / (24 * day(t) * 3600))));

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) *
(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= -0.0000000000000100122 * S3(t)**2 + 0.0000054979410801169 * 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= 0.000000000070914938797* S4(t)**2 + 0.0283167682444349 * S4(t) + 866387.569904218;

level4(t).. WL4(t) =E= -0.0000000000000926947* S4(t)**2 + 0.0000097016482745947* 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) / Rt4_2t_max)**3)) - (13.6479 * ((Rt4_1t(t) / Rt4_2t_max)**2)) + (5.1611 * (Rt4_1t(t) / Rt4_2t_max));
efficiency4_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) =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))));
level6(t) .. WL6(t) =E= -0.00000000000000878115 * 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) .. Nt6(t) =E= (AvWL6(t) - twe6(t)) * 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 * (Rt6_1t(t) + Rt6_2t(t) + Rs5(t) + D5(t) + Rt6_1t(t) + Rt6_2t(t) + Rs6(t) + D6(t)) * flK6;

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= -0.000000000014752816534 * S7(t)**2 + 0.03813514196672350000 * S7(t) + 194569.54853835;

level7(t) .. WL7(t) =E= -0.000000000000000575896 * S7(t)**2 + 0.000000000000000575896 * 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) .. Nt7(t) =E= (AvWL7(t) - tween7(t)) * 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 * ((Rt7_2t(t) / Rt7_2t_max)**3)) * (13.6479 * ((Rt7_2t(t) / Rt7_2t_max)**2)) + (5.1611 * (Rt7_2t(t) / Rt7_2t_max));
((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= -0.00000000000912024038 * S8(t)**2 + 0.0298598482442959 * S8(t) + 224018.558801985;

level8(t) .. WL8(t) =E= -0.0000000000000734449 * S8(t)**2 + 0.0000133510205382715 * 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= -0.00000000002464184466 * S9(t)**2 + 0.0296284465913661 * S9(t) - 1103325.02966546;

level9(t) .. WL9(t) =E= -0.0000000000043103 * S9(t)**2 + 0.000004391579660186 * 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;
\[
net\_head9(t) = E \frac{(AVWL9(t) - twe9) \times 0.95 - \left(\frac{(Rt9\_1t(t) \times 24 \times day(t) \times 3600) + (Rt9\_2t(t) \times 24 \times day(t) \times 3600) + (Rt9\_3t(t) \times 24 \times day(t) \times 3600) + (Rt9\_2t(t) \times 24 \times day(t) \times 3600) + (Rt9\_3t(t) \times 24 \times day(t) \times 3600)}{95} \right)}{24 \times day(t) \times 3600}}{\times (flK9)};
\]

\[
\text{efficiency9}_1t(t) = E \left( -1.4849 \times \left(\frac{Rt9\_1t(t)}{Rt9\_3t\_max}\right)^6 + 7.4008 \times \left(\frac{Rt9\_1t(t)}{Rt9\_3t\_max}\right)^5 - 16.7253 \times \left(\frac{Rt9\_1t(t)}{Rt9\_3t\_max}\right)^4 + 20.2156 \times \left(\frac{Rt9\_1t(t)}{Rt9\_3t\_max}\right)^3 - 13.6479 \times \left(\frac{Rt9\_1t(t)}{Rt9\_3t\_max}\right)^2 + 5.1611 \times \left(\frac{Rt9\_1t(t)}{Rt9\_3t\_max}\right) \right) \times (flK9);
\]

\[
\text{efficiency9}_2t(t) = E \left( -1.4849 \times \left(\frac{Rt9\_2t(t)}{Rt9\_3t\_max}\right)^6 + 7.4008 \times \left(\frac{Rt9\_2t(t)}{Rt9\_3t\_max}\right)^5 - 16.7253 \times \left(\frac{Rt9\_2t(t)}{Rt9\_3t\_max}\right)^4 + 20.2156 \times \left(\frac{Rt9\_2t(t)}{Rt9\_3t\_max}\right)^3 - 13.6479 \times \left(\frac{Rt9\_2t(t)}{Rt9\_3t\_max}\right)^2 + 5.1611 \times \left(\frac{Rt9\_2t(t)}{Rt9\_3t\_max}\right) \right) \times (flK9);
\]

\[
\text{efficiency9}_3t(t) = E \left( -1.4849 \times \left(\frac{Rt9\_3t(t)}{Rt9\_3t\_max}\right)^6 + 7.4008 \times \left(\frac{Rt9\_3t(t)}{Rt9\_3t\_max}\right)^5 - 16.7253 \times \left(\frac{Rt9\_3t(t)}{Rt9\_3t\_max}\right)^4 + 20.2156 \times \left(\frac{Rt9\_3t(t)}{Rt9\_3t\_max}\right)^3 - 13.6479 \times \left(\frac{Rt9\_3t(t)}{Rt9\_3t\_max}\right)^2 + 5.1611 \times \left(\frac{Rt9\_3t(t)}{Rt9\_3t\_max}\right) \right) \times (flK9);
\]

