THE OPTIMAL JOINT PROVISION OF WATER FOR IRRIGATION AND HYDROPOWER IN THE EUPHRATES RIVER: THE CASE OF CONFLICT BETWEEN TURKEY AND SYRIA

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CHAPTER I

INTRODUCTION

The Euphrates River overflows the borders of Turkey, Syria and Iraq. Each country, especially Turkey and Syria, is undergoing social and economic changes that result in the increased demand water from the Euphrates River. Unfortunately, separate planning and lack of coordination among the riparian states in regards to the process of water resources development has caused adverse effects on the level of exploitation of the Euphrates basin. Such major water problems arise primarily from water allocation within states rather than from water allocation between states. Therefore, this research concerns the current water conflict between Turkey and Syria in the mode of Turkey's extensive irrigation and hydroelectric power projects on the Euphrates River. Furthermore, this study proposes to define a total economic benefit function that is concave in water consumption. In addition, it uses a mathematical programming model to analyze the optimal inter-temporal allocation of surface water for hydropower generation and irrigation in the Euphrates River. Moreover, this modeling approach addresses the question of whether or not conflict is artificial because of inefficient utilization of resources or there insufficient water supplies for both nations' needs. Thus, three different Euphrates mainstream flow conditions (average, highest and lowest) are used to examine whether or not the conflict between Turkey and Syria is artificial.

Although Turkey was motivated by its own interests, the construction of huge storage dams in that country has had a positive effect on Turkey's downstream neighbors. The lack of coordination among the riparian states on the process of water resources development may provide positive externalities to downstream states. A large reservoir capacity keeps a ample amount of water and provides water for downstream states during drought seasons. Consequently, results of the model demonstrate how economically related allocations in analysis may provide a more acceptable regional solution compared to political hostilities among to these countries. A "Virtual Water " approach could provide some value so that a downstream country could compensate the upstream one in order to release more water for its own consumption.

This study is organized as followings: In the first chapter, the recent global water shortage problem is described and is the institutional approach for solving water conflicts on the sharing a river basin is explained. The second chapter presents the conflict on the Euphrates River regarding the utilization of the river basin by Syria and Turkey. Furthermore, it explains both countries' objectives in so far as the utilization of the Euphrates River goes and it ends by presenting the problem statement. The third chapter presents an up-to-date and exhaustive literature review on this topic. It also reviews the economic framework and the case studies related to water allocation among its competing uses between the two users. The fourth chapter describes the model, methodology, and data that are used for the economic analysis of the water conflict. The fifth chapter discusses the results of the models and analysis them. Finally, chapter six concludes by summarizing the results and discussing future implications and possible avenues of further research.

Water Scarcity Problem

Of all natural resources, water is probably the most critical for the creation of life and the survival of nations. By reason of easy access to water for drinking, farming, and transportation, the early civilizations and habitats developed along the banks of several major rivers such as the Nile, Euphrates, Tigris, and Indus. Throughout history, human survival and welfare generally depended on regular availability and control of water. Ancient societies on the Nile in Egypt, the Tigris and Euphrates in the Middle East, the Indus in Pakistan, and Hwang Ho in China built large irrigation systems and made land productive. Tragically, the collapse of these civilizations was closely connected with the failure of water supplies (Biswas, 1970).

With the development of capitalism, there was a dramatic increase in the need for water. Increasing population and water-use activities, such as food production, power generation, navigation, recreation, and much commercial and manufacturing process have increased global water requirements. In fact, the growth rate of total global water use accelerated remarkably in the twentieth century. In 1900, the world population was 1.6 billion people and water consumption per capita was 360 m^3/year. In 1990, the world population was 5.3 billion and water withdrawal per capita 570 m^3/year. In sum, the global water use growth rate has been almost three times faster than the world population growth rate and continues to grow rapidly as agricultural, industrial, and domestic demand increases (Raskin, 1996).

In addition to the rapid increase of water requirements, utilization of water patterns changed from agricultural use to industrial use between 1900 and 1995. During this period, the industrial revolution and rising urbanization transformed water from agricultural input to industrial input. For example, the agricultural share of all water use declined from nearly 90 percent to around 62 percent. By contrast, the share of the total industrial water use increased from 6 percent to about 24 percent (Biswas, 1996).

Recently, depending on countries' respective levels of economic development, these global percentages of water-use patterns are significantly different at the national level. Highly industrialized countries withdraw the highest percentage for industry and less industrialized or developing countries consume more water for agricultural than industrial and domestic use. For example, industrialized regions like Western Europe and North America withdraw water for industry at a rate of 49 percent and 47 percent, respectively, and for agriculture 37 percent and 39 percent, respectively. However, the picture in the developing world is quite the opposite: the Middle East and Latin America withdraw water for agriculture at a rate of 89 percent and 76 percent, respectively and for industry 6 percent and 11 percent, respectively (WRI, 1998).

The existing data shows that there is plenty of water in the world. Human uses of fresh water are modest relative to available renewable resources. Annual global water withdrawals of 3,000 km^3 are about 8 percent of average annual runoff of about 41 000 km^3 (WRI, 1998). Globally, water supplies are abundant; but they are either in the wrong place or not available when needed. According to Raskin's paper (1996) on regional data for renewable freshwater resources, Latin America and North America enjoy the most abundant per capita water resources at 24,000 and 20,000 m^3, respectively. In contrast, Eastern Europe and the Middle East are at only 1,500 m^3 per capita, roughly one-fifteenth of the resources of the Americas.

The unequal distribution of water resources and increasing demand for all type of water uses (agricultural, industrial, and domestic) creates water scarcity in many regions. It is estimated that countries with 40 percent of the world population already suffer from serious water shortages. Low-income nations (developing countries) are especially vulnerable to water scarcity due to increasing population and economic growth. Moreover, a large number of these countries are found in the arid or semiarid regions; and for most of them, international water bodies are the only major new sources of water that could still be economically developed (Gleick, 1993; Falkenmark and Lindh, 1993).

Water Conflicts

According to a United Nations (UN) study, there are about 214 international rivers in the world, 69 in America, 48 in Europe, 57 in Africa, and 40 in Asia. Three or more countries share 53 of these water basins, and nearly 40 percent of the world's people live in these river basins (United Nation, 1975). In this situation, one riparian country's plans to utilize a river for economic development may be incompatible with their downstream neighbors. A distinction should be made between an upstream state, through which runs the upper section of the river, and downstream states, through which runs the lower section of the river. Naturally, demand for water by upstream states affects the ability of downstream states to use the river's water. The resulting interdependencies among nations, rising costs of fresh water, and increasing competition over use of transboundary water resources lead to resource conflicts among riparian countries.

Water scarcity is not only an issue in the efficient allocation between sectors, but also one of sharing among the riparian countries. However, sharing water with two or more countries is an obstacle to more efficient allocation and management of water resources. The fugitive nature of the resource makes it difficult to establish clear property rights, and the interdependencies among users might cause externalities or third-party impacts when the use or location of water is changed.

Two extreme and opposing doctrines have been proposed for establishing property rights over international waters, the first of which is the doctrine of unlimited territorial sovereignty states, which asserts that a country has exclusive rights to the use of waters within its territory. Here, the most advantageously positioned countries can claim and use resources with little concern for the impacts on others. Hence, they can establish their own agendas and ignore developing countries' desire for food security and self-sufficiency, and thus create an imbalance between those who need more water resources and those who simply want more of it.

The second doctrine, the contrasting doctrine of unlimited territorial integrity, states that one country cannot alter the quantity and quality of water available to another. This doctrine greatly constrains how the upstream country can use its resources. However, the upstream country is unwilling to forego its sovereignty. In practice, international water disputes generally have moved away from the extreme positions implied by these two doctrines and toward a doctrine of equitable and reasonable use. Although this narrows the likely range of disagreement among competing users, it does not provide clear property rights.

The absence of comprehensive international law and a determination on the property rights for international water is an obstacle to the development of efficient markets. Markets can provide individual people as well as countries with increased opportunities and incentives to develop, transfer, and use a resource in ways that would benefit all parties. Thus, introducing markets and market-based prices might help promote a more efficient and flexible allocation of water resources on an international basis (Frederick, 1996).

CHAPTER II

CONFLICT ON THE EUPHRATES RIVER

Today, water has become an important in arid and semi-arid regions and the potential for devastation and widespread conflict exists in many countries, both developing and developed. Especially in the Middle East, the situation is dreadful. Continuing population growth, increased industrial activities, and dependence on food and fiber production have caused a critical demand for water and land resources in Middle East. Therefore, current water use in the region is unsustainable and poorly allocated and/or managed.

The link between water scarcity and violent conflict is a serious threat in the region. The tensions over the waters of the basin have reached an internationally acknowledged level, and a lack of cooperation among the riparians confronts the world with a new potential conflict area. Ismail Serageldin, Vice President of the World Bank, predicted in 1995, "Many of the wars of this century were about oil, but wars in the next century will be over water" (Butts, 1997). Furthermore, Middle Eastern leaders, both past and present, have stated that water is the factor most likely to lead to war. In July 1992, Turkish president, Suleyman Demirel, proclaimed; "Neither Syria nor Iraq can lay claim to Turkey's rivers any more than Ankara could claim their oil... We have a right to do anything we like. The water resources are Turkey's, the oil resources are theirs. We do not say we share the oil resources and they cannot share our water resources" (The Boston Globe, 1992).

In May 1997, the United Nations agreed on the International Watercourses Convention by 104 votes to three. Turkey was one of the three countries that voted against the Convention. Israel, Egypt, and Iraq were among those whom abstained or did not attend. The Syrians attacked Turkey because it had not attended a meeting of the joint committee set up to investigate the Euphrates since 1992. The river is so polluted that it is "affecting the environment and causing new diseases that were nonexistent before," they added. They claim it is now too salty to be used for irrigation. Therefore, it is important to note that strategic, geopolitical and economic considerations have become intertwined with hydrological factors.

While water remains a commodity to be fought over by rival nation states, the supply of this vital resource will continue to be threatened by selfish national interests. Therefore, water provisions must be developed on a rational and planned international basis if future catastrophes are to be avoided. In order to understand the economic and political issues at stake with respect to water conflicts in the Middle East, it is necessary to fully comprehend their geographic and hydrological dimensions.

The Euphrates River

The Euphrates River flows from Turkey through two downstream countries in the Middle East, Syria and Iraq. According to Kilgour and Dinar's (1995) flow model, which represents the geography of water flow within a river basin, the Euphrates River would be classified as a Three-State I-Geography model. In this model, there are three states called UP, MID, and DOWN; and river flow begins in the Source State UP and then passes through MID to the Outlet State DOWN. Turkey is in an upstream position in the river basin, enabling it to cut off the river flow. Syria is in a downstream position from Turkey but an upstream position from to Iraq. Thus, Syria is called the MID State and Iraq is called the DOWN State.

These three co-riparian's mainly developed and developing water utilization projects on both rivers are irrigation and hydropower production. By the post-2000 year, Turkey plans to irrigate 1,250,000 ha within the Tigris-Euphrates basin and uses 21.5 billion m^3 from 28.7 billion m^3 of total demand and 18.42 billion cubic meter of that total demand is from the Euphrates River. While Syria demands 11.30 billion m^3, Iraq plans to use 23 billion m^3 the from the Euphrates River (Table 1). In addition, the three countries have already used and developed projects to utilize water for hydropower production to improve their industrial sectors. Hydroelectric power plays a vital role in Turkish and Syrian energy resources. Agricultural and industrial sectors are therefore important for all three countries' economic development.

Geography and Hydrography of the Basin

The Euphrates River has its springs in the highlands of Eastern Turkey and its mouth at the Persian Gulf. It is the longest river in southwestern Asia at 2,700 km, and its actual annual volume is 35.6 billion cubic meters (Kolar and Mitchell, 1991). The Euphrates River is formed in Turkey by two major tributaries, the Murat and the Karasu. Turkey built Keban Dam at the point where these two tributaries meet. Below the dam, the Euphrates flows through the Anti-Taurus mountains and crosses into Syria at Karkamish (Carchemish) downstream from the Turkish town of Birecik. After entering Syria, the Euphrates continues its southeastern course and is joined by two main tributaries, the Khabur – 187 miles long, and Balikh –100 miles long. Both of these tributaries also originate in Turkey; 13 percent of length of the Khabur River and 50 percent of length of Balikh River and their catchments are almost entirely inside Turkey. Therefore, tapping aquifers on the Turkish side can affect their flow. There is no tributary adding to the Euphrates downstream from the Khabur. After entering Iraq, the Euphrates River joins the Tigris River near the city of Qurna, and the combined rivers are called the Shatt al-Arab, which serves as a border between Iran and Iraq (Kolar and Mitchell, 1991).

Table I

Water Contribution of Turkey, Syria and Iraq to the Euphrates River and Their Demands (Turkey Minister of Foreign Affairs, 1994)

COUNTRIES	WATER CONTRIBUTION		WATER DEMAND	
	BILLION M^3	%	BILLION M^3	%
Turkey	31.58	88.7 %	18.42	34.94 %
Syria	4.00	11.3 %	11.30	21.43 %
Iraq	0.00	0.0 %	23.00	43.63 %
Total	35.58	100.0 %	52.72	100.00 %

As seen in Table 1, the average annual runoff of the Euphrates is about 35 billion cubic meters. This quantity is far beyond that necessary to meet the region's water requirement. Turkey's contribution of that amount is 31 billion cubic meters. In other words, almost 89 percent of the total water potential of the Euphrates River is generated in Turkey. Syria contributes around 12 per cent of the total and Iraq contribution to the runoff is nil. However, 10 percent of the Syrian contribution originates from the northern tributaries, the Khabur and the Balikh, which both have their catchments in Turkey. Therefore, some resources show Turkish contribution to be more than 90 percent (Kolars, 1994).

According to records (The Global River Discharge Database, 1996 and TEAS 2001) obtained between 1937 and 2000 at the Keban gauging site, starting point of the Euphrates, the mean annual discharge is 20.223 billion cubic meters (Figure 1). The annual discharge amounts to 26.781 billion cubic meters at the Ataturk Dam, and at Birecik/Kargamis, where the Euphrates crosses the Syrian border and leaves Turkey, to 30.777 billion cubic meters (Bagis, 1997).

Naturally, the Euphrates' water capacity changes from one year to the next year depending on the level of precipitation and its drainage basin. Figure 1 "Historical Annual Water Income of the Euphrates River at Keban" demonstrates that annual fluctuation of the Euphrates River and the discharge was not steady over long periods. In 1961, the Euphrates River had its lowest water flow value at 9.981 billion cubic meters, which is almost half of all average annual discharge. Therefore, the period between 1956 and 1963 is called the "First Critical Period".