\[
\text{energy9}(t) = E \frac{0.985 \times 0.975 \times 24 \times day(t) \times 9.81 \times (NtH9(t) \times (\text{efficiency9}_1t(t) \times \left(\frac{Rt9\_1t(t)}{24 \times day(t) \times 3600}\right)) + (\text{efficiency9}_2t(t) \times \left(\frac{Rt9\_2t(t)}{24 \times day(t) \times 3600}\right)) + (\text{efficiency9}_3t(t) \times \left(\frac{Rt9\_3t(t)}{24 \times day(t) \times 3600}\right)))}{Pervari\ Dam\ and\ HEPP}
\]

\[
\text{balance10}(t) = E \frac{\text{beg}\_S10(\text{ord}(t) \text{EQ} 1) + S10(t-1)(\text{ord}(t) \text{GT} 1) + Q10(t) - Rt10\_1t(t) - Rt10\_2t(t) - Rt10\_3t(t) - Rt10\_4t(t) - Rs10(t) - D10(t) - E10(t) \times (\text{beg}\_A10(\text{ord}(t) \text{EQ} 1) + A10(t-1)(\text{ord}(t) \text{GT} 1)) + Rt9\_1t(t) + Rt9\_2t(t) + Rt9\_3t(t) + Rs9(t) + D9(t)}{area10(t) = E \frac{-0.00000000001954957843 \times S10(t) \times 2 + 0.0176108160825508 \times S10(t) + 623348.3519888101}{level10(t) = E \frac{-0.0000000000000066174 \times S10(t) \times 2 + 0.0000005621329057088 \times S10(t) + 883.685020854896}{ave\_level10(t) = E \frac{(\text{beg}\_WL10 \times (\text{ord}(t) \text{EQ} 1) + WL10(t-1)(\text{ord}(t) \text{GT} 1)) \times WL10(t) \times 2;}{net\_head10(t) = E \frac{\text{AvWL10}(t) - twe10) \times 0.95 - ((Rt10\_1t(t) \times 24 \times day(t) \times 3600)) + (Rt10\_2t(t) \times 24 \times day(t) \times 3600)) + (Rt10\_3t(t) \times 24 \times day(t) \times 3600)) + (Rt10\_4t(t) \times 24 \times day(t) \times 3600)) \times (flK10)}{efficiency10\_1t(t) = E \left( -1.4849 \times \left(\frac{Rt10\_1t(t)}{Rt10\_4t\_max}\right)^6 + 7.4008 \times \left(\frac{Rt10\_1t(t)}{Rt10\_4t\_max}\right)^5 - 16.7253 \times \left(\frac{Rt10\_1t(t)}{Rt10\_4t\_max}\right)^4 + 20.2156 \times \left(\frac{Rt10\_1t(t)}{Rt10\_4t\_max}\right)^3 - 13.6479 \times \left(\frac{Rt10\_1t(t)}{Rt10\_4t\_max}\right)^2 + 5.1611 \times \left(\frac{Rt10\_1t(t)}{Rt10\_4t\_max}\right) \right) \times (flK10);
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= -0.000000000000011103 * 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) - twell) * 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));

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 *
\[(\frac{Rt_{11.2t}(t)}{Rt_{11.5t\max}})^3) - (13.6479 \times (\frac{Rt_{11.2t}(t)}{Rt_{11.5t\max}})^2) + (5.1611 \times (\frac{Rt_{11.2t}(t)}{Rt_{11.5t\max}}))\]

\[\text{efficiency}_{11.3t}(t) = \text{eff}\_11.3t(t) = - (1.4849 \times (\frac{Rt_{11.3t}(t)}{Rt_{11.5t\max}})^6) + (7.4008 \times (\frac{Rt_{11.3t}(t)}{Rt_{11.5t\max}})^5) - (16.7253 \times (\frac{Rt_{11.3t}(t)}{Rt_{11.5t\max}})^4) + (20.2156 \times (\frac{Rt_{11.3t}(t)}{Rt_{11.5t\max}})^3) - (13.6479 \times (\frac{Rt_{11.3t}(t)}{Rt_{11.5t\max}})^2) + (5.1611 \times (\frac{Rt_{11.3t}(t)}{Rt_{11.5t\max}}))\]

\[\text{efficiency}_{11.4t}(t) = \text{eff}\_11.4t(t) = - (1.4849 \times (\frac{Rt_{11.4t}(t)}{Rt_{11.5t\max}})^6) + (7.4008 \times (\frac{Rt_{11.4t}(t)}{Rt_{11.5t\max}})^5) - (16.7253 \times (\frac{Rt_{11.4t}(t)}{Rt_{11.5t\max}})^4) + (20.2156 \times (\frac{Rt_{11.4t}(t)}{Rt_{11.5t\max}})^3) - (13.6479 \times (\frac{Rt_{11.4t}(t)}{Rt_{11.5t\max}})^2) + (5.1611 \times (\frac{Rt_{11.4t}(t)}{Rt_{11.5t\max}}))\]

\[\text{efficiency}_{11.5t}(t) = \text{eff}\_11.5t(t) = - (1.4849 \times (\frac{Rt_{11.5t}(t)}{Rt_{11.5t\max}})^6) + (7.4008 \times (\frac{Rt_{11.5t}(t)}{Rt_{11.5t\max}})^5) - (16.7253 \times (\frac{Rt_{11.5t}(t)}{Rt_{11.5t\max}})^4) + (20.2156 \times (\frac{Rt_{11.5t}(t)}{Rt_{11.5t\max}})^3) - (13.6479 \times (\frac{Rt_{11.5t}(t)}{Rt_{11.5t\max}})^2) + (5.1611 \times (\frac{Rt_{11.5t}(t)}{Rt_{11.5t\max}}))\]

\[\text{energy}_{11}(t) = \text{eng}\_11(t) = 0.985 \times 0.975 \times 24 \times \text{day}(t) \times 9.81 \times \text{NtH}_{11}(t) \times (\text{eff}_{11.1t}(t) \times (\frac{Rt_{11.1t}(t)}{24 \times \text{day}(t) \times 3600})) + (\text{eff}_{11.2t}(t) \times (\frac{Rt_{11.2t}(t)}{24 \times \text{day}(t) \times 3600})) + (\text{eff}_{11.3t}(t) \times (\frac{Rt_{11.3t}(t)}{24 \times \text{day}(t) \times 3600})) + (\text{eff}_{11.4t}(t) \times (\frac{Rt_{11.4t}(t)}{24 \times \text{day}(t) \times 3600})) + (\text{eff}_{11.5t}(t) \times (\frac{Rt_{11.5t}(t)}{24 \times \text{day}(t) \times 3600}))\]

\[\text{balance}_{12}(t) = \text{beg}\_S12(\text{ord}(t) = 1) + \text{S12}(t-1) - \text{Q12}(t) - \text{Rt}_{12.1t}(t) - \text{Rt}_{12.2t}(t) - \text{Rt}_{12.3t}(t) - \text{Rs}_{12}(t) - \text{D12}(t) - \text{E12}(t) \times (\text{beg}\_A12(\text{ord}(t) = 1) + \text{A12}(t-1)) \times \text{flK}_{12}\]

\[\text{area}_{12}(t) = \text{A12}(t) = -0.00000000001559512673 \times \text{S12}(t)^2 + 0.029354038716462 \times \text{S12}(t) + 1200473.54745129\]

\[\text{level}_{12}(t) = \text{WL}_{12}(t) = -0.0000000000000014861 \times \text{S12}(t)^2 + 0.0000002121969217737 \times \text{S12}(t) + 583.116482562263\]

\[\text{ave}\_\text{level}_{12}(t) = \text{AvWL}_{12}(t) = (\text{beg}\_\text{WL}_{12}(\text{ord}(t) = 1) + \text{WL}_{12}(t-1)) / 2\]

\[\text{net}\_\text{head}_{12}(t) = \text{NtH}_{12}(t) = \text{AWL}_{12}(t) - \text{twe}_{12} \times 0.95 - (\text{Rt}_{12.1t}(t) / (24 \times \text{day}(t) \times 3600)) + (\text{Rt}_{12.2t}(t) / (24 \times \text{day}(t) \times 3600)) + (\text{Rt}_{12.3t}(t) / (24 \times \text{day}(t) \times 3600)) + (\text{Rt}_{12.4t}(t) / (24 \times \text{day}(t) \times 3600)) + (\text{Rt}_{12.5t}(t) / (24 \times \text{day}(t) \times 3600)) \times \text{flK}_{12}\]

\[\text{efficiency}_{12.1t}(t) = \text{eff}_{12.1t}(t) = - (1.4849 \times (\frac{Rt_{12.1t}(t)}{Rt_{12.3t\max}})^6) + (7.4008 \times (\frac{Rt_{12.1t}(t)}{Rt_{12.3t\max}})^5) - (16.7253 \times (\frac{Rt_{12.1t}(t)}{Rt_{12.3t\max}})^4) + (20.2156 \times (\frac{Rt_{12.1t}(t)}{Rt_{12.3t\max}})^3) - (13.6479 \times (\frac{Rt_{12.1t}(t)}{Rt_{12.3t\max}})^2) + (5.1611 \times (\frac{Rt_{12.1t}(t)}{Rt_{12.3t\max}}))\]

\[\text{efficiency}_{12.2t}(t) = \text{eff}_{12.2t}(t) = - (1.4849 \times (\frac{Rt_{12.2t}(t)}{Rt_{12.3t\max}})^6) + (7.4008 \times (\frac{Rt_{12.2t}(t)}{Rt_{12.3t\max}})^5) - (16.7253 \times (\frac{Rt_{12.2t}(t)}{Rt_{12.3t\max}})^4) + (20.2156 \times (\frac{Rt_{12.2t}(t)}{Rt_{12.3t\max}})^3) - (13.6479 \times (\frac{Rt_{12.2t}(t)}{Rt_{12.3t\max}})^2) + (5.1611 \times (\frac{Rt_{12.2t}(t)}{Rt_{12.3t\max}}))\]
(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= -0.00000000000000000000000000000031 * S13(t)**3 + 0.000000000000006257948004 * S13(t)**2 + 0.0256815810607943 * S13(t) + 904149.720943853;