Figure 1. Historical Annual Water Income of Euphrates at Keban

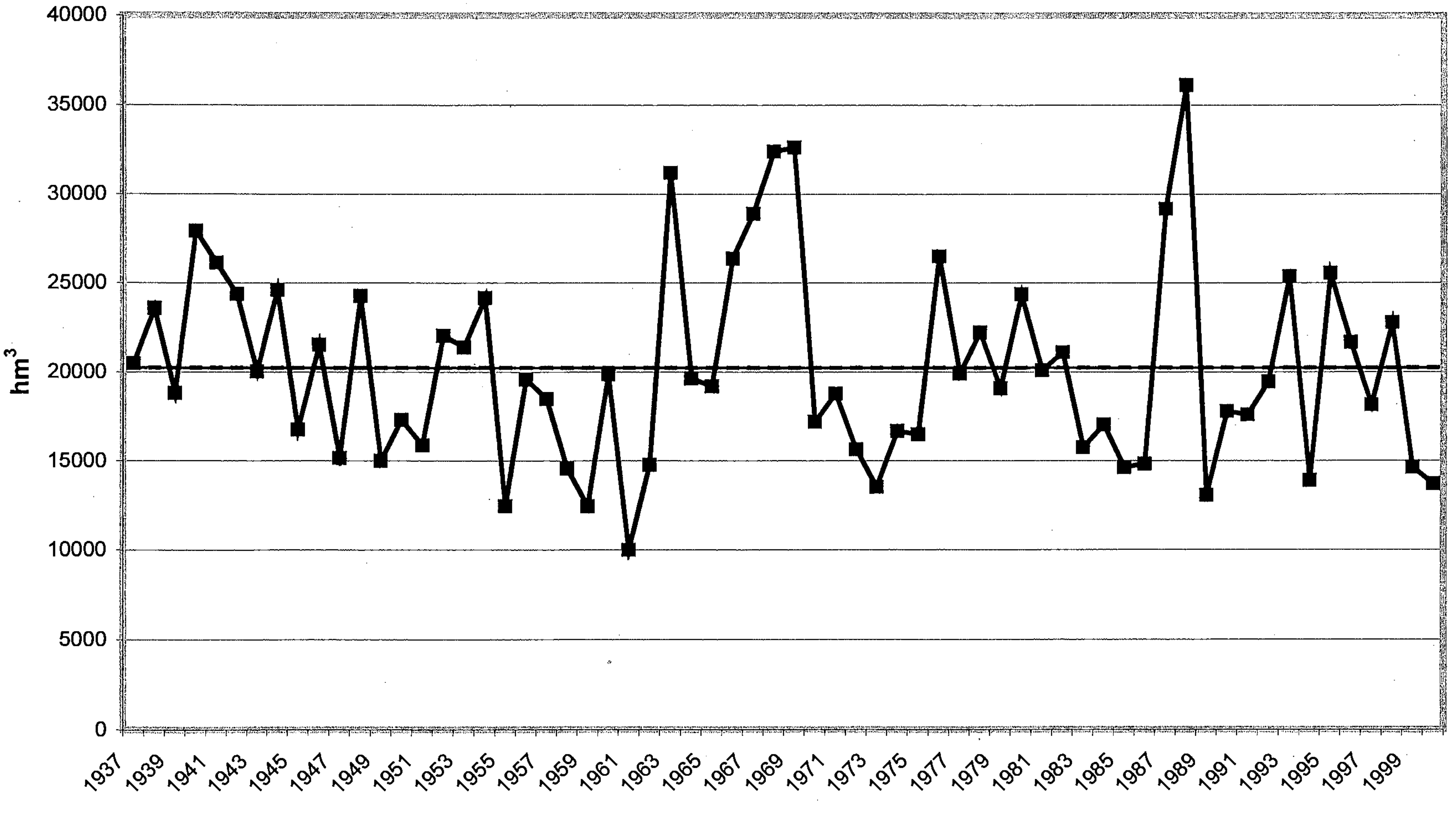
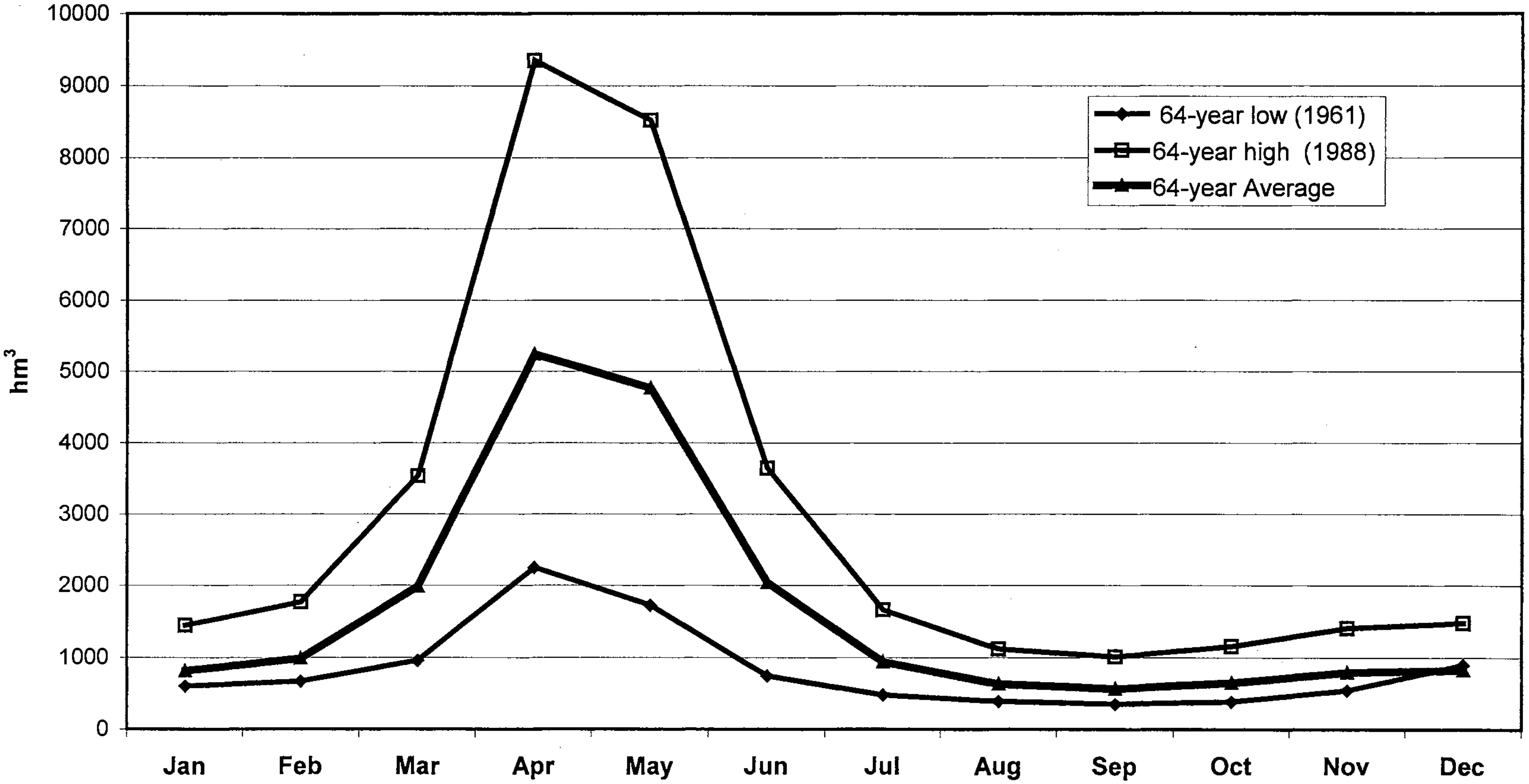


Figure 2. Variation in mean monthly flow of the Euphrates at Keban



The period between 1970-1975 and 1989-1992 are also defining points of the 64-year water discharge at Keban. In 1988, flow rates reached highest value of 36 billion cubic meters. It shows that the Euphrates River annual flow rises one-half of its average annual water value. In addition, the monthly flow of the Euphrates River changes 28 times, its minimum amounts. The Figure 2 "Variation in mean monthly flow of the Euphrates River at Keban" shows the significant seasonal variation at most critical periods and most flood period for the 64-year period (1937-2000). The maximum monthly flow, which occurred in April 1988, was 3607.8 m^3/s or 9351.304 hm^3/ month. The extreme monthly low flow, which occurred in September 1961, was 383.616 hm^3/month. The annual flow of 1961 was and 1988 was 36 billion cubic meters.

Utilization of Euphrates River in Turkey

Turkey has begun a large water management scheme known as the SouthEast Anatolia Project, or GAP using its Turkish initials. It is the biggest development project ever undertaken by Turkey and one of the biggest of its kind in the world. The project was envisioned by Turkish leaders in the 1950s and 1960s and began with the construction of the Keban dam in the upper Euphrates River. The main push for the project came during the 1980s; in 1986, the Turkish government established the GAP as one of the main regional development programs in the country. The integrated project comprises not only multipurpose dams and irrigation systems, but also investments in all development-related sectors such as agriculture, energy, transportation, telecommunications, health care, education, and urban and rural infrastructure development. The total costs of the project were estimated to be around $11 to 12 billion (Duztepe,1990).

The water resources development program of the GAP project includes 13 major projects, which are primarily for irrigation and hydropower generation, planned by the Turkish State Hydraulic Works. It is planned that at full development, over 1.7 million hectares of land will be irrigated and 27 billion kilowatt hours (kWh) of electricity will be generated annually with an installed capacity over 7,500 megawatts (MW). Seven of these project plans are for the Euphrates River and its tributaries and the other six projects are for the Tigris and its tributaries. The project envisions the construction of 22 dams and 19 hydroelectric power plants (Table II).

As seen in Table II, the largest part of the project is the Lower Euphrates project. Two important instruments of the project are the massive Ataturk dam and Sanliurfa twin irrigation tunnels system that will supply irrigation water to 370,246 hectares of land from the Ataturk reservoir. These gravity irrigation systems consist of the two circular-lined tunnels each with a 7.62 diameter and 26.4 kilometers in length and both capacity is 328 cubic meter per second (Akuzum et al., 1997).

The area to be irrigated accounts for 19 percent of the economically irrigable area in Turkey (8.5 million hectares), and the annual electricity generation accounts for 22 percent of the country's economically viable hydropower potential (11 8 billion kWh). Consequently, the GAP Master Plan's basic development scenario is to transform the region into an export base for its agricultural products and provide cheap electric power to industry (GAP Administration, 1994).

Table II

Southeaster Anatolian Water Resources Development Project
(GAP Administration, 1994)

EUPHRATES RIVER PROJECTS	**Irrigation Area (ha)**	**Energy Production (GWh)**
1.Karakaya Dam & HEPP		7, 354
2.Lower Euphrates Project	706,281	9,024
3.Border Euphrates Project		3,168
4.Suruc-Baziki Project	146,500	
5. Adiyaman-Kahta Project	78,700	509
6. Adiyaman-Goksu-Araban	7,160	43
7.Gaziantep Project	90,000	
TIGRIS RIVER PROJECT		
1.Dicle-Kralkizi Project	130,150	444
2. Batman Project	37,350	483
3. Batman-Silvan Project	257,000	964
4.Garzan Project	60,000	315
5.Ilisu Project		3,833
6.Cizre project	121,000	1,208

The Southeastern Anatolian Project (GAP) plans to develop long-ignored southeastern Turkey, where a major outflow of population has combined with high levels of unemployment and political instability. In addition, the region is a hot bed of a separatist Kurdish movement led by the Kurdish Workers Party (PKK). Furthermore, the region has been hit hard economically by the UN sanctions on Iraq because trade with Iraq accounted for a major portion of the region's total economy before sanctions were imposed. The Turkish government perceives the GAP as a solution to the problems in the region and places heavy emphasis on its existence. This is a very critical point in understanding Turkish attitudes towards the entire issue.

The major water control facilities in the system are the Keban, Karakaya, Ataturk, Birecik, and Karkamish dams on the Euphrates River. Currently three major dams are operating at full capacity on the river: Keban, Karakaya, and Ataturk. The Karkamish dam commenced operation in January 2000 and Birecik in November 2000. Only Keban, Karakaya, and Karkamish are built for electricity production; their capacities are 1,240 MW, 1,800 MW, and 180 MW, respectively. The Ataturk and Birecik dams are built for two purposes, irrigation and hydropower generation. Generally, hydropower generation accounts for 39% of Turkey's total electricity generation. However, this amount drops to around 25% for the last two years due to dry seasons. The Euphrates basin's reservoirs generate approximately 60% of the hydropower production in Turkey (Table III). In 2000, Turkey's electricity consumption was 128 544.7 GW hour (Turkish Ministry of Energy and Natural Resources, 2001).

Table III

Electricity Generation on the Euphrates River for 1995-2000 (GWh)
(Turkish Ministry of Energy and Natural Resources, 2001)

	1995	1996	1997	1998	1999	2000
KEBAN	6,266.7	6,519.1	6,521.9	7,586.4	5,696.4	4,482.2
KARAKAYA	6,714.2	8,030.28	8,026.9	8,924.4	7,127.9	5,223.6
ATATURK	9,399.9	10,879.7	10,535.3	1,0595.	7,608.3	6,227.4
BIRECIK						230.0
KARGAMISH						288.2
TOTAL	22,380.8	25,429.08	25,084.1	27,106	20,432.6	16,451.4
HPP	35,541	40,475.2	39,816.1	42,229	34,677.5	30,930.4

The Ataturk dam is the largest structure ever built in Turkey for irrigation purposes and hydropower generation. It will generate 8.9 billion kWh of electricity annually and irrigate about 872,385 hectares, 476,000 hectares by gravity flow and the remaining 406,000 hectares by pumping. The Birecik Dam is the fourth major dam on the Euphrates. Its production capacity is 672 megawatts of electricity and irrigation of 81,670 hectares. The Birecik Dam is the only one in the system to be built and operated by a private company. The model of Build, Operate and Transfer (BOT) has been implemented for Birecik Dam. Under the BOT model, private investors build and operate private sector generation facilities for a set number of years, at which point they transfer ownership to the state.

The agricultural sector plays an important role in the Turkish economy. It accounts for approximately 20 percent of the GDP, 10 percent of exports, and 50 percent of civilian employment. The new irrigation systems created by the GAP will double Turkey's irrigable farmland in a region that has traditionally suffered from light rainfall. New irrigation has already brought about a corresponding boom in agricultural activity. From just one crop per year, in many areas five crops in a two-year cycle have become or will soon be possible. Tunnels from the Ataturk Dam have opened 180,000 acres of the Harran plain to irrigation, and this represents only one-quarter of the land area waiting to be brought under irrigation. Crop yields of cotton, wheat, barley, lentils, and other grains have reportedly tripled in the Harran plain because of irrigation from the Ataturk Dam.

Utilization of Euphrates River in Syria

Syria has a separate water development project on the Euphrates River. Syrian development projects are primarily for irrigation, hydropower generation and domestic water supply. Syria planned to build three dams on the Euphrates River. Their names are Tabqa (Euphrates), Al-Baath and Tishrin. The Table IV establishes the characteristics and multi-purpose functions of these dams in the basin.

The project Tabqa Dam was completed in 1975, and the main reasons for building the dam were to provide irrigation for over 600,000 hectares, hydropower generation, and regulation of the Euphrates river (Saliba, 1997). Thus, about 14-billion m^3 storage capacity at Lake Assad is formed by the Tabqa

(Euphrates) Dam. Another dam, Al Baath Dam, was constructed downstream below the Euphrates Dam. It was intended to satisfy multiple needs such as maintaining a constant flow for the electric turbines of the upper Dam, irrigating fields, and producing energy. The Al-Baath Dam, which completed in 1986, has a storage capacity of 90 million m^3 and The Tishrin Dam, at the Turkish-Syrian border, was launched in order to generate electricity and store water. Construction ended in October 1999; the dam will be fully operative within four years (Daoudy, 2000).

Table IV

Syrian Dams on the Euphrates River
(Daoudy, 2000)

DAMS	STORAGE CAPACITY hm^3	ENERGY MW	IRRIGATION HA
Tabqa (1978)	1410	800	600,000
Al Baath (1990)	90	64	NO
Tishrine (1999)	19	1.6	NO

Syria needs Euphrates water for electricity production for the same reason as Turkey – to avoid importing other energy sources, including oil. The Tabqa Dam produces 800 megawatt of electricity; the Al Baath Dam, 64 megawatts; and Tishreen Dam is planned to produce 1.6 megawatts (Soffer, 1999). Hydropower constitutes about 25 percent of Syria's installed capacity. The electric power utilities that supply the rest are oil-fired and gas-fired stations with effective generating capacity of 2,589 megawatts. Thus, Syria needs the Euphrates waters for hydropower as a cheap and non-depleting source of energy (Kliot, 1994). However, when the water level in Lake Assad dropped in 1990 after Turkey blocked the Euphrates's flow, the dam's yield fell to a mere 10 percent of its generating capacity, which caused serious damage to the Syrian economy (Soffer 1999).

Agriculture is also extremely important for the Syrian economy. It accounts for approximately 28 percent of the GDP, 10 percent of exports, and 40 percent of civilian employment. However, the dominant agricultural sector remains underdeveloped, with roughly 80 percent of agricultural land still dependent on rain-fed sources. Although Syria has sufficient water supplies in aggregate at normal levels of precipitation, the great distance between major water supplies and population centers poses serious distribution problems. In 1990, the irrigated area stood at 0.660-0.693 million hectares according to official data (Kliot, 1994).

Syrian officials originally estimated that the Tabqa Dam would increase the irrigated area within the basin to 600,000 - 650,000 ha, but by 1981 only 60,000 ha had been brought under irrigation. Land reclamation and irrigation was proceeding at a rate of less than 12,000 ha per year, only one-fifth to one-quarter of the annual reclamation target (Naff and Matson, 1984). Kolar and Mitchell (1991) point out that less than half of the originally estimated target is reasonably good land for irrigation purposes. They estimated water being applied from Lake Assad to absolute maximum of 345,000 ha or, more realistically, 240,000 ha.

Turkish-Syrian Conflict

Syria and Turkey began to harness the waters of the Euphrates with large-scale irrigation and hydroelectric power generation projects. Each of these riparians to date has tended to develop its water use plans unilaterally, without regard to needs of other riparians, the environment, or the actual capacity of the basin. Although there have been some international efforts from foreign investors to coordinate projects to develop the rivers for the interest of all, a common joint development project has never become reality (Chalabi and Majzoub, 1995).

Up to the beginning of the 1990s, typical upstream-downstream conflicts occurred between Turkey, on one side, and Syria and Iraq other side. Tensions rose in January 1990 when Turkey began filling the Ataturk Dam reservoir. With Ataturk Dam and some others as storage reservoirs for irrigation, the water use in southeastern Turkey will turn into a consumptive one with a permanent withdrawal of water. This implies a lowering of the quality and quantity of water due to its upstream position. Both Syria and Iraq accuse Turkey of not informing them about the cut-off, thereby causing considerable harm. Thus, they claim the dams in Turkey are perceived as threats, not as means to store water.

Turkey's Objectives on Utilization of the Euphrates River

- The construction of dams on the Euphrates River provides regular and stable water flows to downstream riparians. In summer months, the average flow of the river ranges between 150-

$200m^3$/second or more, and in the springtime, it reaches the level of 5000 m^3 or more. Given the high rate of seasonal fluctuation of the Euphrates River, water storage is a vital necessity in the basin. Turkey claims that building dams for the stability of river flow would build up the upper Euphrates River, because Turkey's geographical and topographical characteristics provide less evaporation from reservoirs. The Boulder dam in the basin of the Colorado River provides an example. The upstream dam works as water storage not only for the U.S. but also for Mexico. This illustrates that the utility of controlled water quantity is greater than the utility of uncontrolled water of greater volume (Bilen, 2000).