level13(t).. WL13(t) =E= 0.00000000000000000000000000000072 * S13(t)**3 - 0.0000000000000036771574947 * S13(t)**2 + 0.0000000792104901537661 * 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)));
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) + 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) + 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) + 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) + 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) + 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) + 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) + Q21(t) - Rt21_1(t) - Rt21_2(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);
area21(t) = \(E= -0.00000000000208879061 \times S21(t) \times 0.00000000000208879061 \times S21(t) - 2947877.26530275\);

level21(t) = \(E= -0.0000000000000000045 \times S21(t)^2 + 0.00000001169908645675 \times S21(t) + 761.06155118528\);

ave_level21(t) = \(E= ((\text{beg}_W21 $($\text{ord}(t) \text{ EQ} 1) + W21(t-1)$($\text{ord}(t) \text{ GT} 1)) + W21(t)) / 2\);

net_head21(t) = \(E= (AvWL21(t) - \text{twe21}) \times 0.95 - ((Rt21_1t(t) / (24 \times \text{day}(t) \times 3600)) + (Rt21_2t(t) / (24 \times \text{day}(t) \times 3600)) + (Rt21_3t(t) / (24 \times \text{day}(t) \times 3600)) + (Rt21_4t(t) / (24 \times \text{day}(t) \times 3600)) + (Rt21_3t(t) / (24 \times \text{day}(t) \times 3600)) + (Rt21_4t(t) / (24 \times \text{day}(t) \times 3600))) \times \text{flK21};\)

efficiency21_1t(t) = \(E= -1.4849 \times ((Rt21_1t(t) / \text{Rt21_4t_max})^6) + 7.4008 \times ((Rt21_1t(t) / \text{Rt21_4t_max})^5) - 16.7253 \times ((Rt21_1t(t) / \text{Rt21_4t_max})^4) + (20.2156 \times ((Rt21_1t(t) / \text{Rt21_4t_max})^3) - (13.6479 \times ((Rt21_1t(t) / \text{Rt21_4t_max})^2) \times \text{Rt21_4t_max});\)

efficiency21_2t(t) = \(E= -1.4849 \times ((Rt21_2t(t) / \text{Rt21_4t_max})^6) + 7.4008 \times ((Rt21_2t(t) / \text{Rt21_4t_max})^5) - 16.7253 \times ((Rt21_2t(t) / \text{Rt21_4t_max})^4) + (20.2156 \times ((Rt21_2t(t) / \text{Rt21_4t_max})^3) - (13.6479 \times ((Rt21_2t(t) / \text{Rt21_4t_max})^2) \times \text{Rt21_4t_max});\)

efficiency21_3t(t) = \(E= -1.4849 \times ((Rt21_3t(t) / \text{Rt21_4t_max})^6) + 7.4008 \times ((Rt21_3t(t) / \text{Rt21_4t_max})^5) - 16.7253 \times ((Rt21_3t(t) / \text{Rt21_4t_max})^4) + (20.2156 \times ((Rt21_3t(t) / \text{Rt21_4t_max})^3) - (13.6479 \times ((Rt21_3t(t) / \text{Rt21_4t_max})^2) \times \text{Rt21_4t_max});\)

efficiency21_4t(t) = \(E= -1.4849 \times ((Rt21_4t(t) / \text{Rt21_4t_max})^6) + 7.4008 \times ((Rt21_4t(t) / \text{Rt21_4t_max})^5) - 16.7253 \times ((Rt21_4t(t) / \text{Rt21_4t_max})^4) + (20.2156 \times ((Rt21_4t(t) / \text{Rt21_4t_max})^3) - (13.6479 \times ((Rt21_4t(t) / \text{Rt21_4t_max})^2) \times \text{Rt21_4t_max});\)

energy21(t) = \(E= 0.985 \times 0.975 \times 24 \times \text{day}(t) \times 9.81 \times \text{Nth21}(t) \times (\text{eff21_1t}(t) \times (Rt21_1t(t) / (24 \times \text{day}(t) \times 3600))) + (\text{eff21_2t}(t) \times (Rt21_2t(t) / (24 \times \text{day}(t) \times 3600))) + (\text{eff21_3t}(t) \times (Rt21_3t(t) / (24 \times \text{day}(t) \times 3600))) + (\text{eff21_4t}(t) \times (Rt21_4t(t) / (24 \times \text{day}(t) \times 3600)))) ;\)

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balance22(t) = \(E= \text{beg}_S22($($\text{ord}(t) \text{ EQ} 1) + S22(t-1)$($\text{ord}(t) \text{ GT} 1) + Q22(t) - \text{Rt22_1t}(t) - \text{Rt22_2t}(t) - \text{Rt22_3t}(t) - \text{Rs22}(t) - \text{D22}(t) - \text{E22}(t) \times (\text{beg}_A22$$($($\text{ord}(t) \text{ EQ} 1) + A22(t-1)$($\text{ord}(t) \text{ GT} 1)) + \text{Rt22_1t}(t) + \text{Rt22_2t}(t) + \text{Rt22_3t}(t) + \text{Rt22_4t}(t) + \text{Rs22}(t);\)

area22(t) = \(E= -0.000000000001312912859 \times S22(t)^2 + 0.0453475791841959 \times S22(t) + 8442134.15596033;\)