- Turkey states that while 88.7 percent of total water potential of the Euphrates Basin originates in Turkey, Syria contributes only about of 11.3%. Iraq's contribution to the runoff is nil. While the contribution of these two downstream countries to water of the Euphrates is such a modest percentage, they have been demanding 22 percent and 43 percent, respectively, out of this potential. Turkey envisages utilizing only 35 percent of the total consumption target while providing 88.7 percent of the total flow.

- Turkey classifies both the Euphrates and Tigris rivers as trans-boundary rivers. Turkey approaches the Euphrates-Tigris basin issue from that position, and it offers a "Three-Staged Plan Optimum, Equitable, and Reasonable Utilization of the Basin." This plan was first introduced during the fifth meeting of the Joint Technical Committee between 5-8 November 1984. The plan proposes these three stages: 1) inventory Studies for Water Resources, 2) inventory Studies for Land Resources, and 3) evaluation of Water and Land Resources. Turkey believes that equitable, rational, and optimum utilization of water resources can be achieved through a scientific study that will determine the true water needs of each riparian country (Turkey Minister of Foreign Affairs, 1994).

- In the publications pertaining to the irrigation matters, lands are divided into six categories (Kolar and Mitchell, 1991; (USAID, 1980). The first three categories of lands are the most efficient and can yield maximum production by way of irrigation. The fourth category of land is of marginal value. Yield can be obtained from the fifth category only with a considerable amount of investment. Finally, sixth category lands are of an unyielding type, and production cannot be obtained even by way of irrigation. While all of the Turkish lands to be irrigated by the Euphrates River are of the first, second, and third categories, the similar categories of lands in Syria represent only 48 percent of the agricultural lands that are contemplated to be irrigated with the Euphrates. Therefore, it will not only be uneconomical but will also be inequitable to utilize scarce water resources to irrigate infertile lands at the expense of fertile lands (Turkey Minister of Foreign Affairs, 1994).

Syrian's Objectives on The Euphrates River

- After Ataturk Dam and Birecik dam construction, Turkish diversion for irrigation may be almost half of total flow of that Euphrates (15.5 km^3), leaving just 50 percent for both Syria and Iraq. It has caused significant damage to Syrian agriculture as well as hydropower generation and water supply facilities.

- Syria claims that the Euphrates and Tigris rivers are international watercourses, which can be classified as "shared resources". The water of those rivers must be shared among the riparian states according to quota to be determined. Syria foresees that: (a) Each riparian state shall declare its demands on each river separately; (b) The capacities of both rivers in each riparian state shall be calculated; (c) If the total demand does not exceed the total supply, the water shall be shared accordingly to stated figures; (d) In the case of total demand for water, declared by the three riparians, exceeds the water potential of a given river, the exceeding amount should be deducted proportionally from the demand of each riparian state. Further, Syria believes that the UN must be present at all negotiations, and it requests that the International Law Commission's studies be finalized and that rules and regulations be established as soon as possible.

- 3,3 km^3 of irrigation return flow is expected to re-enter the river upstream from Turkey. The prospect of reduced and degraded flow has concerned Syria and Iraq.

Negotiations between Turkey and Syria

In 1982 and 1983 Turkey, Syria, and Iraq established a Joint Technical Committee. The committee has been meeting for a general project discussion and exchange of hydrological data. Nevertheless, these meetings have not been held regularly and the committee has not been able to find a solution. Until 1987, Turkey was under no obligation or pressure from international agencies. At that year in July, a Protocol of Economic Cooperation was signed between the Turkish Prime Minister Turgut Ozal and the Syrian Prime Minister Hafiz Al-Asad (Bagis, 1997). In Article 6 the Protocol says:

"*During the filling up of the Ataturk Dam reservoir and until the final allocation of the waters of the Euphrates among the Three riparian countries, the Turkish side undertakes to release a yearly average of more than 500 cubic meters per second at the Turkish/Syrian Border and in cases where the monthly flow falls below the level of 500 cubic meters, the Turkish side agrees to make up the difference during the following month*" (Turkey Ministry of Foreign Affairs, 1994).

Turkey accepted the realization of a yearly average of more than 500 m^3/s, at the Turkish-Syrian border. It should be added that the Protocol was regarded as a temporary arrangement by Turkey because of the Statement of "*During the filling up of the Ataturk Dam reservoir and until the final allocation of* *the waters of the Euphrates among the Three riparian countries*". Article 7 confined that Turkey and Syria should draw up, together with Iraq, a "real treaty" within the shortest possible time (Scheumann, 1993). Although this commitment was noted by the Financial Times January 3,1990, "*has been the strongest formal agreement reached on the regional water management since World War* II", there has been more negotiations and misunderstandings has taking place between the two countries. These negotiations are as follows: *1-) Negotiations held between 19-20 January 1993*: The agreement had been reached to start negotiations, which would be headed by top level officials from Ministries of Foreign Affairs of both countries, with a view to reaching a solution. It was also agreed that those negotiations be conducted in coordination with Turkish and Syrian Foreign Ministers. *2-) Meeting of 17-20 May 1993 Between Turkey and Syria:* In this framework, a Syrian delegation came to Ankara for negotiations between 17-20 May 1993. During the meeting, Turkey proposed that the Orontes River should also be included in the negotiations, but Syria refused to discuss this issue. Consequently, it was concluded that the next meeting was to be held between June 21-24, with the participation of Iraq as well. No breakthrough was achieved and not even a press release was issued at the end of these negotiations. *3-) The Meeting held with Iraq on 21 June 1993:* The Iraqi delegation attended, but Syria did not participate in this meeting. During the said meeting, the Iraqi delegation demanded that the quantity of water released by Turkey be increased to 700 cubic meters per second. *4-) Notes given by Syria and Iraq on the construction of the Birecik Dam:* A Note related to the construction of the Birecik after-bay Dam has been given to the Embassy of the Republic of Turkey in Damascus on 3 December 1995. In this Note, Syria stated that the Birecik Dam would reduce the flow of the Euphrates and that the waters of the Euphrates have been polluted by Turkish irrigation activities. Turkey has answered on 31 December 1995 the Syrian Note and refuted the Syrian allegations (Turkey Ministry of Foreign Affairs, 1994).

Although the 1987 protocol in which Turkey promised 500 cubic meters per second at its border with Syria has not been solidified into a firm agreement or treaty, Turkey has consistently endured commitment under the protocol of 1987. However, the problem is the current dispute over actual size of the annual flow of the Euphrates. Data on the average discharge varies enormously. Syria's claims that Turkey is deliberately reducing the flow of the Euphrates River are countered by Turkey's claim that region suffers periodic droughts (Drake, 1997).

Statement of Problem

This research treats water as an economic good and seeks optimal utilization of water resources of the Euphrates River used in Turkey to satisfy water usage for agricultural and hydroelectrical purposes. Within the confines of this model, the political and economic conflicts between Turkey and Syria will be explained. Following, the different possibilities for water release from Turkey to Syria will be discussed within a framework that will be satisfactory for both countries. Furthermore, the possibility of market issues in physical water and virtual water cases will be analyzed and evaluated, since the strategy of substituting food imports for irrigated agricultural production reduces the water consumption of the upstream user. Therefore, a Virtual Water approach can help to reveal the benefits of a compensatory arrangement for both sides.

In the water system analysis, the Euphrates and Tigris rivers are defined as international rivers that share a twin basin. However, this study focuses only on the Euphrates River, which shares a basin between Syria and Turkey, for two main reasons. First, Turkey has completed four major dams on the Euphrates River and could cut off the river's flow. Not surprisingly, Syria is complaining about Turkish development projects, which Syria believes will reduce the flow of the Euphrates River to Syria by 40%. Nevertheless, Tigris River projects in Turkey are being planned and designed. The second reason is political. Since Syria is worried about becoming totally dependent on Turkish control of the river, Turkey and Syria are in serious danger of escalating hostilities over the waters of the Euphrates River. Syria is engaged in certain activities targeted against Turkey. Among those is their continued support for the Kurdish Workers Party, PKK (Partiya Kerkarani Kurdistan), which aims at the creation of a Kurdish State in southeastern Turkey. In response, Turkey has decided to use the water issue as a bargaining point against Syria (Guner, 1998). Such tends are exacerbating existing conflict and economic improvement. Permanent solutions on the Turkish and Syrian issue over the Euphrates River could provide economic benefits not only for these two rivals, but also other countries in the region. In the Middle East, water is essential as a major component in achieving economic development, which is associated with more urbanization, higher levels of industrialization, and greater productivity in agriculture.

Despite the issue of water allocation, which continues to cause friction between Iraq and Turkey, Iraq is left out of this study. Since the UN Security Council imposed the embargo when the Iraqi army occupied Kuwait in 1990, only limited data is available on Iraqi development projects on the Euphrates River. In addition, the geography and hydrography of the Euphrates-Tigris basin in Iraqi territory requires separate study for water resources management because Iraq has completed a canal to divert more water from the Tigris to the Euphrates in order to utilize the basin to their needs. Nevertheless, this would involve a cutback in irrigated land in the Tigris basin (Soffer, 1999). Unlike the Euphrates, the Tigris River has several major tributaries in Iraq's territories, and Iraq contributes 57 percent of average annual flows of the Tigris River. Furthermore, Iraq does not yet exploit the Euphrates River water fully for irrigation as well as on the Tigris.

One of the objectives of this proposal is to use a dynamic joint maximization model that will provide Pareto optimal utilization of the water resources of the Euphrates River for two purposes: irrigation and hydropower production. To accomplish this objective, the proposal has the following sub-objectives:

1. present up-to-date data on the Euphrates River basin water resources, identify net benefit functions for agriculture and hydropower production due to five reservoirs in Turkey; moreover,

estimate the optimal water requirement, taking into account the value of water both for irrigation and hydropower production;

2. under the result of the optimal allocation of water resources in the system, analyze the conflict between Turkey and Syria and address the questions of whether or not the conflict is artificial and whether or not there is sufficient water for the riparians' needs;
3. analyze and evaluate the possibility of water market application between the two countries and discuss virtual water transfer in the region; furthermore, analyze the conflict over water as a development constraint for the region.

CHAPTER III

LITERATURE REVIEW

In environmental and natural resource economics, water has been classified or defined as a “renewable resource” or “flow resource,” which means naturally renewed within a sufficiently short time span to be of relevance to human beings (Hackett, 1998; (Rees, 1990). However, there are many ways in which water differs from other renewable natural resources – such as forests, the air, fisheries, and wildlife population. First, it is inherent in the nature of a fluid resource, therefore, the property rights are difficult to establish and enforce. Second, its total quantity on earth is fixed and can be neither increased nor decreased. Thus, water could be treated as a non-renewable resource. Thirdly, water is essential for human survival (Clarke, 1993).

Because of these natural characteristics of water, few markets exist to allocate water efficiently according to price. Furthermore, where markets and pricing are not feasible, benefit cost analysis, employing shadow prices for non-market impacts, will help to improve economic information and allocate water more efficiently. However, this approach assumes that economic efficiency is the relevant objective for public water resources interventions (Young and Haveman, 1985).

Howe, Schurmeier, and Shaw, (1986) identify six criteria for alternative allocative mechanisms of water supply such as flexibility, security, predictability, fairness, resource's opportunity cost, and reflecting public value of water in their paper. They point out that these allocative mechanisms attribute economic efficiency, however, to a lesser degree than exchange through markets. These sub-optimalities are attributed to a number of factors, including improper pricing, lack of markets to reflect opportunity costs, alternative uses of water. Furthermore, they state that benefit cost analysis use in practice is a necessary condition for Pareto optimality: an allocation A is efficient relative to allocation B if and only if in the move from B to A the winners would be able to fully compensate any losers. Hence, the shadow price, which represents the true value of given resources, employed in benefit cost analysis for water resource planning.

Thus, the benefit cost analysis in river basin optimization models provides a rational framework for efficiently allocating scarce water across multiple uses, locations and times by linking interdependent economic and hydrologic variables. Procedures for estimating the benefit and costs of a non-marketed commodity such as water can be interpreted as efforts to simulate hypothetical market outcomes, and maximizing net benefits leads economic efficiency in resource allocation.

Burt and Cummings (1970) set out a general theory for the inter-temporal allocation of natural resources from the standpoint of society and show that both production from and investment in natural resources are simultaneously optimized over a social planning horizon. In their study, the social benefit function is derived as a profit function and results applied to the optimum behavior of firm.

Therefore, the benefit function is appropriately concave, continuous, and differentiable and the necessary underlying production relationships exist. These economic assumptions provide that the objective function is the sum of the present value of the net social benefits from resources used throughout the planning horizon.

A more recent line of net benefit analysis has employed mathematical programming models to estimate market allocations and identify the optimal interregional, inter-sectoral allocations and prices that would emerge from hypothetical water markets. Most state and regional economic impact studies of water management have been conducted in the western United States. For example, Gisser et al. (1979) analyzed utilization of water for energy development and agricultural development in the Four Corners area of the southwestern U.S. They used a linear programming model to maximize net revenue from agriculture (returns to water and land) and hydropower production. Booker and Young (1994) published a model that optimizes the water-related benefits of irrigation, hydroelectricity, municipal uses, and salinity control in the Colorado River Basin. Furthermore, a model that is to maximize the economic yield from individual reservoirs in which corporate hydroelectricity generation irrigation and municipal demands is developed by Simonovic (1987).

In addition, McCarl and Ross (1985), Houston and Wittlesey (1986), McCarl and Parandvash (1988), and Hamilton, Wittlesey and Halverson (1989) have investigated the use of water from the Snake-Columbia river system. These studies seek to maximize benefit functions that are concave in water consumption and use mathematical programming to model the optimal use of competing demands for water resources. They suggest conceptual models that capture the major physical and economic relations relevant for the management problems in the river basin. However, different mathematical programming models were used to determine the optimal flow of water releases on the reservoir systems on these works.

Furthermore, water management analysis could be classified as an application of mathematical modeling on the engineering-economic literature. Application of mathematical modeling of river systems can be classified into two categories: Optimization modeling and Simulation modeling. Both provide a management tool for improving the economic performance of river basin management (Ward and Lynch, 1996).

Optimization Models

Based on mathematical programming techniques, William Yeh (1985) classified optimization methods for river and reservoir management in three techniques: Linear, dynamic, and nonlinear programming. Each of these techniques can be applied in deterministic and stochastic formulations of modeling due to characteristics of model parameters – certain or uncertain. Every optimization model structures has two essential parts: The objective function and the constraint set. The objective function represents a way to measure the level of performance obtained by specific changes in the decision variables. The decision variable set is the desired output of optimization model.

Constraints describe the system or process that is being designed or analyzed, and force the model to obey the physical laws, economic requirements, and social as well as other restrictions. The constraints can be of forms: equality constraint and inequality constraints. The feasible solution to optimization problem is set of the decision variables that simultaneously satisfy the constraints.

The general framework of an optimization problem in water resources may be formulated as:

$$\text{Optimize } f(x) \tag{1}$$

subject to constraints

$$g(x) = 0 \tag{2}$$

and bound constraints on decision variables

$$x_{min} < x < x_{max} \tag{3}$$

where x is vector of n decision variables (x_1, x_2, . . . x_n), $g(x)$ is a vector of m equations called constraints, and x_{min} and x_{max} represent the lower and upper bounds, respectively, on decision variables. In general, the objective equation (1) is to be maximized or minimized. Maximizing equation f(x) is equivalent to minimizing –f(x) or vice versa (Mays & Tung, 1992).

Although each of three optimization techniques requires a very specific formulation of the reservoir management problem in order to apply the particular cases, the mathematical formulation of the objective function and constraints determines the differences. If problems are represented by nonlinear equations, it is called nonlinear programming techniques. On the other hand, if the objective function and constraints are set in linear equation, it is called linear programming techniques. Dynamic programming is a procedure for optimizing a multistage decision process, and an efficient mathematical technique for making a sequence of interrelated decisions. It can handle linear or nonlinear objective function and constraints very easily. The dynamic programming procedure is to structure of allocation problem as a sequential allocation process. Consequently, dynamic programming is very well suited to reservoir problems. For most reservoir problems, if dynamic programming technique is applied to determine reservoir releases, the state variable is storage, the decision variable is the release, and the stage is represented by the time period (Simonovic, 1992).

In practice, the objective functions to be optimized will be a dominant purpose for a particular reservoir system. The primary purposes in the reservoir system include hydroelectric generation, municipal/industrial water supply, irrigation, recreation and instream flow maintenance. The objective is to determine the optimal storage capacity and release policy for each reservoir in the system to maximize the total net benefit of the system operated over T period. The typical constraints in the reservoir optimization models are mass-balance equations; maximum and minimum storage levels; maximum and minimum releases; flow-carrying capacities of hydraulic structures such as penstock; contractual, legal, and institutional requirements for various purpose of the system (Mays & Tung, 1992).

Water allocation between hydropower and agricultural uses has been analyzed in several previous studies using the optimization mathematical modeling. Houston and Wittlesey (1986) constructed a linear programming model for the Columbia-Snake River system and examined the potential for water markets that would permit sales of water from agriculture to the hydropower sector for energy production. They concluded that both farmers and energy consumers could be better off by adopting water markets to reallocate water among these competing uses. In their study, total consumers' plus producers' surplus change in the agriculture sector becomes the measure of potential net benefits to be gained through any reallocation of water resources.

McCarl and Parandvash (1988) have developed a stochastic programming model that examines the efficiency of two proposed irrigation projects in the Pacific Northwest. They show that interruptible irrigation to increase hydropower production in water-short years can significantly reduce costs to hydropower of irrigation development. Keith et al. (1989) used a chance-constrained programming model for the Upper Colorado and Utah's portion of the Great Basin and showed that with existing storage facilities and limited water right transfers, water quantity would not significantly limit Utah's economic growth. Their model included agricultural and energy sectors requiring water. The objective function consisted of profit (net return) to both sectors.

Chatterjee et al. (1998) address the optimal inter-seasonal allocation of surface water for both irrigation and hydropower production by developing a dynamic optimization model. The dynamic model was applied to irrigation districts in central California and they concluded water released for irrigation in spring reduces the reservoir head and diminishes the capacity to generate power during summer peak demands.

Simulation Model

Simulation models are another technique for optimizing reservoir management that is used to approximate the behavior of system on a computer. It is different from the optimization technique. Optimization techniques find an optimum decision for system operation meeting all system constraints while maximizing or minimizing some objective. On the other hand, the simulation model provides a means to predict precisely the response of the system to specified inputs, including management decisions. Therefore, it enables a decision-maker to examine the consequences of various scenarios of an existing system or a new system without actually building it. Hence, simulation models evaluate the merits of competing management alternatives (Yeh, 1986).

A typical simulation model for a water resources system is simply a model that simulates the interval-by-interval operation of the system with specified inflows at all locations during each interval, specified system characteristics and specified operating rules. The purpose of operating rules is to find operating procedures that maximize net benefits from each physical system – or reservoirs – and produce results as close to the economic optimum as possible. These rules may be designed to vary seasonally in response to the seasonal demands for water and the stochastic nature of supplies. It is common practice to define operating rules in term of a minimum yield or target value. Consequently, operating rules for a water resources system are based on economic trade-offs among the effects of alternative decision possibilities. However, optimization by simulation does not yield a direct answer; it may require a very large number of trails to developed reservoir operation policies (Yeh, 1986).

The U.S. Army Corps of Engineers has developed the most extensive basin optimization research program to simulate the operation of multipurpose, multireservoir systems. These computer programs have been applied to determine both reservoir storage requirements and operational strategies for flood control, water supply, hydropower, and instream flow maintenance for many river networks in the U.S., such as Missouri and Colombia river basins (Ward and Lynch).

All of the above studies used mathematical programming models to analyze the impact on water allocation between competing uses by ignoring water resources under different state jurisdiction. In fact, some of river basins are utilized under more than one state jurisdiction. In that case, the absence of a common goal among the riparian states and the increasing scarcity of water arising from multiple uses are the core conflicts in river basins. However, different institutional settings and legal arrangements are commonly used to resolve trans-boundary conflicts.

The use of treaties in resolution of conflicts regarding the allocation of water resources across borders is a common practice. These treaties have been categorized into four theories: (1) absolute territorial sovereignty, (2) limited territorial sovereignty, (3) absolute territorial integrity, and (4) community. The theory of absolute territorial sovereignty allows an upstream state to do as it wishes with waters flowing within its boundaries, with no regard to downstream states. Limited territorial sovereignty allows each state to make use of the water flowing within its borders but prohibits the interference of either state in the reasonable use of waters of by the other. Absolute territorial integrity prohibits the restriction of water flow by upstream states to downstream states. Finally, community provides that the waters of a basin should be developed as if the basin were one political unit, with the benefits and costs of development shared among the stated (Burke et al., 1998).

For example, The U.S. Supreme Court has adopted the theory of limited territorial sovereignty to resolve water disputes between individual states. Therefore, the river optimization model considers the alternative market institutions for water resources allocation. Booker and Young (1992) evaluate gain and loss from institutional change in interstate and intrastate water transfer in Colorado River Basin. They developed a nonlinear optimization model to estimate river flows and economic demand levels for consumptive use (irrigation, municipal) and non-consumptive use (hydropower, water quality) with the six alternative institutional scenarios. The model is formulated as an optimization problem with the objective of maximization of net economic surplus, defined over selected economic sectors, subject to physical and institutional constraint.

As related to the Euphrates water system, Al-Hadithi (1979) finds the near-optimal utilization of the water resources of the Euphrates River within the new conditions of the river in Iraq after major developments of irrigation and power generation projects on the Euphrates in Turkey and Syria. The methodology used in his study is a modification of the standard cost-effectiveness method and is named the varied cost-effectiveness method. A computer linear programming model is used to find the optimal utilization of Euphrates River water, based on allocation of irrigation water to main crops such that it will yield maximum benefits from agriculture. He concludes that the main two reasons for water distribution in Iraq are inadequate in both space and time. First, the existing irrigation and water supply system and water management and agricultural practices are not a good condition. Second, the annual and monthly flow distribution of the Euphrates River does not coincide with demand curves of water requirements due to lack of river flow control and improper reservoir and canal operations. Therefore, improving the existing irrigation system is very essential to optimal water utilization.

Al-Hadithi's (1979) study uses an engineering approach for utilization of water resources of the Euphrates River in Iraq; however, he does not consider the institutional problems on that trans-boundary river. Al-Jayyousi (1993) analyses the impact of water scarcity in both Syria and Iraq due to the construction of Atatürk Dam in Turkey. He addresses the problem of institutional mechanisms for water resources allocation issues in the region. His research explores future scenarios for cooperative strategies based on both individual "communicative action" and institutional analysis. He suggests that the establishment of a river basin commission under the supervision of an international body may help to find a permanent solution for conflicts among the three riparians.

Albert (2000) states that optimal models, which maximize or minimize one or more objective quantities, are often well suited to addressing river basin problems. Using system approaches, engineers and planners have found that water yield can be maximized when the planning scale is watershed as whole rather than a portion of the watershed. Therefore, joint maximization modeling approach will be used to evaluate the optimal water utilization of water resources on the Euphrates River for irrigation and hydropower generation in Turkey and Syria.

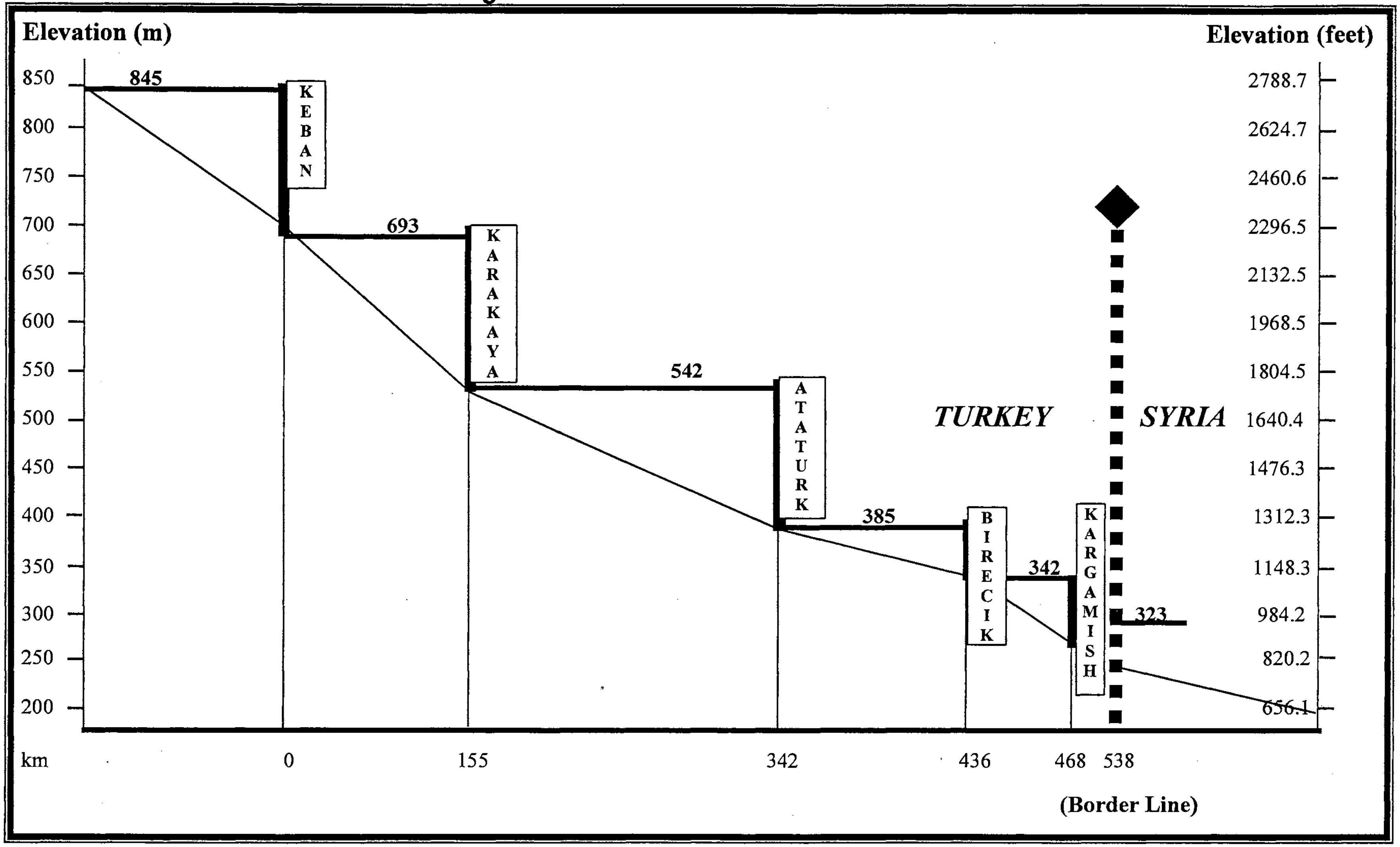
CHAPTER IV

MODEL AND METHODOLOGY

The model is formulated in the context of a reservoir system located in the Euphrates River's main streams. Main facilities existing on the Euphrates River system are Keban, Karakaya, Ataturk, Birecik, and Kargamis Dams. All these reservoirs are located on the main stream of the Euphrates River and they use the entire potential drop downstream from Keban.

Figure 3 shows the distance and elevation positions of the five reservoirs in the system. The Keban reservoir is first and is located at the highest elevation of the river system (850-meter). 155 kilometers/100 miles away from Keban and at 700 meters elevation is the second reservoir, where the Karakaya reservoir is located. The third reservoir on the system is Ataturk Reservoir, which has the biggest active volume and one of the multipurpose reservoirs. Birecik reservoir, located 436 km downstream of the Keban and at elevation of 385-meter, began to operate in November 2000. With 0.16 km^3 active capacity, the Kargamish Reservoir is the smallest and last reservoir in the system. It is located at 4.5 km/2.8 miles from Turkish-Syrian Border and a 340-meter elevation (Bilen, 2000). The goals of these projects are both power production and supply of irrigation water. However, Turkey, as an upstream riparian with these five reservoirs, extensively controls the natural flow regime of the Euphrates River.

Figure 3. Distance from Keban Reservoir



Characteristic of Reservoirs

Starting from upstream, these reservoirs' purposes and characteristics are briefly described in the following paragraphs;

1. ***Keban Reservoir:*** The dam was constructed during the period between 1965 and 1974 and is intended to regulate the seasonal fluctuations of the Euphrates River and generate power. Its reservoir holds 31,000 Mm^3 and has area of 675 sq. km at the 845-meter water-surface elevation. With 1330 MW capacity, the average annual electricity generated is 6.2 billion kWh (Nethaber, 2000).

Table V

Keban Reservoir Characteristics

Elevation Meter	Surface hm^2	Volume hm^3
800	26,000	9,500
805	30,000	11,000
815	38,500	14,600
818_{min}	$42{,}500_{min}$	$16{,}000_{min}$
820	44,000	17,000
825	48,000	19,200
830	52,500	21,700
835	57,000	24,200
840	62,000	27,000
845_{max}	$67{,}500_{max}$	$31{,}000_{max}$

Minimum Operating level = 818.0 m
Full supply level = 845.0 m
Tailgater level (at all discharges) = 693.0 m
Active Storage Volume = 31,000 – 16,000 = 15,000 hm^3

Turbine Characteristic:

Turbine Capacity: 4 x 157(MW) + 4 x 175(MW) = 1330 MW
Flow Capacity : 135 m^3/s

2. ***Karakaya Reservoir:*** The dam construction began in 1967 and was completed in 1988 for hydropower purposes. Its reservoir holds 9,500 hm^3 and has an area of 675 sq. km at the 845-meter water-surface elevation. Its proposed generating capacity is 1800 MW capacity, and its average annual electricity generated is 6.2 billion kWh (Nethaber, 2000).

Table VI

Karakaya Reservoir Characteristics

Surface Hm^2	Volume Hm^3	Elevation Meter
0	0	560
400	100	590
600	200	600
800	300	615
1250	300	620
1800	500	630
3750	800	640
6300	1000	645
8750	1500	650
13750	2500	660
17500	4000	670
19700	4889	675
21900	6000	680
26250	8500	690
26800_{max}	9242_{max}	693_{max}

Minimum Operating level = 670.0 m
Full supply level = 693.0 m
Tailgater level (at all discharges) = 542.0 m
Active Storage Volume = 9242 – 4000 = 5242 hm^3

Turbine Characteristic:

Turbine Capacity: 6 x 300(MW) = 1800 MW
Flow Capacity : 233 m^3/s

3. ***Ataturk Reservoir***: Dam construction began in 1967 and was completed in 1988. In January 1990, Turkey stopped the Euphrates flow for one month in order to fill the reservoir. It is the largest reservoir in the system. Its reservoir holds 48,700 hm^3 and has an area of 817 sq. km at the 542-meter water-surface elevation. Ataturk reservoir is a multipurpose project for power and irrigation. The proposed generating capacity is 2,400 MW capacity, and the average annual electricity generated is 8.2 billion kWh (Nethaber, 2000). Ataturk reservoir water is used to irrigate approximately 750,000-hectare area. The irrigation areas of the Ataturk reservoir and present stage are shown in Table VI.

Table VII

Ataturk Reservoir Irrigation Projects

IRRIGATION PROJECTS	IRRIGATION AREA (Ha)		PRESENT STAGE
Urfa Tunnel Project	370 246		
1.Şanlıurfa-Harran		141835	90 000 ha under operation
2.Mardin-Ceylanpınar		228411	Planning
Suruç-Yaylak (Pumping)	146 500		Reconnaissance
Bozova	47 368		Reconnaissance
Siverek –Hilvan	160 105		Reconnaissance
Adıyaman-Kahta	29 599		Planning
Total	753 718		

Table VIII

Ataturk Reservoir Characteristics

Surface Hm^2	Volume Hm^3	Elevation Meter
0	0	385
2500	500	400
5800	700	410
13100	2600	430
17500	4000	440
20800	6000	450
29300	11000	470
17500	4000	440
35500	14300	480
38000	16100	485
41690	18200	490
49700	22900	500
57400	27800	510
49700	22900	500
57400	27800	510
59700	29400	513
70000_{min}	37700_{min}	526_{min}
72800	40000	530
76770	44000	535
80410	47000	540
81700_{max}	48700_{max}	542_{max}

Minimum Operating level = 526.0 m
Full supply level = 542.0 m
Tailgater level (at all discharges) =383 .0 m
Active Storage Volume = 48,700 – 37,700 = 11,000 hm^3

Turbine Characteristic:

Turbine Capacity : 8 x 300(MW) = 2400 MW
Flow Capacity : 320 m^3/s

4. <u>Birecik Reservoir</u>: The Birecik reservoir construction started on the fourth of April 1996 and was completed on June 6, 1999. The first Birecik dam turbine started working in November 2000. Its reservoir holds 1,220.2 hm^3 and has an area of 56.25 sq. km at the 385-meter water-surface elevation. The Birecik reservoir is also a multipurpose project for power and irrigation. The proposed generating capacity is 672 MW capacity, and its average annual electricity generated is 2518 GWh (DSI, 2000). Birecik reservoir water is used to irrigate only one district which is called the Gaziantep project and has 53,030 hectare.

Table IX

Birecik Reservoir Characteristics

Surface Hm^2	**Volume** Hm^3	**Elevation Meter**
5625_{max}	1220.2_{max}	387_{max}
4970	937	380
4340	715	375
3940_{min}	600_{min}	372_{min}
2890	310	365
1440	105	355
0	0	345

Minimum Operating level = 372.0 m
Full supply level = 387.0 m
Tailgater level (at all discharges) = 340.0 m
Active Storage Volume = 1220.2 – 600 = 620.2 hm^3

<u>Turbine Characteristic:</u>
Turbine Capacity: 6 x 112(MW) = 672 MW

5. ***Kargamish Reservoir:*** The Kargamish reservoir has a hydroelectric plant and is located 4.5 km from the Syrian border and 33 km downstream from Birecik reservoir. Construction of this 180MW plant started on 1 June 1996 after several years of negotiations with the Turkish General Directorate of State Hydraulic Works (Turkish initials is DSI) was concluded successfully in 1995. Work is completed in the last quarter of 1999. The first Kargamish dam turbine started working in January 2000. Its reservoir holds 157 hm^3 and has an area of 28.4 sq. km at the 340-meter water-surface elevation. Kargamish reservoir is a single purpose project for hydropower (DSI, 2000).