level22(t) = \(E= -0.00000000000000000864 \times S22(t)^2 + 0.00000004315742428013 \times S22(t) + 626.593036867525;\)
ave_level22(t) = \((\text{beg}\_WL22(t) \ (\text{ord}(t) \ EQ \ 1) + WL22(t-1) \ (\text{ord}(t) \ GT \ 1)) + WL22(t)\) / 2;

net_head22(t) = \((\text{AvWL}\_22(t) - \text{twe22}) \times 0.95 - (\text{Rt22}_1(t) / (24 \times \text{day}(t) \times 3600)) + (\text{Rt22}_2(t) / (24 \times \text{day}(t) \times 3600)) + (\text{Rt22}_3(t) / (24 \times \text{day}(t) \times 3600)) \times ((\text{Rt22}_1(t) / \text{Rt22}_3\_\text{max}(t))^{**3}) - (13.6479 \times ((\text{Rt22}_1(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (20.2156 \times ((\text{Rt22}_2(t) / \text{Rt22}_3\_\text{max}(t))^{**3}) - (13.6479 \times ((\text{Rt22}_2(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (5.1611 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**3}) - (13.6479 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (5.1611 \times (\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))))\) * flK22;

efficiency22\_1(t) = \(-1.4849 \times ((\text{Rt22}_1(t) / \text{Rt22}_3\_\text{max}(t))^{**6}) + (7.4008 \times ((\text{Rt22}_1(t) / \text{Rt22}_3\_\text{max}(t))^{**5}) - (16.7523 \times ((\text{Rt22}_1(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (20.2156 \times ((\text{Rt22}_2(t) / \text{Rt22}_3\_\text{max}(t))^{**3}) - (13.6479 \times ((\text{Rt22}_2(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (5.1611 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**3}) - (13.6479 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (5.1611 \times (\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))))\);

efficiency22\_2(t) = \(-1.4849 \times ((\text{Rt22}_2(t) / \text{Rt22}_3\_\text{max}(t))^{**6}) + (7.4008 \times ((\text{Rt22}_2(t) / \text{Rt22}_3\_\text{max}(t))^{**5}) - (16.7523 \times ((\text{Rt22}_2(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (20.2156 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**3}) - (13.6479 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (5.1611 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**3}) - (13.6479 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (5.1611 \times (\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))))\);

efficiency22\_3(t) = \(-1.4849 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**6}) + (7.4008 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**5}) - (16.7523 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (20.2156 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**3}) - (13.6479 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (5.1611 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**3}) - (13.6479 \times ((\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))^{**4}) + (5.1611 \times (\text{Rt22}_3(t) / \text{Rt22}_3\_\text{max}(t))))\);

energy22(t) = \(0.985 \times 0.975 \times 24 \times \text{day}(t) \times 9.81 \times NtH22(t) \times ((\text{eff22}\_1(t) \times (\text{Rt22}_1(t) / (24 \times \text{day}(t) \times 3600))) + (\text{eff22}\_2(t) \times (\text{Rt22}_2(t) / (24 \times \text{day}(t) \times 3600))) + (\text{eff22}\_3(t) \times (\text{Rt22}_3(t) / (24 \times \text{day}(t) \times 3600))))\);

(balance23(t) = \(\text{beg}\_S23(t) \ (\text{ord}(t) \ EQ \ 1) + S23(t-1) \ (\text{ord}(t) \ GT \ 1) + Q23(t) - \text{Rs23}(t) - \text{D23}(t) - \text{E23}(t) \times (\text{beg}\_A23(t) \ (\text{ord}(t) \ EQ \ 1) + A23(t-1) \ (\text{ord}(t) \ GT \ 1)))\);

area23(t) = \(-0.00000000185648984544 \times S23(t)^2 + 0.0782686613259762 \times S23(t) + 124704.070389418\);

(balance24(t) = \(\text{beg}\_S24(t) \ (\text{ord}(t) \ EQ \ 1) + S24(t-1) \ (\text{ord}(t) \ GT \ 1) + Q24(t) - \text{Rs24}(t) - \text{D24}(t) - \text{E24}(t) \times (\text{beg}\_A24(t) \ (\text{ord}(t) \ EQ \ 1) + A24(t-1) \ (\text{ord}(t) \ GT \ 1)) + \text{Rs23}(t) + \text{D23}(t) - \text{EIRR}(t))\);

area24(t) = \(-0.00000000000000000314 \times S24(t)^2 + 0.00000000103957183719 \times S24(t) + 741696.440081436\);

(balance25(t) = \(\text{beg}\_S25(t) \ (\text{ord}(t) \ EQ \ 1) + S25(t-1) \ (\text{ord}(t) \ GT \ 1) + Q25(t) - \text{Rt25}_1(t) - \text{Rt25}_2(t) - \text{Rs25}(t) - \text{D25}(t) - \text{E25}(t) \times (\text{beg}\_A25(t) \ (\text{ord}(t) \ EQ \ 1) + A25(t-1) \ (\text{ord}(t) \ GT \ 1)))\);

area25(t) = \(-0.00000000000021857543 \times S25(t)^2 + 0.00377189223608465 \times S25(t) + 519327.912317403\);
level25(t).. WL25(t) =E= -0.00000000000000003612 * S25(t)**2 + 0.00000008160674702119 * S25(t) + 804.974838099189;