Table X

Kargamish Reservoir Characteristics

Surface Hm^2	Volume Hm^3	Elevation meter
2840_{max}	1.57_{max}	342_{max}
2650	1.2	340
2240_{min}	0.67_{min}	336_{min}
1507	0.304	330
758	0.13	325
0	0	320

Minimum Operating level = 342.0 m
Full supply level = 336.0 m
Tailgater level (at all discharges) = 0.0 m
Active Storage Volume = 1.57 – 0.67 = 9.0 hm^3

Turbine Characteristic:

Turbine Capacity: 6 x 31.5(MW) = 189 MW
Flow Capacity : 6 x 331 m^3/s

Model Description

A Linear dynamic programming approach is used in the optimization of water resource systems in the Euphrates River Basin. In the model framework, the decision variables are “the releases for irrigation”, “power generation”, and “instream flow requirement” in each period. For a given set of releases, the amount of total benefit for each period can be calculated based on a benefit function. The decision on releases for each period should be limited by the demands and the reservoir storage (state variable) available. The optimization problem sets up the maximization of the net economic benefit of the selected water use patterns -irrigation and hydropower- in the Euphrates River subject to physical constraints. Model solutions ensure that each period estimate of economically efficient allocations of the water use for irrigation and hydropower.

Objective Function:

The objective is to seek storage and release patterns that maximize net total economic benefits. Total net benefits are the sum of hydropower net benefits from all power generated, and irrigation net benefits.

$$\max \sum_{t=1}^{T} \sum_{s=1}^{S} BE_{st} E_{st}$$

$$+ \left(\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{z=1}^{Z} BI_{jszt} L_{jszt} - \sum_{\Gamma=1}^{\acute{\Gamma}} e^{\Gamma}_{jszt} W^{\Gamma}_{jszt} \right) \tag{4}$$

where BE_{st} is the net benefit from producing per kilowatt-hour electricity at reservoir s in month t. E_{st} is the amount of electricity generated at reservoir s at period t. The instream water use benefit from hydropower generation (BE_{st}) at hydropower station s is

$$BE_{st} = (PE_{st} - CE_{st}) \tag{5}$$

where PE_{st} is selling price of power and CE_{st} is the power generation cost. In which case, the first part of equation (4) represents total net benefits from hydropower generation at (**s**) reservoirs in each period (**t**).

The second part of equation four shows net benefit gain from irrigation. Farm Crop Budget analyses is used for formulating the net economic benefit of irrigation. In this approach, the net benefit calculated according to the maximum net revenue share of the water input in the production unit (Gibbons, 1986). Therefore, the total net economic benefit from agriculture in equation four is formulated by the total crop revenue (per hectare net revenue multiplied by total land used) minus total water cost (total water demand multiplied by cost of per unit of water). The subscripts used in the model are:

j ≡Crops
t ≡Time periods
z ≡Irrigation districts
s ≡Reservoir used for irrigation
ŕ ≡Harvest periods

Definitions of the symbols used in the irrigation benefit are as follows:

BI_{jszt} ≡ Net return of irrigated per hectare land for crop **j** at reservoir **s**, district **z** in period **t**

L_{jszt} ≡Total hectares of irrigated land for crop **j** at reservoir **s**, district **z** in period **t**.

e^{Γ}_{jszt} ≡Per cubic meter water cost for irrigated crop **j** in period Γ harvested in period **t**, reservoir **s** at district **z**.

W^{Γ}_{jszt} ≡Total water demand for irrigated crop **j** in period Γ harvested in period **t**, reservoir **s** at district **z**.

The definition of the net economic revenue from per hectare producing crop (j) is formulated in the equation 6.

$$BI_{jszt} = P_{jt}\, Y_{jszt} - C_{jszt} \tag{6}$$

where, P_{jt} represent selling price of crop (j), and Y_{jszt} is yield per hectare of crop (j) at district (z) in period (t). Thus, Multiplying P_{jt} and Y_{jszt} show per hectare revenue of producing crop (j). C_{jszt} is non-water-related cost per hectare for irrigated crop (j), at district (z) in period (t). Consequently, the net economic benefit from agriculture (***BI***) is the total crop revenue less non-water input costs is a residual, the maximum amount the farmer could pay for water and still cover the cost of production under the constraint of the reservoir storage available. Farmer's demand for irrigation water (or the crop water requirement) is derived from the value of its use in crop production.

The objective function, shown in equation (4), is the sum of hydropower benefit from all power generated and benefit from the supply of irrigation water as input in to farm production. Therefore, Total economic benefit functions are formulated for hydropower generation and irrigation by time and location in the basin. The objective of determining the best water releases policies for each period from reservoir to an irrigation district is defined according to simultaneous maximization of both net economic benefits of the crop production in the irrigation district and hydropower generation benefit subject to constraints. These constraints may be economic or physical, such as acreage limitations for each crop, input costs per unit, constant water requirements set for each crop, crop prices and so forth.

Constraints:

The constraints on the reservoir system force the model to obey the physical laws, economic requirement and restrictions. Typical reservoir constraints to the model involve the following:

a) Mass Balance Constraint:

The mass balance equation determines the amount of water available in the reservoir to use for different purposes in each period and depends on various hydrological elements. The mass balance Equation can be written

$$ST_{t+1} = (1 - \mathrm{Evap}_t)\, ST_t + QF_t - R_t \qquad (7)$$

$$(t = 1, \ldots, T)$$

which says that the storage in the reservoir at the beginning of the following season (ST_{t+1}) must equal the storage at the beginning of the present season (ST_t) plus any additions during the present season (the inflow, QF_{11t}) minus any deductions during the present season (the reservoir release R_t). $Evap_t$ is the average evaporation loss and is defined as a difference between precipitation and evaporation rate in the same period **t**. It is expressed as a fraction of storage from the reservoir during season **t** (Major and Lenton, 1979).

b) Relationship between total release and releases for various purposes:

The water release from reservoir depends on reservoir purposes. It is assumed that a reservoir has three purposes: irrigation, water supply and hydropower, so that relationship between total release and release for three purposes can be written

$$R_t = R_{\mathrm{ir},t} + R_{ws,t} + R_{\mathrm{in},t} \quad (t = 1, \ldots, \mathrm{T}) \tag{8}$$

$$R_{\mathrm{in},t} = R_{pt} \quad (t = 1, \ldots, \mathrm{T}) \tag{9}$$

where $R_{\mathrm{ir},t}$, $R_{ws,t}$, $R_{\mathrm{in},t}$, *and* R_{pt} are, respectively, releases for irrigation, water supply, instream flow requirement and hydropower generation during period **t**. Total release from the reservoir is equal to the sum of release for irrigation, water supply and instream water requirement during period **t** (equation 8). In equation (9), the instream water requirement is equal to water release for hydropower generation in each period (May and Tung, 1992).

c) Reservoir capacity and per period storage relationship:

The storage in a reservoir cannot exceed the storage capacity during any season **t**.

$$ST_t + K_{d,t} - K_{max,t} \leq 0 \quad (t = 1, \ldots, \mathrm{T}) \tag{10}$$

in which $K_{\mathrm{max},t}$ is the storage capacity and $K_{\mathrm{d},t}$ is dead storage of the reservoir. The constraint (eq.10) says that the active storage, $\mathbf{ST_t}$, must stay between those upper and lower bounds.

d) Hydropower production constraints:

Hydropower production constraints define the calculation of the hydropower energy production at the reservoir. There are only three variables that affect energy production: (1) the flow ($R_{p,t}$) through the turbines of the power plant, (2) the head associated with this flow, and (3) the installed capacity of the power plant. The energy constraints reflect the relationships of these variables to hydroelectric energy production. Total energy generation during a given season t is calculated by

$$e_t k_t R_{p,t} \mathbf{h}_t = E_t \qquad (t = 1, \ldots, T) \tag{11}$$

e_t ≡Power plant efficiency

k_t ≡Conversion factor (number of second in season t)

$R_{p,t}$ ≡Average turbine release at reservoir during season t

h_t ≡Average turbine head during season

E_t ≡Total energy generation in season t

In Equation (11), the calculation of energy generation is the product of the power efficiency, conversion factor, average turbine release, and average turbine head. Power plant efficiency is the product of the turbine efficiency and generator efficiency. Turbine efficiency defines the lose of power due to resistance in the pipes (penstocks) that carry the water, incomplete transfer of all of the water's energy to the hydraulic turbine blades, and other factors. Turbine efficiency is a complex function of the type of turbine used, the head, the percentage of the maximum power being generated, and other factors. It is usually in the range of 80-95 percent. Generator efficiency defines the loss in the generator because the shaft of the turbine is connected to the generator. It is usually in the range of 80-95 percent. The conversion factor defines the number of seconds in a season, because water release ($\mathbf{R}_{p,t}$) is measured as cubic meter/feet per second (Healy et al., 1983).

The energy available for conversion to electrical energy of the water impounded by the reservoir is the function of the gross head;

Gross Head (h) = Elevation of Water Surface – Elevation of the Tailrace

Gross head is the elevation of the surface of the reservoir less minus the elevation of the afterbay, or downstream water level below the hydroelectric plant. The head available to the turbine itself is slightly less than the gross head due to the friction losses in the intake, penstock, and draft tubing. Furthermore, storage volume is changed one period to other causes the change on the elevation of water surface. Therefore, this is usually expressed as the "net head" (Wood and Wollenberg, 1984).

The height of the water above the turbine (**h**) is a function of active storage volume, (**s**) of water stored in reservoir. It may be written as the linear function

$$h = h_0 + m(s) \tag{12}$$

From this equation, we can derive the average head, which can be used as a net head. The average gross head (h_t) in period t may be defined as a function of the average storage (s_t) in period t. Consequently, the average gross head can be written as a function of the average active storage volume;

$$h_t = h_0 + m(ST_{t-1} + ST_t) / 2 \tag{13}$$

The average gross head is defined as the average of the storage active volume, and is used to calculate hydropower production in equation (11).

A hydropower generation has the upper bounds of capacity constraints. It calls power plant capacity and the constraint name hydropower generation constraint,

$$E_t \leq \mathrm{N}_t \quad (t = 1, \ldots, \mathrm{T}) \tag{14}$$

in which $\mathbf{N}_t$ is the capacity of the power plant and E_t is energy production in the period **t**.

e) Irrigation constraints;

The irrigation constraints shape the relationships between water and the production of crops. Crop production depends on irrigation water volume, water requirements for crops, and the amount of land available for irrigation.

i) *Water Transfer Constraint*: The volume of water supply ($\check{\mathbf{R}}_{ir,\ szt}$) for irrigation district **z** from reservoir **s** in period **t** is limited due to irrigation canal capacity. Therefore, water supply capacity ($\check{\mathbf{R}}_{ir,\ szt}$) must equal or greater than to total water supply ($\mathbf{R}_{ir,\ szt}$)for irrigation district **z** from reservoir **s** in period **t.** It is the main irrigation constraint and is represented in equation (15);

$$R_{ir,\ szt} \leq \check{R}_{ir,\ szt} \tag{15}$$

ii) *Water Transfer To Irrigation District:* Another constraint in irrigation is the water transfer constraint, which shows the water distribution requirement to each district, irrigated by same reservoir. This equation (16) represents that total amount of water provided for irrigation ($\mathbf{R}_{ir,st}$) from reservoir **s** in period **t** must equal to sum of water supply for each districts ($\mathbf{R}_{ir,\,s1t}+\mathbf{R}_{ir,\,s2t}+\ldots.+\mathbf{R}_{ir,\,sZt}$).

$$R_{ir,\,st} = \sum_{z=1,}^{z} R_{ir,\,szt} \tag{16}$$

iii) *Irrigation Water Demand:* This constraint defines the total quantity of water ($\mathbf{W}^{\Gamma}_{jszt}$) required in each period **t** of growing season (Γ) of crop **j** in the $\mathbf{z}^{th}$ district. The total water demanded for crop **j** is per hectare water requirement of crop **j** ($\mathbf{f}_{jszt}$) multiplied by total land used for that crop ($\mathbf{L}_{jszt}$).

$$f_{jszt}\, L_{jszt} = W^{\Gamma}_{jszt} \tag{17}$$

A theoretical approach for estimating crop water requirements based on the approximate relationship between plant evapotranspiration and evaporation from a free water surface as measured by a "pan" or as estimated by an equation such as Penman. It is called "net water requirement." However, while water is reaching from the point of supply all the way channel to crop, there would be water loss on the way. Thus, $\mathbf{f}_{jszt}$ should be the gross water requirement. Gross water requirement is crop water requirement multiplied overall efficiency.

Overall efficiency = (Conveyance Efficiency) x (Distribution Efficiency) x (Field application efficiency)

Conveyance Efficiency is the percentage of source water reaches the field by supply system.

Distribution Efficiency; is the percentage of water delivered to irrigation field.

Field application efficiency; is the percentage of water delivered to field is used by crop.

These three efficiency percentages are changed according to surface irrigation and sprinkler irrigation systems. Surface irrigation system efficiencies range is 60-100 % (Rogers etc, 1997).

iv) *Total Irrigation water demand:* In this case, total water supply ($\mathbf{R}_{ir,szt}$) equals or greater than total water demand($\mathbf{W}^{r}{}_{1szt}$ + $\mathbf{W}^{r}{}_{2szt}$ +......+ $\mathbf{W}^{r}{}_{Jszt}$) at reservoir **s** in district **z** ,period **t**.

$$\sum_{j=1}^{J} W^{r}{}_{jszt} \leq R_{ir,\,szt} \qquad (17)$$

v) Irrigation Land constraint: a Land constraint shows the relationship between total land available for irrigation and land use for crop **j**.

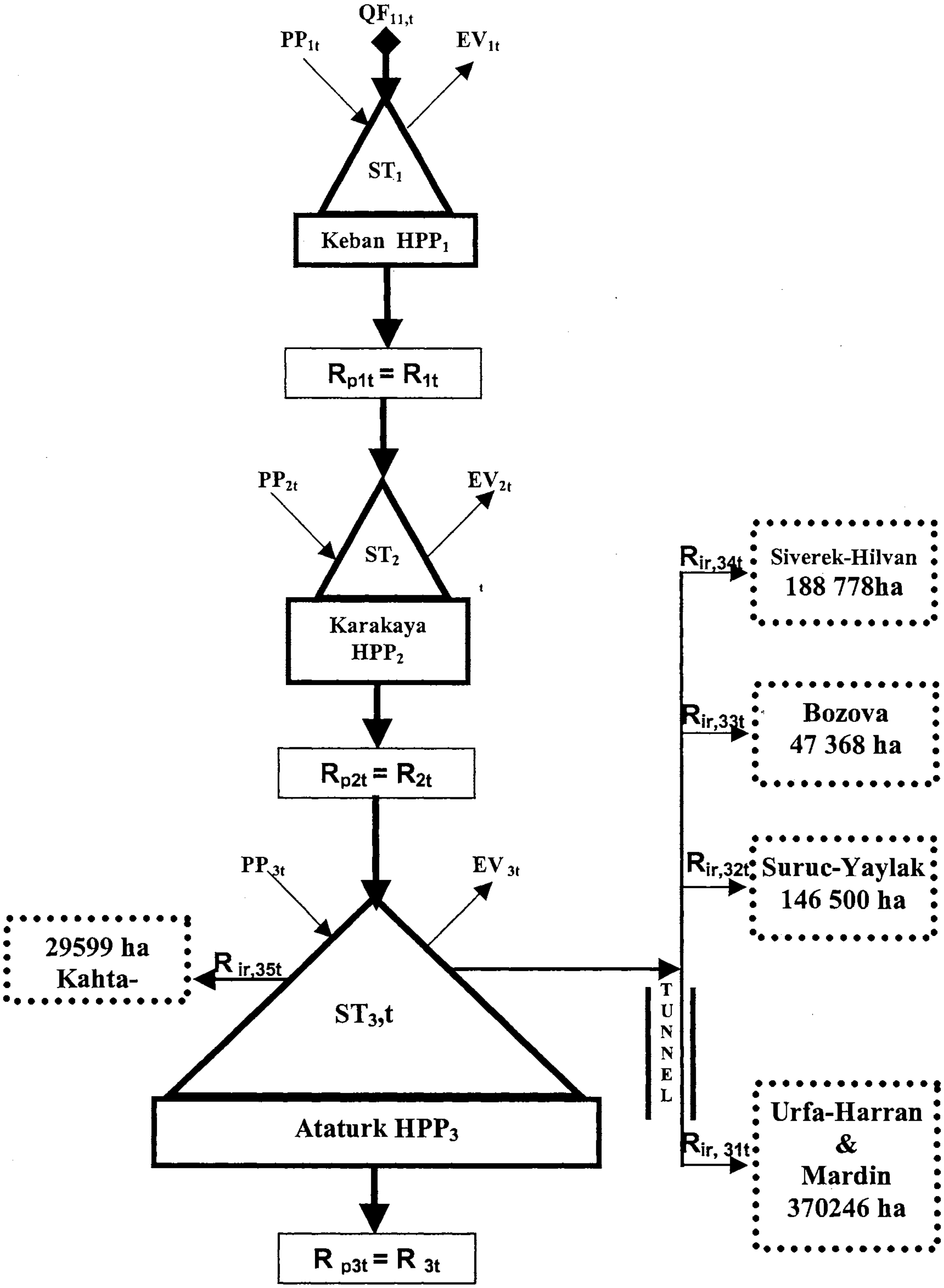
$$\sum_{j=1}^{J} L_{jszt} \leq \acute{L}_{szt} \qquad (18)$$

Total land available for irrigation ($\acute{\mathbf{L}}_{szt}$) in district **z**, period **t** is equal or greater than the amount of land use for all crops ($\mathbf{L}_{jszt}$) in that district.

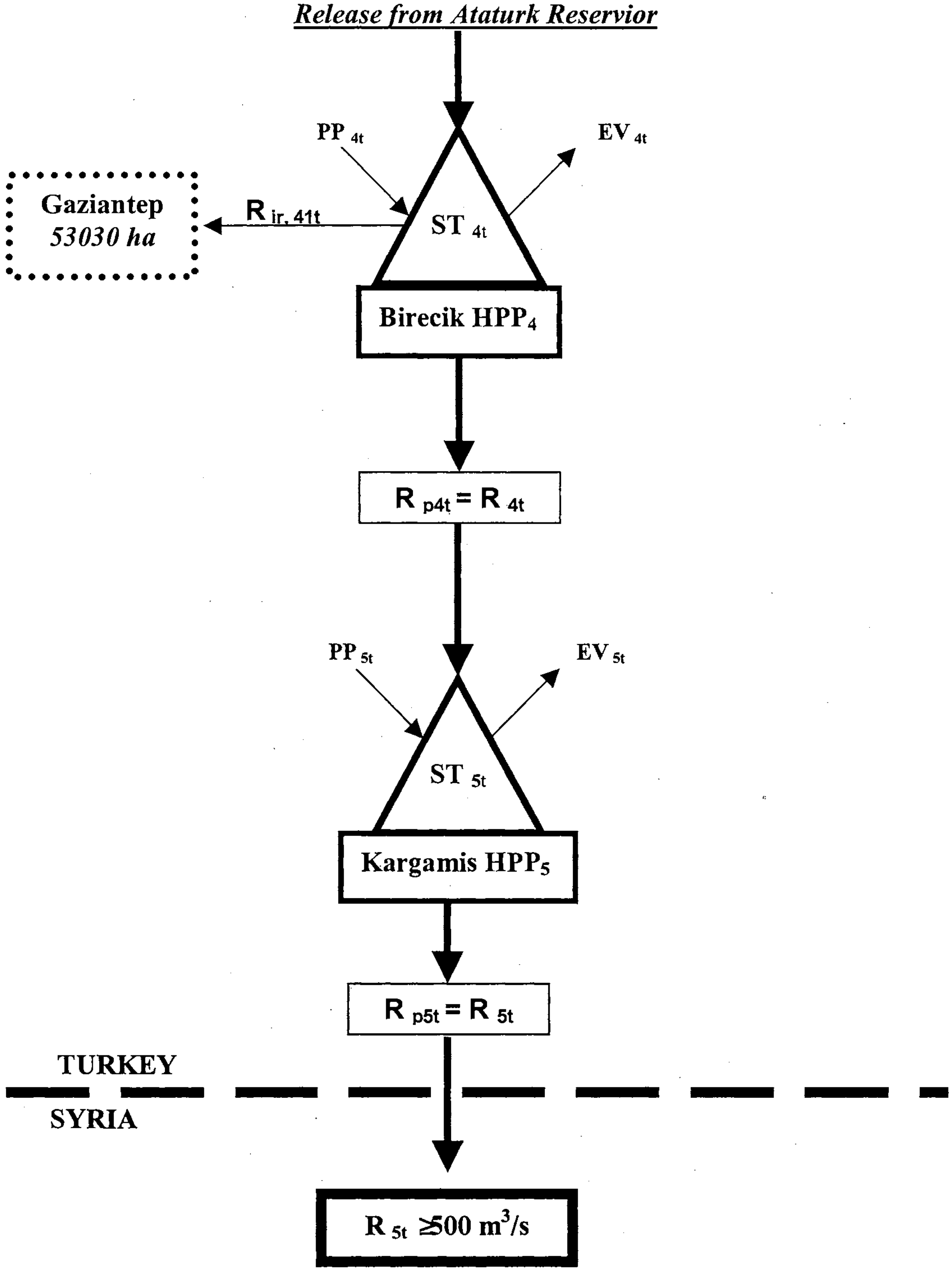
Modeling the Euphrates System

The Euphrates River model on the Turkish side is shown in Figure 4. Keban, Karakaya, and Kargamish Reservoirs are single purpose reservoirs and are used only hydropower production. Ataturk and Birecik reservoirs are multipurpose reservoirs. Their waters are used hydropower production and irrigation of their districts. The model is formulated in the context of the reservoirs system as shown in Figure 4.

Figure 4. Schematic Diagram of Reservoir System in the Euphrates River



(Continuation of Figure 4)



The Euphrates River model is formulated as an economic objective of the maximizing the sum of hydropower and irrigation benefits in the five reservoirs subject to constraints each reservoir. The Optimization Model is as follows;

$$\max \sum_{t=1}^{12} \sum_{s=1}^{5} B_{e,st} E_{st}$$

$$+ \sum_{t=1}^{12} \sum_{j=1}^{5} \sum_{z=1}^{6} \left(B_{i,j3zt} L_{j3zt} - e_{j3zt} W_{j3zt} \right) \tag{19}$$

$$+ \sum_{t=1}^{12} \sum_{j=1}^{5} \left(B_{i,j31t} L_{j31t} - e_{j31t} W_{j31t} \right)$$

subject to

Reservoir I: Keban (s=1)

$$(1 - 0.0171\, ev_{1t}) ST_{1t} - ST_{1t+1} - 430\,000\,000\, ev_{1t} - R_{1hpt} = - QF_{1t} \tag{20}$$

$$(t=1,\ldots.,12)$$

(Mass balance Constraint)

$$ST_{11t} \leq 16\,000\,000\,000 \tag{21}$$

$$(t=1,\ldots.,12)$$

(Constraint on reservoir storage)

$$E_{1t} = 0.00273 * (1.65*(ST_t+ST_{t+1}) + 132.83*R_{1pt} - 17589267409.2)* 0.855 \tag{22}$$

$$(t=1,\ldots.,12)$$

(Hydropower Generation Constraint)

$$E_{1t} \leq 957\,600\,000 \tag{23}$$

$$(t=1,\ldots.,12)$$

(Hydropower generation capacity constraint)

Reservoir II: Karakaya (s=2)

$$(1-0.0168\,ev_{2t})ST_{2t}-ST_{2t+1}-175\ 000\ 000\,ev_{2t}-R_{2hpt}=-R_{1hp\,t} \tag{24}$$

$(t=1,....,12)$

(Mass balance Constraint)

$$ST_{2t}\leq 5\ 600\ 000\ 000\ \ m^3 \tag{25}$$

$(t=1,....,12)$

(Constraint on reservoir storage)

$$E_{2t}=0.00273*(2.87*(ST_{2t}+ST_{2t+1})+138.71*R_{2pt}-20354913263.79)*0.855 \tag{26}$$

$(t=1,....,12)$

(Hydropower Generation Constraint)

$$E_{2t}\leq 1\ 296\ 000\ 000\quad kWh \tag{27}$$

$(t=1,....,12)$

(Hydropower generation capacity constraint)

Reservoir III: Ataturk (s=3)

$$(1-0.0122\,ev_{3t})ST_{3t}-ST_{3t+1}-685\ 700\ 000\,ev_{3t}-R_{3hpt}=-R_{2hp\,t} \tag{28}$$

$(t=1,....,12)$

(Mass balance Constraint)

$$ST_{3t}\leq 11\ 000\ 000\ 000\ \ m^3 \tag{29}$$

$(t=1,....,12)$

(Constraint on reservoir storage)

$$E_{3t}=0.00273*(1.018*(ST_{3t}+ST_{3t+1})+144.49*R_{3hpt}-9\ 878\ 975\ 513.64)*0.855 \tag{30}$$

$(t=1,....,12)$

(Hydropower Generation Constraint)

$$E_{3t} \leq 1\ 728\ 000\ 000 \ \text{kWh} \tag{31}$$

(t=1,....,12)

(Hydropower generation capacity constraint)

$$R_{i\,31t} \leq 321\ 408\ 000\ m^3$$

(Urfa-Harran & Mardin District)

$$R_{i\,32t} \leq 597\ 273\ 175\ m^3$$

(Suruc-Yaylak District)

$$R_{i\,33t} \leq 193\ 116\ 967\ m^3 \tag{32}$$

(Bozova District)

$$R_{i\,34t} \leq 652\ 740\ 080\ m^3$$

(Siverek-Hilvan District)

$$R_{i\,35t} \leq 120\ 673\ 643\ m^3$$

(Adiyaman-Kahta District)

(t=1,....,12)

(Water Transfer Constraint)

$$R_{i3t} = \sum_{z=1}^{5} R_{I\,3zt} \tag{33}$$

(z = Urfa-Harran & Mardin, Suruc-Yaylak, Bozova, Siverek-Hilvan, Adiyaman-Kahta)

(t=1,....,12)

(Water Transfer to irrigation district)

$$f_{j3zt}\, L_{j3zt} = W^{r}{}_{j3zt} \tag{34}$$

(j=Wheat, Barley, Lentil, Cotton, Corn)

(z = Urfa-Harran & Mardin, Suruc-Yaylak, Bozova, Siverek-Hilvan, Adiyaman-Kahta)

(t=1,....,12)

(Irrigation Water Demand)

$$\sum_{j=1}^{5} W^{I}_{j3zt} \leq R_{i3zt} \tag{35}$$

(j=Wheat, Barley, Lentil, Cotton, Corn)

(z = Urfa-Harran & Mardin, Suruc-Yaylak, Bozova, Siverek-Hilvan, Adiyaman-Kahta)

(t=1,....,12)

(Total Irrigation water demand)

$$\sum_{j=1}^{5} L_{j31t} \leq 370\ 246 \text{ ha}$$

(Urfa-Harran & Mardin District)

$$\sum_{j=1}^{5} L_{j32t} \leq 146\ 500 \text{ ha}$$

(Suruc-Yaylak District)

$$\sum_{j=1}^{5} L_{j33t} \leq 47\ 368 \text{ ha} \tag{36}$$

(Bozova District)

$$\sum_{j=1}^{5} L_{j34t} \leq 160\ 105 \text{ ha}$$

(Siverek-Hilvan District)

$$\sum_{j=1}^{5} L_{j35t} \leq 29\ 599 \text{ ha}$$

(Adiyaman-Kahta District)

(j=Wheat, Barley, Lentil, Cotton, Corn)

(t=1,....,12)

(Irrigation Land constraint)

Reservoir IV: Birecik (s=4)

$$(1-0.0353\ ev_{4t})ST_{4t} - ST_{4t+1} - 35\ 000\ 000\ ev_{4t} - R_{4hpt} = -R_{3hp\ t} \qquad (37)$$

$$(t=1,\ldots.,12)$$

(Mass balance Constraint)

$$ST_{4t} \leq 590\ 200\ 000\ \ m^3 \qquad (38)$$

$$(t=1,\ldots.,12)$$

(Constraint on reservoir storage)

$$E_{4t} = 0.00273*(19.9*(ST_{4t}+ST_{4t+1}) + 36.49*R_{4hpt} - 4\ 844\ 108\ 591.9)*0.855 \qquad (39)$$

$$(t=1,\ldots.,12)$$

(Hydropower Generation Constraint)

$$E_{4t} \leq 483\ 840\ 000\ \ \ kWh \qquad (40)$$

$$(t=1,\ldots.,12)$$

(Hydropower generation capacity constraint)

$$R_{i\,4zt} \leq 216\ 200\ 658.5\ \ m^3 \qquad (41)$$

$$(t=1,\ldots.,12)$$

$$(z = Gaziantep)$$

(Water Transfer Constraint)

$$R_{i4t} = R_{i\,4zt} \qquad (42)$$

$$(t=1,\ldots.,12)$$

$$(z = Gaziantep)$$

(Water Transfer to irrigation district)

$$f_{j4zt}\ L_{j4zt} = W^{T}{}_{j4zt} \qquad (44)$$

(j=Wheat, Barley, Lentil, Cotton, Corn)

(z = Gaziantep)

(t=1,….,12)

(Irrigation Water Demand)

$$\sum_{j=1}^{5} W^{I}_{j4zt} \le R_{i4zt} \tag{45}$$

(j=Wheat, Barley, Lentil, Cotton, Corn)

(z = Gaziantep)

(t=1,….,12)

(Total Irrigation water demand)

$$\sum_{j=1}^{5} L_{j41t} \le 53\,030 \text{ ha} \tag{46}$$

(Gaziantep District)

(j=Wheat, Barley, Lentil, Cotton, Corn)

(t=1,….,12)

(Irrigation Land constraint)

Reservoir V: Kargamish (s=5)

$$(1-0.1175\, ev_{5t})ST_{5t} - ST_{5t+1} - 18\,000\,000\, ev_{5t} - R_{5hpt} = -R_{4hp\,t} \tag{47}$$

(t=1,….,12)

(Mass balance Constraint)

$$ST_{5t} \le 89\,700\,000 \text{ m}^3 \tag{48}$$

(t=1,….,12)

(Constraint on reservoir storage)

$$E_{5t} = 0.00273 * (19.9*(ST_{5t}+ST_{5t+1}) + 36.49*R_{5hpt} - 4\,844\,108\,591.9) * 0.855 \tag{49}$$

$$(t=1,\dots,12)$$

(Hydropower Generation Constraint)

$$E_{5t} \leq 129\ 600\ 000 \quad kWh \tag{50}$$

$$(t=1,\dots,12)$$

(Hydropower generation capacity constraint)

$$R_{5hpt} \geq 777\ 600\ 000 \ m^3 \tag{51}$$

$$(t=1,\dots,12)$$

(Flow constraint at the Turkish-Syrian Border)

The notations used above the optimization model have following meaning.

$B_{e,st}$ ≡ Net benefit of generating per kWh electricity in period t, at reservoir s;

$B_{e,st}$ ≡ Net return per hectare for irrigated crop j harvested in period t at reservoir s ;

E_{st} ≡ Electricity generated at reservoir s in period t;

$e^{\acute{r}}{}_{,jszt}$ ≡ Per-cubic meter water cost for irrigated crop j in period $\acute{r}$ harvested in period t at site s, district z ;

$W^{\acute{r}}{}_{,jszt}$ ≡ Total water demand for irrigated crop j in period $\acute{r}$ harvested in period t, at reservoir s, district z;

L_{jszt} ≡ Hectares of irrigated land for crop j at site s, district z, and period t;

$ST_{s\,(t+1)}$ ≡ Initial storage volume of reservoir s at the beginning of period t;

ev_{st} ≡ Evaporation from reservoir s in period t;

QF_{1t} ≡ Cumulative inflows to first reservoir in the system, period t;

$R_{i,st}$ ≡ Release for irrigation activity at reservoir s , period t;

R_{shpt} ≡ Release for hydropower generation at reservoir s in period t;

$R_{i,\,szt}$ ≡ Water at reservoir s transferred to district z for irrigation in period t;

$f^{\acute{r}}{}_{,jszt}$ ≡ Water demand per hectare for irrigated crop j in period $\acute{r}$ harvested in period t, reservoir s, district z, ;

The objective of the Euphrates Model is to maximize the total net benefit of each reservoir hydropower generation and irrigation activities simultaneously to define optimal value of water consumption for hydropower and irrigation and optimal amount of land use for each crop in the each district. Hence, the decision variables in this model are the $R_{ir,szt}$, R_{shpt}, and L_{jszt} for all **s**, **j**, and **z** in each period **t**. Therefore, Equation (19) shows the total net benefit of hydropower and irrigation in the system. Equations (20) – (50) define the model constraints for each of the reservoirs in the system. Equation (51) shows water release requirement on the Turkish - Syrian border due to agreement the 1987.

Model Data

The model described in this research is applied for one-year time horizon. The major state variable of the model is monthly reservoir storage (ST). The major flow process variables include the flow in the reservoir system, evaporation rates (ev), the flow restriction to the irrigation district and the electricity generating capability of each reservoir associated with all these process. Economic parameters such as crop price, water supply price, electricity price, and the cost of crop production per hectare and per kilowatt-hour electricity are all taken as external data. All these data for the Euphrates Model comes from a variety of sources.

Evaporation Rates:

Monthly evaporation data for all reservoirs (Keban, Karakaya, Ataturk, Birecik, and Kargamish) is provided by the Turkish General Directorate of State

Hydraulic Works (DSI, 2000). “Pan-Evaporation” approaches and “Class-A” pan is used to calculate monthly evaporation amount. “Pan-Evaporation” is a direct approach to determine free-water evaporation to expose a cylindrical pan of liquid water to the atmosphere and solve a simplified water–balance equation for a convenient time period, Δt (usually one day):

$$EV = W - (V_2 - V_1) \tag{52}$$

where W is precipitation during Δt, and V_1 and V_2 are the storage at the beginning and end of Δt, respectively. Pan evaporation measurements are commonly made at monitoring sites, which are part of weather station networks. Although pan evaporation typically overestimate the rate of evaporation from open water bodies, they can be corrected using empirical 'pan coefficients'. Its annual average is about 0.70. The evaporation amount of the reservoir is calculated to multiply the surface area of the reservoir with the corrected evaporation rate (Dingman, 1994).