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

net_head25(t).. NtH25(t) =E= ((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));

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))));

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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= -0.0499258396986249 * S26(t)**2 + 0.0499258396986249 * S26(t) - 1326920.12221243;

level26(t).. WL26(t) =E= -0.0000000000000001175 * S26(t)**2 + 0.00000005555476256921 * S26(t) + 752.055480469782;

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

net_head26(t).. NtH26(t) =E= ((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));

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))));
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))));

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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)) - (16.7523 * ((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)) - (16.7523 * ((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))));

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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= 0.000000000000042621031 * S28(t) + 0.020553538372832 * S28(t) + 45122073.8522646;
level28(t).. WL28(t) =E= -0.000000000000000036 * S28(t)**2 + 0.000000010068284339 * S28(t) + 458.007628499163;

ave_level28(t).. AvWL28(t) =E= ((beg_WL28 $(ord(t) EQ 1) + WL28(t) $(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_2t(t) / Rt28_6t_max)**5)) - (16.7253 * ((Rt28_3t(t) / Rt28_6t_max)**4)) + (20.2156 * ((Rt28_4t(t) / Rt28_6t_max)**3)) - (13.6479 * ((Rt28_5t(t) / Rt28_6t_max)**2)) + (5.1611 * (Rt28_6t(t) / Rt28_6t_max));

efficiency28_2t(t).. eff28_2t(t) =E= - (1.4849 * ((Rt28_2t(t) / Rt28_6t_max)**6)) + (7.4008 * ((Rt28_3t(t) / Rt28_6t_max)**5)) - (16.7253 * ((Rt28_4t(t) / Rt28_6t_max)**4)) + (20.2156 * ((Rt28_5t(t) / Rt28_6t_max)**3)) - (13.6479 * ((Rt28_6t(t) / Rt28_6t_max)**2)) + (5.1611 * (Rt28_6t(t) / Rt28_6t_max));

efficiency28_3t(t).. eff28_3t(t) =E= - (1.4849 * ((Rt28_3t(t) / Rt28_6t_max)**6)) + (7.4008 * ((Rt28_4t(t) / Rt28_6t_max)**5)) - (16.7253 * ((Rt28_5t(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));

efficiency28_4t(t).. eff28_4t(t) =E= - (1.4849 * ((Rt28_4t(t) / Rt28_6t_max)**6)) + (7.4008 * ((Rt28_5t(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));

efficiency28_5t(t).. eff28_5t(t) =E= - (1.4849 * ((Rt28_5t(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));

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) / (24 * day(t) * 3600))) + (eff28_6t(t) * (Rt28_6t(t) / (24 * day(t) * 3600)))) * flK28;
/ (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), 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))));


\[ pwr_{11}(t) = 9.81 \times N_{tH11.L}(t) \times \left( (eff_{11_1t.L}(t) \times \left( \frac{R_{t11_1t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{11_2t.L}(t) \times \left( \frac{R_{t11_2t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{11_3t.L}(t) \times \left( \frac{R_{t11_3t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{11_4t.L}(t) \times \left( \frac{R_{t11_4t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{11_5t.L}(t) \times \left( \frac{R_{t11_5t.L}(t)}{24 \times day(t) \times 3600} \right)) \right) \right); \]

\[ pwr_{12}(t) = 9.81 \times N_{tH12.L}(t) \times \left( (eff_{12_1t.L}(t) \times \left( \frac{R_{t12_1t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{12_2t.L}(t) \times \left( \frac{R_{t12_2t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{12_3t.L}(t) \times \left( \frac{R_{t12_3t.L}(t)}{24 \times day(t) \times 3600} \right) \right) \right); \]

\[ pwr_{13}(t) = 9.81 \times N_{tH13.L}(t) \times \left( (eff_{13_1t.L}(t) \times \left( \frac{R_{t13_1t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{13_2t.L}(t) \times \left( \frac{R_{t13_2t.L}(t)}{24 \times day(t) \times 3600} \right) \right) \right); \]

\[ pwr_{21}(t) = 9.81 \times N_{tH21.L}(t) \times \left( (eff_{21_1t.L}(t) \times \left( \frac{R_{t21_1t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{21_2t.L}(t) \times \left( \frac{R_{t21_2t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{21_3t.L}(t) \times \left( \frac{R_{t21_3t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{21_4t.L}(t) \times \left( \frac{R_{t21_4t.L}(t)}{24 \times day(t) \times 3600} \right) \right) \right); \]

\[ pwr_{22}(t) = 9.81 \times N_{tH22.L}(t) \times \left( (eff_{22_1t.L}(t) \times \left( \frac{R_{t22_1t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{22_2t.L}(t) \times \left( \frac{R_{t22_2t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{22_3t.L}(t) \times \left( \frac{R_{t22_3t.L}(t)}{24 \times day(t) \times 3600} \right) \right) \right); \]

\[ pwr_{25}(t) = 9.81 \times N_{tH25.L}(t) \times \left( (eff_{25_1t.L}(t) \times \left( \frac{R_{t25_1t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{25_2t.L}(t) \times \left( \frac{R_{t25_2t.L}(t)}{24 \times day(t) \times 3600} \right) \right) \right); \]