Therefore, the precipitation amount has been subtracted from evaporation data in the Tables 11 through 14. Evaporation Rates ($\mathbf{ev_{st}}$) in those Tables is calculated according to mean Surface area ($\mathbf{SF_{st}}$) of each reservoir.

$$ev_{st} = EV_{st} / SF_{st} \tag{53}$$

Table XI

Keban Reservoir Monthly Evaporation amount
(DSI, 2000)

	1996 hm^3	1997 hm^3	1998 hm^3	1999 hm^3	2000 hm^3	Evaporation Rate (ev_{1t})hm
Jan	9.8	10.4	8.9	9	8	0.000172
Feb	11.5	12	10.1	10	9	0.000196
March	18.5	19.8	16.6	16.4	15	0.000322
April	41.6	40	35	36.3	34	0.000698
May	78.7	75.7	77.8	68.6	65.3	0.001366
June	121	116	120	105	98	0.002088
July	152	146	152	133	119	0.002614
August	140	131	135.6	119	106	0.002351
Sept	93	85.7	88.7	78	70	0.001546
Oct	45	46	42.6	43.7	38.7	0.000807
Nov	21	21	19.3	19.6	17.4	0.000367
Dec	10	10	9	9	8	0.000172

Keban Mean Surface Area = 57 000 hm^2

$ev_{1t} = EV_{1t} / 57\ 000$

Table XII

Karakaya Reservoir Monthly Evaporation Amount (EV_{2t})

(DSI, 2000)

	1996 hm^3	1997 hm^3	1998 hm^3	1999 hm^3	2000 hm^3	Evaporation Rate (ev_{2t})hm
Jan	5.1	5.1	5	4.6	4	0.000194
Feb	6.1	6	6	5.5	4.6	0.000230
March	11.9	12.1	12	11.2	9.5	0.000463
April	20.1	20.5	18.7	18.7	15	0.000760
May	33.5	33.5	31.5	31.5	25.6	0.001272
June	53.5	51	49.5	48.5	40.6	0.001987
July	71	65	65	63	53.1	0.002592
August	68	62	63	60	51.5	0.002489
Sept	45	42	42.7	40	35	0.001673
Oct	26.8	25.3	24.5	24.4	23	0.001016
Nov	12.5	12	11.6	11	10.3	0.000470
Dec	5.8	5.7	5.4	5.1	4.5	0.000216

Karakaya Mean surface Area = 26 250 hm^2

ev_{2t}= EV_{2t} / Mean surface Area

Table XIII

Ataturk Reservoir Monthly Evaporation Amount (EV_{3t})

(DSI, 2000)

	1996 hm^3	1997 hm^3	1998 hm^3	1999 hm^3	2000 hm^3	Evaporation Rate (ev_{3t}) hm
Jan	15.3	15.4	14.8	14.5	14.4	0.000207
Feb	18	17.9	17.3	17	16.9	0.000243
March	38	38	36.5	36.4	35.3	0.000513
April	69.5	68	65.8	65.8	62.9	0.000925
May	113	110.7	107	107	102.2	0.001504
June	166.6	161	155.7	156.8	148	0.002195
July	226.3	217	208.5	210	200	0.002957
August	206	198	191.7	194	183.2	0.002710
Sept	156.1	149	145.1	147.1	139.6	0.002053
Oct	91.6	92	88.6	86.3	87	0.001241
Nov	39	39.1	37.8	37	36.8	0.000528
Dec	18.6	18.8	18.1	17.7	17.8	0.000254

Ataturk Mean surface Area = 74 000 hm^2

$ev_{3t} = EV_{3t}$ / Mean surface Area

Table XIV

Birecik and Kargamish Reservoir Monthly Evaporation Amount

(DSI, 2000)

2000	BIRECIK		KARGAMISH	
	Evaporation Amount (EV_{4t}) hm^3	Evaporation Rate (ev_{4t}) hm	Evaporation Amount (EV_{5t}) hm^3	Evaporation Rate (ev_{5t}) hm
Jan	0.8	0.000216	0.40	0.000216
Feb	1	0.000252	0.48	0.000252
March	2	0.00052	1.00	0.00052
April	3.7	0.000939	1.80	0.000939
May	6	0.001561	3.00	0.001561
June	8.7	0.002341	4.50	0.002341
July	11.8	0.003086	6.00	0.003086
August	10.8	0.002845	5.50	0.002845
Sept	8.2	0.002091	4.00	0.002091
Oct	4.9	0.001265	2.40	0.001265
Nov	2.1	0.000541	1.00	0.000541
Dec	1	0.000244	0.45	0.000244

Birecik Reservoir

Mean surface Area = 3800 hm^2

$ev_{4t} = EV_{4t}$ / Mean surface Area

Kargamish Reservoir

Mean surface Area = 1950 hm^2

$ev_{5t} = EV_{5t}$ / Mean surface Area

The Mass balance equation of five reservoirs is derived from evaporation data and reservoirs surface–volume function. Surface-volume functions are defined by reservoir characteristics. All these calculations and water inflow Keban data are shown in the Appendix A.

Hydropower Generation :

Monthly hydropower generation data for all reservoirs (Keban, Karakaya, Ataturk, Birecik, and Kargamish) is provided by the Turkish General Directorate of State Hydraulic Works (DSI, 2000). Hydropower generation function is derived from that information. Data and calculation of hydropower function are shown in the Appendix B.

The Turkish electricity market established two separate organizations; one for generation and transmission and the other for distribution and trade of electricity. The state owned Turkey's Electricity Generating and Transmission Corporation (TEAS) constructs Thermal Power Plant (TPP) and transmission lines, generates electricity from TPPs and Hydro Power Plants (HPP), operates the transmission networks. TEAS operates 16 thermal and 30 hydroelectric plants (including Keban, Karakaya, Ataturk, and Kargamish) generating 91% of Turkey's electricity (TEAS, home page). In addition, TEAS buys electricity from private power producers. TEAS sells all electricity to the state-owned distribution corporation that the Turkish Electricity Distribution Corporation (TEDAS) and its affiliated companies controlled. The Turkish electricity Distribution Corporation (TEDAS) with seven affiliated regional distribution companies is responsible for distribution of electricity at voltage 34.5kV and below. TEDAS and its companies purchase the electricity from TEAS and small amount (about 2%) from private auto producers and generating companies.

According to a Turkish newspaper (Hurriyet, Feb 11, 2000), the cost of electricity, generated by TEAS is less than **4 cent/kWh** and the seller price to TEDAS is 4 cent per kilowatt-hour. This value is adopted as a cost of producing per kWh electricity at the Euphrates River's reservoirs because of the hydropower cost definition.

Hydropower cost consists of two parts, namely capital cost and operation and maintains cost. Capital cost is the present value of the total investment to hydropower plant. Operation and maintenance cost includes expenses associated with operating the facility such as supervising, engineering, and rent expenses and includes labor materials and other direct and indirect expenses incurred for preserving the operating efficiency and/or physical condition (EIA, 1997).

Total cost = Capital cost + Operation and Maintains cost

The U.S. Department of Energy's (USDE, 1999) Hydropower Program estimates the capital cost based on capital costs of 21 hydroelectric plants that commenced operation 1993. They calculate the capital cost per kW in capacity range from $735 to $4778. The average capital cost per kWh is $1700 - $2300. Operation and maintains costs are calculated from 1-2% of total investment. Capital and O&M cost calculation is formulated;

Capital cost per kWh = PV of Capital cost / Annual power production

O&M cost per kWh = 1-2% of capital cost / Annual power production

where Annual power production = Capacity (kW) * 365*24* Capacity Factor (USDE, 1999).

Electricity prices in Turkey reflect the cost imposed by the specific consumer category such as Household and Industry. Therefore, 7.0 cent per kilowatt-hour is used for the price of electricity, which is calculated as average price of household and industry. Net benefit of generating per kWh is

Net Benefit = Price – Cost = 7.0 – 4.0 = 3.0 cent/ kWh

Irrigation Data

In this research, five main crops, Wheat, Barley, Lentil, Corn, and Cotton are defined according to the Southeastern Anatolian region's agricultural production scheme and GAP (Southeastern Anatolian Project) master plan. As of 1998, GAP Region's shares in national total for some crops are: 12.4% in wheat, 14.17% in barley, 41.6% in cotton, 37.7% in sesame, 1.2% in beans, 10.5% in vegetables and 98.6% in red lentil. The shares of the region in the total meat and milk production of the country are 6.7% and 6.57%, respectively.

The GAP (Southeastern Anatolian Project) master plan's basic development scenario is to transform the region into export base for agricultural products. Therefore, the crop patterns of the region that have been determined by the GAP Master Plan are cereals (wheat, barley, corn); pulses (dried beans, lentils, chickpeas); industrial plants (cotton, sugar beet); root vegetables (potatoes, onions, garlic); and fruit (grapes, apricots, pistachio nuts). Table 1.3 shows that the economically important crops of the region are wheat, barley, lentil, cotton and vegetables.

Table XV

Cropping Patterns for GAP region, 1986 and 2005

(Unver, 1997)

Crops	1986 (%)	Master Plan-2005 Irrigated area (%)
Primary Crops:		
Wheat	33.9	25
Barley	18.5	15
Lentil-chickpeas-beans	19.7	8
Cotton	2.8	25
Winter vegetables	0.1	2
Multi-seasonal produce	9.4	20
Other Crops:		
Soybean	0.0	10
Corn	0.1	8
Peanuts	0.0	5
Sunflower	0.2	5
Sesame	1.9	5
Vegetables (inc.potato)	2.2	6
Tobacco	0.4	0
Rice-Maize	0.2	0
Falow	9.5	0
TOTAL(cropping intensity)	99.9	134

According to the Master plan, planting cotton will be extant from 2.8% to 25% and other second crops such as corn, soybeans and sesame, will be planted after the harvesting of wheat, barley and lentils. Therefore, wheat barley, lentils, and cotton will be planted approximately 75% of the irrigated area of GAP in 2005 (Table 15).

The Sanliurfa-Harran Plains Irrigation Scheme (SHPIS) is the first and most important component of the entire GAP project. Irrigation water is supplied from Ataturk Dam reservoir through the Sanliurfa tunnels. One of the tunnels has been operational and the other is progressing in construction. Since 1996, the Sanliurfa-Harran district was chosen as a Pilot Project of the GAP and right now, 90,000 ha of the total 150,000 ha of land has been irrigated. The existing cropping pattern in this area is shown Table XVI.

Table. XVI

Existing cropping pattern in the Sanliurfa-Harran
(Halcrow-Dolsar, 1998)

Crop	Area (ha)	%
Cotton	72000	80
Wheat	13500	15
Barley	1800	2
Corn	1800	2
Vegetables	1800	2
	90000	

According to the projection of the GAP Administration for the year 2010, cereals (wheat, barley and corn) will be the main crops of the region (41.5 percent) while cotton will be grown on 37,500 hectares of land (25 percent of the total land under irrigation). Expected cotton output of the plain is 112,500 tons a year. Vegetable agriculture is planned to have a share of 14 percent in terms of total land under agricultural production.

Under the current cropping pattern, cotton emerged as the dominant crop. Cotton, one of the more profitable crops, consumes a lot of water relative to wheat and barley. When that irrigation project is fully developed with the same crop patterns, water requirements in June, August and September would exceed the available supplies. Consequently, the problem of limited water supplies has been addressed by a demonstration project by GAP-MOM (Halcrow-Dolsar, 1998) and was noted in an interim report (OSU, 1998). Because there is not sufficient water to meet the demands of cotton for entire 150000 ha in this region, alternative production strategies are proposed (Stoecker, 1999). Therefore, this research will be defining land use for those crops due to available water.

According to a study of the Sanliurfa-Harran pilot project (Halcrow-Dolsar, 1998) net water requirement of those five crops is shown in Table (XVII). Using 49% overall efficiency ratio, adopted the same study, the gross water requirement is derived from the net water requirement and shown in Table (XVIII).

Planting and harvest dates for crops grown are as follows: Wheat, Barley and Lentil are winter crops planted in November and harvested in early June.

Corn is planted in the middle of June and harvested in early November. Cotton is a summer crop, planted in April and harvested in November. Growing corn as the second crop between June –November would be comparable to growing only cotton.

Table XVII

Net Water Requirement for Crops

(Halcrow - Dolsar, 1994)

	WHEAT Mm/ha	BARLEY Mm/ha	LENTIL Mm/ha	CORN Mm/ha	COTTON Mm/ha
January					
February					
March	38	41	42		
April	90	82	72		
May	102	40	30		65
June				114	164
July					299
August				231	286
September				177	201
October				25	73
November	40	40	40		
December					
TOTAL	270	203	547	184	1088

Table XVIII

Gross Monthly Water Requirement for Crops

	WHEAT m^3/ha	BARLEY m^3/ha	LENTIL m^3/ha	CORN m^3/ha	COTTON m^3/ha
January					
February					
March	584.6	630.8	646.2		
April	1384.6	1261.5	1107.7		
May	1569.2	615.4	461.4		1000.0
June				1753.9	2523.1
July					4600.0
August				3553.9	4400.0
September				2723.1	3092.3
October				384.6	1123.1
November	615.4	615.4	615.4		
December					
TOTAL					

Conveyance Efficiency = 90 %,

Distribution Efficiency = 90 %

Field application Efficiency = 60 %

Overall efficiency = 90 % x 90 % x 60 % = .486

Water price and Net crop return data are provided by the Stoecker (1999) study and are shown in Table XIX and Table XX respectively.

Table XIX

Water Prices $/ Hectare
(Stoecker, 1999)

Water fee for Cotton	23.0
Water fee for spring cereals (Corn)	23.0
Water fee for tree crops	30.0
Water fee for vegetables	30.0
Water fee for winter cereals (Wheat, Barley, Lentil)	10.0

Table XX

Net return from Crops
(Stoecker, 1999)

CROPS	Price $/ ton	Yield ton /ha	Total cost $ / ha	Net Return $ / ha
Wheat	204.7579	4.4	194.404	706.544
Barley	123	3.08	179.5375	199.3
Corn	174.4	7.7	414.288	928.59
Cotton	745.7088	3.8	999.3082	1834.388
Lentil	350	2	273.936	426.06

Net Return = (Price x Yield) - Cost

CHAPTER V

RESULT AND DISCUSSION

The results were calculated using the Generalized Algebraic Modeling System (GAMS), which was set to maximize Total Net Benefit. First, three different flow conditions were used to define whether or not the conflict between Turkey and Syria is artificial. If there is not enough water to satisfy water consumption needs for both countries, one can conclude that a water scarcity problem causes the conflict. Otherwise, the conflict is artificial. Therefore, the model is divided into the following three sub-models:

Model-1: Average inflow with border restriction
Average inflow without border restriction

Model-2: Lowest inflow with border restriction
Lowest inflow without border restriction

Model-3: Highest inflow with border restriction
Highest inflow without border restriction

In **Model-1**, The Euphrates River's 64-year average monthly inflow (QF) rate is used to find feasible values for water utilization between two competitive uses, hydropower and irrigation. In **Model-2**, the most critical water flow-year, which was in 1961, data from 64 years worth of records will be used to determine the boundaries of the drought year's feasible values. In **Model-3,** the most flood-year, which was in 1988, data recorded between 1937-2000 will be used as a flow rate for the model. The total Net benefit function for all models are maximized under two comparable restrictions: (1) Restriction of water flow at the border is equal or greater than 300 m^3/sc due the to 1987 agreement; (2) There is no restriction on the border.

Results of **Model-1** with a border restriction are shown in Table XXI through Table XXV. Total net benefit is $1,550,512,000, of which $1,014,665,559 of that amount comes from agriculture and $535,846,441 is hydropower generation benefit. Under the assumption of **Model-1**, Turkey is able to irrigate 106% (cropping intensity) of total land with 20% of corn rotation (Table XXIV). However, annual electricity generation of all reservoirs is less than the annual average generating amount. Overall, generation drop is around 30%; specifically, the Ataturk reservoir electricity generation dropped more than 50% (Table XXI). Furthermore, the results of **Model-1** without restriction give almost the same results (XXVI – XXX). Net total benefit rises to $1,563,958,000 because hydropower generating increases only .03%. Thus, irrigation lands stay the same at the restriction condition; the only difference is that electricity generation rises .03%. Therefore, amount of water released from the border rises from 300 m^3 to 360m,^{3} but it is not steady amount for each month (Table XXVII). From both results of **Model-1**, it can be concluded that although the Euphrates River's mainstream flow stays at the average flow amount, there is not enough water available to satisfy both countries demands. There is a trade off between two competing uses of water in Turkey, although, Turkish side maximizes its own benefit, ignoring the downstream user.