\[ pwr_{26}(t) = 9.81 \times N_{tH26.L}(t) \times \left( (eff_{26_1t.L}(t) \times \left( \frac{R_{t26_1t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{26_2t.L}(t) \times \left( \frac{R_{t26_2t.L}(t)}{24 \times day(t) \times 3600} \right) \right) \right); \]

\[ pwr_{27}(t) = 9.81 \times N_{tH27.L}(t) \times \left( (eff_{27_1t.L}(t) \times \left( \frac{R_{t27_1t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{27_2t.L}(t) \times \left( \frac{R_{t27_2t.L}(t)}{24 \times day(t) \times 3600} \right) \right) \right); \]

\[ pwr_{28}(t) = 9.81 \times N_{tH28.L}(t) \times \left( (eff_{28_1t.L}(t) \times \left( \frac{R_{t28_1t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{28_2t.L}(t) \times \left( \frac{R_{t28_2t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{28_3t.L}(t) \times \left( \frac{R_{t28_3t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{28_4t.L}(t) \times \left( \frac{R_{t28_4t.L}(t)}{24 \times day(t) \times 3600} \right) + (eff_{28_5t.L}(t) \times \left( \frac{R_{t28_5t.L}(t)}{24 \times day(t) \times 3600} \right) \right) \right) \right); \]

FILE res /TigrisES.txt/;
PUT res
"Aysehatun Dam and HEPP"/;
PUT "t day(t) S1(t) A1(t) WL1(t) Q1(t) D1(t) E1(t) Rt1_L(t) Rt1_2t(t) Rs1(t) AvWL1(t) NtH1(t) eff1_1t(t) eff1_2t(t) pwr1(t) eng1(t)"
"t0", "--", "", beg_S1, beg_A1, beg_WL1/;
PUT "  ";

PUT "Kor Dam and HEPP"/;
PUT "  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,
    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    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,
    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    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,
    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,
PUT "  ";

PUT "Sirvan Dam and HEPP"/;
PUT "  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,
    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    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 "        ";

PUT "Narli Dam and HEPP"/
PUT " t day(t) S7(t) A7(t) WL7(t) Q7(t) D7(t) E7(t) Rt7_1t.L(t) Rt7_2t.L(t) Rs7(t) AvWL7(t) NtH7(t) eff7_1t.L(t) eff7_2t.L(t) pwr7(t) eng7(t)"


PUT "        ";

PUT "Oran Dam and HEPP"/
PUT " t day(t) S8(t) A8(t) WL8(t) Q8(t) D8(t) E8(t) Rt8_1t.L(t) Rt8_2t.L(t) Rs8(t) AvWL8(t) NtH8(t) eff8_1t.L(t) eff8_2t.L(t) pwr8(t) eng8(t)"


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.L(t) Rt9_2t.L(t) Rs9(t) AvWL9(t) NtH9(t) eff9_1t.L(t) eff9_2t.L(t) eff9_3t.L(t) pwr9(t) eng9(t)"


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)"


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)"

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PUT "t0", " -- ", beg_S10, beg_A10, beg_WL10;/

PUT "        "/;

PUT "Pervari Dam and HEPP (b)/";
PUT " t Rs10(t) AvWL10(t) NtH10(t) eff10_1.t(t)
eff10_2.t(t) eff10_3.t(t) eff10_4.t(t) pwr10(t) eng10(t)"

PUT "        "/;

PUT "Cetin Dam and HEPP (a)/";
PUT " t day(t) S11(t) A11(t) WL11(t) Q11(t) D11(t)
E11(t) Rt11_1.t(t) Rt11_2.t(t) Rt11_3.t(t) Rt11_4.t(t)
Rt11_5.t(t)"
PUT "t0", " -- ", beg_S11, beg_A11, beg_WL11;/

PUT "        "/;

PUT "Cetin Dam and HEPP (b)/";
PUT " t Rs11(t) AvWL11(t) NtH11(t) eff11_1.t(t)
eff11_2.t(t) eff11_3.t(t) eff11_4.t(t) eff11_5.t(t) pwr11(t) eng11(t)"

PUT "        "/;

PUT "Alkumru Dam and HEPP (a)/";
PUT " t day(t) S12(t) A12(t) WL12(t) Q12(t) D12(t)
E12(t) Rt12_1.t(t) Rt12_2.t(t) Rt12_3.t(t)"
PUT "t0", " -- ", beg_S12, beg_A12, beg_WL12;/

PUT "        "/;

PUT "Alkumru Dam and HEPP (b)/";
PUT " t Rs12(t) AvWL12(t) NtH12(t) eff12_1.t(t)
eff12_2.t(t) eff12_3.t(t) pwr12(t) eng12(t)"

PUT "        "/;
PUT "Eruh Dam and HEPP";
PUT "t day(t) S13(t) A13(t) WL13(t) Q13(t) D13(t)
E13(t) R13_1t(t) R13_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;/

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;/
TS14.L(t):13.2/);

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,
TS15.L(t):13.2/);

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,
TS16.L(t):13.2/);

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,
TS17.L(t):13.2/);

PUT "Bulaklidere Dam";
PUT "t day(t) S18(t) A18(t) Q18(t) D18(t) E18(t)
Rs18(t) TS18(t)";/
PUT "t_0"," -- ", beg_S18, beg_A18/;

PUT "/;

PUT "Kibris Dam"/;
PUT " t day(t) S1(t) A1(t) Q1(t) D1(t) E1(t) Rs1(t) TS1.L(t)"
PUT "t_0"," -- ", beg_S1, beg_A1/;

PUT "/;

PUT "Karakalar Dam"/;
PUT " t day(t) S2(t) A2(t) Q2(t) D2(t) E2(t) Rs2(t) TS2(t)"
PUT "t_0"," -- ", beg_S2, beg_A2/;

PUT "/;

PUT "Silvan Dam and HEPP (a)"/;
PUT " t day(t) S21(t) A21(t) Q21(t) D21(t) E21(t) Rs21_1t(t) Rs21_2t(t) Rs21(t)"
PUT "t_0"," -- ", beg_S21, beg_A21, beg_WL21/;

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) eng21(t)"

PUT "/;

PUT "Batman Dam and HEPP (a)"/;
PUT " t day(t) S22(t) A22(t) Q22(t) D22(t) E22(t) Rs22_1t(t) Rs22_2t(t) Rs22_3t(t)"
PUT "t_0"," -- ", beg_S22, beg_A22, beg_WL22/;

PUT "/;
PUT "Batman Dam and HEPP (b)";/
PUT "  t  Rs22(t)  AvWL22(t)  NtH22(t)  eff22_1t(t)
eff22_2L(t)  eff22_3L(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_1L(t):13.2, eff22_2L(t):13.2, eff22_3L(t):13.2,
pwr22(t):13.2, eng22.L(t):13.2/;);
PUT "  "/;
PUT "Ergani Dam";/
PUT "  t  Rs23(t)  A23(t)  Q23(t)  D23(t)  E23(t)  S23(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,
PUT "  "/;
PUT "Devegecidi Dam";/
PUT "  t  Rs24(t)  A24(t)  Q24(t)  D24(t)  E24(t)  S24(t)";/
PUT "t0", -- "  , beg_S24, beg_A24/;
PUT "  "/;
PUT "Dipni Dam and HEPP";/
PUT "  t  Rs25(t)  A25(t)  WL25(t)  Q25(t)  D25(t)
E25(t)  Rt25_1t(t)  Rt25_2t(t)  R25_1L(t)  R25_2L(t)  A25(t)  Q25(t)  D25(t)  E25(t)  NtH25(t)
eff25_1L(t)  eff25_2L(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,
PUT "  "/;
PUT "Kralkizi Dam and HEPP";/
PUT "  t  Rs26(t)  A26(t)  WL26(t)  Q26(t)  D26(t)
E26(t)  Rt26_1t(t)  Rt26_2t(t)  R26_1L(t)  R26_2L(t)  A26(t)  Q26(t)  D26(t)  E26(t)  NtH26(t)
eff26_1L(t)  eff26_2L(t)  pwr26(t)  eng26(t)";/
PUT "t0", -- "  , beg_S26, beg_A26, beg_WL26/;
PUT "  "/;
PUT "Dicle Dam and HEPP";/
PUT "  t  Rs27(t)  A27(t)  WL27(t)  Q27(t)  D27(t)
E27(t)  Rt27_1t(t)  Rt27_2t(t)  R27_1L(t)  R27_2L(t)  A27(t)  Q27(t)  D27(t)  E27(t)  NtH27(t)
eff27_1L(t)  eff27_2L(t)  pwr27(t)  eng27(t)  T27(t)";/
PUT "t0", -- "  , beg_S27, beg_A27, beg_WL27/;

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/;

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)";/

PUT " System Energy:"; Obj.L:25.2;/
CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Yalçın, Emrah
Nationality: Turkish (TC)
Date and Place of Birth: 1 October 1985, Ankara
Marital Status: Single
Phone: +90 505 863 28 16
Email: emrah.yalcin@metu.edu.tr

EDUCATION

<table>
<thead>
<tr>
<th>Degree</th>
<th>Institution</th>
<th>Year of Graduation</th>
</tr>
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<tbody>
<tr>
<td>MS</td>
<td>METU Civil Engineering</td>
<td>2010</td>
</tr>
<tr>
<td>BS</td>
<td>METU Civil Engineering</td>
<td>2008</td>
</tr>
<tr>
<td>High School</td>
<td>Ankara Atatürk High School</td>
<td>2003</td>
</tr>
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</table>

WORK EXPERIENCE

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<thead>
<tr>
<th>Year</th>
<th>Place</th>
<th>Enrolment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011 January - Present</td>
<td>EIN Construction</td>
<td>Company Manager</td>
</tr>
<tr>
<td>2008 July - October</td>
<td>PROSEM Engineering</td>
<td>Design Engineer</td>
</tr>
<tr>
<td>2007 July</td>
<td>VE-NA Construction</td>
<td>Intern Engineering Student</td>
</tr>
<tr>
<td>2006 July</td>
<td>VE-NA Construction</td>
<td>Intern Engineering Student</td>
</tr>
</tbody>
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FOREIGN LANGUAGES

Advanced English

PUBLICATIONS