Table XXI

Hydropower generation (E_{st}) in Model-1 with Restriction (Kilowatt-hours / per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	210,336,100	214,997,700	250,341,400	57,737,960	23,129,250
Feb	265,160,900	272,247,800	309,970,600	66,865,320	30,379,850
Mar	574,450,000	432,989,500	390,591,000	89,454,500	34,960,000
Apr	818,748,000	399,575,900	248,677,100	109,755,100	34,960,000
May	818,748,000	513,580,300	261,011,700	109,756,600	34,960,000
Jun	818,748,000	624,168,300	279,135,000	109,758,500	34,960,000
Jul	818,748,000	763,486,000	290,142,200	109,760,300	34,960,000
Aug	818,748,000	939,355,500	312,192,500	109,759,800	34,960,000
Sep	142,754,800	737,129,100	292,039,400	109,757,900	34,960,000
Oct	158,859,000	375,819,800	254,275,000	109,755,900	34,960,000
Nov	204,130,400	669,986,200	625,899,900	206,348,700	68,896,460
Dec	214,978,100	319,043,600	356,618,400	162,260,700	110,808,000
Total	5,864,409,300	6,262,379,700	3,870,894,200	1,350,971,280	512,893,560
Annual Average	6,200,000,000	7,400,000,000	8,200,000,000	2,518,000,000	699,840,000
Change	-5 %	-15%	-53%	-46%	-27%

Table XXII

Water Release for Hydropower Generation ($R_{hp, st}$) in Model-1 with Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	810,824,000	810,789,200	810,648,600	810,641,000	777,600,000
Feb	987,652,600	987,612,500	987,452,700	834,268,400	777,600,000
Mar	1,985,214,000	1,473,495,000	1,226,497,000	777,614,800	777,600,000
Apr	2,742,110,000	1,330,503,000	805,713,800	777,626,800	777,600,000
May	2,685,179,000	1,631,621,000	842,286,500	777,644,600	777,600,000
Jun	2,689,838,000	1,935,799,000	896,023,200	777,666,800	777,600,000
Jul	2,716,914,000	2,342,775,000	928,660,200	777,688,100	777,600,000
Aug	2,746,122,000	2,881,042,000	994,040,700	777,681,200	777,600,000
Sep	592,474,000	2,294,470,000	934,285,700	777,659,700	777,600,000
Oct	644,793,100	1,225,775,000	822,312,000	777,636,100	777,600,000
Nov	790,808,600	2,175,008,000	1,924,202,000	1,911,711,000	1,911,696,000
Dec	825,796,000	1,125,936,000	1,125,766,000	1,715,953,000	777,600,000

Table XXIII

Total Storage Volume ($ST_{st} + K_{ds}$) in Model-1 with Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	16,000,000,000	5,600,000,000	11,000,000,000	630,000,000	67,300,000
Feb	16,000,000,000	5,600,000,000	11,000,000,000	630,000,000	100,337,140
Mar	16,000,000,000	5,600,000,000	11,000,000,000	783,175,500	157,000,000
Apr	16,000,000,000	6,111,637,800	11,000,000,000	1,220,200,000	157,000,000
May	18,499,448,000	7,523,107,000	11,000,000,000	1,220,200,000	157,000,000
Jun	20,583,063,000	8,576,401,000	11,000,000,000	1,220,200,000	157,000,000
Jul	19,929,883,000	9,330,015,000	11,000,000,000	1,220,200,000	157,000,000
Aug	18,146,042,000	9,703,572,000	11,000,000,000	1,220,200,000	157,000,000
Sep	16,030,392,750	9,568,071,000	11,000,000,000	1,220,200,000	157,000,000
Oct	16,000,000,000	7,865,676,000	11,000,000,000	1,220,200,000	157,000,000
Nov	16,000,000,000	7,284,474,000	11,000,000,000	1,220,200,000	157,000,000
Dec	16,000,000,000	5,900,179,100	11,000,000,000	1,220,200,000	157,000,000

Table XXIV

Irrigated Land Amount in each District (L_{jsz}) in Model-1 with Restriction (Hectares)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
WHEAT	118,551.632	55,935.262	18,085.608	61,129.796	11,301.214	20,247.419
BARLEY						
LENTIL	141,971.121					
CORN	3,932.092	55,935.262	18,085.608	611,29.796	11,301.214	20,247.419
COTTON	69,871.304	9,564.738	29,282.392	989,75.204	18,297.786	32,782.581
Irrigated Land	334,326.149	121,435.262	65,453.608	221,234.796	40,900.214	73,277.419
Total Land	370,246	146,500	47,358	188,778	29,599	53,030
Percentage of Irrigated Land	90%	83%	138%	138%	138%	138%

Table XXV

Water Release for Irrigation ($R_{ir,\,jszt}$) in Model-1 with Restriction (Cubic meter/per month)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
Jan						
Feb						
Mar	161,047,000	32,699,750	10,572,850	35,736,480	6,606,690	11,836,640
Apr	321,408,000	77,447,960	25,041,330	846,40,310	15,647,660	28,034,580
May	321,408,000	178,338,400	57,662,330	194,900,100	36,031,650	64,554,830
Jun	183,188,800	326,608,700	105,602,800	356,939,900	65,988,340	118,225,700
Jul	321,408,000	416,597,800	134,699,000	455,285,900	84,169,820	150,799,900
Aug	321,408,000	597,273,200	193,117,000	652,740,100	120,673,600	216,200,700
Sep	226,770,500	432,370,700	139,798,900	472,523,600	87,356,580	156,509,300
Oct	79,984,740	123,226,000	39,842,780	134,669,600	24,896,690	44,605,270
Nov	160,325,700	34,422,560	11,129,880	37,619,280	6,954,767	12,460,260
Dec						

Table XXVI

Hydropower Generation (E_{st}) in Model-1 without Restriction (Kilowatt-hours / per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	210,336,100	173,544,800	206,248,800	23,748,030	
Feb	265,160,900			49,311,220	13,724,880
Mar	574,450,000	614,49,480		48,301,790	13,370,010
Apr	818,748,000	195,378,300		46,953,360	12,895,910
May	483,072,800	300,320,900		43,839,860	11,801,510
Jun	356,706,300	402,507,400	16,880,550	43,527,900	
Jul	482,545,900	534,274,100	27,887,770	43,529,720	
Aug	807,644,300	873,907,200	51,151,640	43,529,130	
Sep	818,748,000	902,153,600	418,547,100	141,070,100	45,960,860
Oct	723,878,500	1,108,080,000	1,110,786,000	325,644,700	110,808,000
Nov	204,130,400	1,108,080,000	1,098,618,000	325,642,900	110,808,000
Dec	214,978,100	897,020,900	946,475,300	311,225,200	110,808,000
Total	5,960,399,300	6,556,716,680	3,876,595,160	1,446,323,910	434,617,822
Annual average	6,200,000,000	7,400,000,000	8,200,000,000	2,518,000,000	699,840,000
Change	-4%	-11%	-53%	-43%	-38 %

Table XXVII

Water Release for Hydropower Generation ($R_{hp, st}$) in Model-1 without Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	810,824,000	680,052,000	679,911,400	89,703,890	
Feb	987,652,600	123,454,300	67,981,640	67,967,570	67,960,380
Mar	1,985,214,000	259,667,100	67,981,640	56,115,960	56,101,120
Apr	2,742,110,000	593,160,700	68,371,340	40,284,340	40,257,540
May	1,588,896,000	857,706,000	68,371,340	3,729,356	3,684,806
Jun	1,158,707,000	1,158,199,000	118,423,200	66,812	
Jul	1,565,834,000	1,565,175,000	151,060,200	88,074	
Aug	2,614,811,000	2,614,170,000	216,440,700	81,196	
Sep	2,701,856,000	2,701,412,000	1,301,915,000	1,145,289,000	1,145,229,000
Oct	2,444,812,000	3,356,304,000	3,357,017,000	3,312,341,000	3,312,305,000
Nov	790,808,600	3,429,774,000	3,324,811,000	3,312,320,000	3,312,305,000
Dec	825,796,000	2,874,897,000	2,874,727,000	3,464,914,000	3,554,607,000

Table XXVIII

Total Storage Volume ($ST_{st} + K_{ds}$) in Model-1 without Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	16,000,000,000	5,600,000,000	11,000,000,000	630,000,000	67,300,000
Feb	16,000,000,000	5,730,737,100	11,000,000,000	1,220,200,000	157,000,000
Mar	16,000,000,000	6,594,894,800	11,055,312,920	1,220,200,000	157,000,000
Apr	16,000,000,000	8,320,353,000	11,000,000,000	1,220,200,000	157,000,000
May	18,499,448,000	10,469,136,000	11,000,000,000	1,220,200,000	157,000,000
Jun	21,679,346,000	11,200,000,000	11,000,000,000	1,220,200,000	157,000,000
Jul	22,557,263,000	11,200,000,000	11,000,000,000	1,220,200,000	157,000,000
Aug	21,924,397,000	11,200,000,000	11,000,000,000	1,220,200,000	157,000,000
Sep	19,939,917,000	11,200,000,000	11,510,728,000	1,220,200,000	157,000,000
Oct	17,800,044,000	11,200,000,000	11,550,028,200	1,220,200,000	157,000,000
Nov	16,000,000,000	10,288,230,000	11,145,844,400	1,220,200,000	157,000,000
Dec	16,000,000,000	7,649,146,000	11,000,000,000	1,220,200,000	157,000,000

Table XXIX

Irrigated Land Amount in each District (L_{jsz}) in Model-1 without Restriction (ha)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
WHEAT	118,551.632	55,935.262	18,085.608	61,129.796	11,301.214	20,247.419
BARLEY						
LENTIL	141,971.121					
CORN	3,932.092	55,935.262	18,085.608	61,129.796	11,301.214	20,247.419
COTTON	69,871.304	9,564.738	29,282.392	98,975.204	18,297.786	32,782.581
TOTAL	334,326.149	121,435.262	65,453.608	221,234.796	40,900.214	73,277.419
Total Land	370,246	14,6500	47,358	160,105	29,599	53,030
Percentage of Irrigated Land	90 %	83 %	138 %	138 %	138 %	138 %

Table XXX

Water Release for Irrigation ($R_{ir,\, jszt}$) in Model-1 without Restriction (Cubic meter/per month)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
Jan						
Feb						
Mar	161,047,000	32,699,750	10,572,850	35,736,480	6,606,690	11,836,640
Apr	321,408,000	774,47,960	25,041,330	84,640,310	15,647,660	28,034,580
May	321,408,000	178,338,400	57,662,330	194,900,100	36,031,650	64,554,830
Jun	183,188,800	326,608,700	105,602,800	356,939,900	65,988,340	118,225,700
Jul	321,408,000	416,597,800	134,699,000	455,285,900	84,169,820	150,799,900
Aug	321,408,000	597,273,200	193,117,000	652,740,100	120,673,600	216,200,700
Sep	226,770,500	432,370,700	139,798,900	472,523,600	87,356,580	156,509,300
Oct	79,984,740	123,226,000	39,842,780	134,669,600	24,896,690	44,605,270
Nov	160,325,700	34,422,560	11,129,880	37,619,280	6,954,767	12,460,260
Dec						

In **Model-2**, the lowest water flow amount was chosen to analyze the water scarcity problem. Between 1937 and 2000, the lowest water flow to the Keban Reservoir was in the 1961. It is called the "critical season" in the water year. Results of **Model-2** with the border restriction are shown in Tables XXXI through Table XXXIII. During critical season, there is not enough water for irrigation. There is no agricultural production and water release for irrigation. Therefore, total net benefit, $293,751,300 came from only hydropower generation. However, annual electricity generation of all reservoirs is less than the annual average generating amount. Five reservoirs electricity generation drop 61% comparing annual average generation (Table XXXI). As a result, during the lowest water flow year, water was only used for hydropower generation because of border restrictions.

The results of **Model-2** without border constraint are shown in Table XXXIV through Table XXXVIII. Total net benefit is $1,204,123,000 and $1,009,163,462 of that amount comes from agriculture, while $194,959,538 is from hydropower generation benefit. Without the border restriction, Turkey is able to irrigate 85% (cropping intensity) of its total land, including land use for corn as a secondary crop (Table XXXV). Annual electricity generation of all reservoirs is less than the annual average generating amount. Overall hydropower generation dropped 75 percent. Significantly, it is only 10% less than with border restriction model. Without the border constraint, all water is consumed by Turkey. Thus, Turkey released only 96,588,920 cubic meters of water across the border.

Table XXXI

Hydropower Generation (E_{st}) in Model-2 with Restriction (Kilowatt-hours / per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	144,561,600	239,645,000	239,458,700	54,924,080	20,458,810
Feb	166,255,800	168,964,500	239,459,300	54,924,140	20,458,810
Mar	255,441,400	262,084,700	239,628,300	54,924,550	20,458,810
Apr	656,407,900	680,784,700	243,555,100	54,925,190	20,458,810
May	494,000,400	511,158,400	477,000,100	89,980,720	27,709,400
Jun	188,541,800	192,142,900	248,276,200	109,758,500	34,960,000
Jul	106,505,900	106,443,800	247,481,300	109,760,300	34,960,000
Aug	79,998,830	78,767,300	245,825,300	109,759,800	34,960,000
Sep	68,042,400	66,322,950	16,173,520	74,703,350	27,709,400
Oct	77,773,100	76,519,530	472,788,900	89,980,270	27,709,400
Nov	126,851,800	127,802,700	216,643,100	106,528,100	34,960,000
Dec	236,174,400	241,978,700	213,306,100	96,261,320	27,709,400
Total	2,600,555,330	2,752,615,180	3,099,595,920	1,006,430,320	332,512,840
Annual Average	6,200,000,000	7,400,000,000	8,200,000,000	2,518,000,000	699,840,000
Change	-58 %	-63 %	-62 %	-60 %	-52 %

Table XXXII

Water Release for Hydropower Generation ($R_{hp, st}$) in Model-2 with Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	598,679,300	886,915,100	777,611,400	777,603,900	777,600,000
Feb	668,650,400	668,610,400	777,613,400	777,604,500	777,600,000
Mar	956,303,900	956,222,600	777,627,600	777,609,400	777,600,000
Apr	2,249,556,000	2,249,425,000	777,649,800	777,616,900	777,600,000
May	1,725,737,000	1,725,515,000	1,457,583,000	867,328,100	777,600,000
Jun	740,530,300	740,199,500	777,797,500	777,666,800	777,600,000
Jul	475,936,800	475,508,100	777,860,400	777,688,100	777,600,000
Aug	390,442,600	390,026,100	777,840,000	777,681,200	777,600,000
Sep	351,879,000	351,590,300	978,76,430	687,959,700	777,600,000
Oct	383,263,800	383,083,600	1,457,567,000	867,322,800	777,600,000
Nov	541,559,000	541,477,300	708,193,400	777,615,400	777,600,000
Dec	894,161,300	894,123,000	700,836,700	687,907,000	777,600,000

Table XXXIII

Total Storage Volume ($ST_{st} + K_{ds}$) in Model-2 with Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	16,000,000,000	5,600,000,000	11,000,000,000	630,000,000	67,300,000
Feb	16,000,000,000	5,600,000,000	11,109,163,100	630,000,000	67,300,000
Mar	16,000,000,000	5,600,000,000	11,178,259,700	630,000,000	67,300,000
Apr	16,000,000,000	5,600,000,000	12,649,429,000	630,000,000	67,300,000
May	16,000,000,000	5,600,000,000	12,916,337,000	1,220,200,000	157,000,000
Jun	16,000,000,000	5,600,000,000	12,877,243,000	1,220,200,000	157,000,000
Jul	16,000,000,000	5,600,000,000	12,572,871,000	1,220,200,000	157,000,000
Aug	16,000,000,000	5,600,000,000	12,183,218,000	1,220,200,000	157,000,000
Sep	16,000,000,000	5,600,000,000	12,435,538,000	630,000,000	67,300,000
Oct	16,000,000,000	5,600,000,000	11,360,189,800	1,220,200,000	157,000,000
Nov	16,000,000,000	5,600,000,000	11,000,000,000	1,110,987,500	157,000,000
Dec	16,000,000,000	5,600,000,000	11,000,000,000	1,123,904,200	67,300,000

Table XXXIV

Hydropower Generation (E_{st}) in Model-2 without Restriction (Kilowatt-hours / per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	144,561,600	88,819,680	117,640,300	11,544,340	
Feb	166,255,800			22,270,780	
Mar	255,441,400	54,940,950		28,031,280	
Apr	656,407,900	187,543,400		32,506,980	
May	494,000,400	281,848,700		34,550,060	
Jun	188,541,800	353,411,700		32,398,840	
Jul	106,505,900	429,521,100		26,235,990	
Aug	79,998,830	956,531,800		15,150,770	
Sep	68,042,400	66,322,950		3,414,087	
Oct	77,773,100	76,519,530			
Nov	126,851,800	127,802,700	68,789,830	13,145,380	
Dec	236,174,400	241,978,700	278,437,000	103,433,820	110,808,000
Total	2,600,555,330	2,865,241,210	464,867,130	335,827,707	110,808,000
Annual Average	6,200,000,000	7,400,000,000	8,200,000,000	2,518,000,000	699,840,000
Change	-58 %	-61 %	-94 %	-69 %	-84 %

Table XXXV

Water Release for Hydropower Generation ($R_{hp, st}$) in Model-2 without Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	598,679,300	417,322,300	417,181,700	89,703,890	
Feb	668,650,400	128,056,600	67,948,980	7,192	
Mar	956,303,900	272,415,300	67,948,980	14,841	
Apr	2,249,556,000	634,409,100	68,371,340	26,799	
May	1,725,737,000	874,663,000	68,371,340	44,551	
Jun	740,530,300	1,085,232,000	68,371,340	668,112	
Jul	475,936,800	1,345,448,000	68,371,340	88,074	
Aug	390,442,600	3,046,142,000	60,452,990	81,196	
Sep	351,879,000	351,590,300	59,985,980	59,677	
Oct	383,263,800	383,083,600	67,904,340	36,103	
Nov	541,559,000	541,477,300	272,337,300		
Dec	894,161,300	894,123,000	893,953,600	1,287,082,000	96,588,920

Table XXXVI

Total Storage Volume (ST_{st} + K_{ds}) in Model-2 without Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	16,000,000,000	5,600,000,000	11,000,000,000	630,000,000	67,300,000
Feb	16,000,000,000	5,781,322,200	11,000,000,000	917,670,300	157,000,000
Mar	16,000,000,000	6,321,875,200	11,059,947,890	985,600,300	157,000,000
Apr	16,000,000,000	7,005,677,000	11,000,000,000	1,041,672,400	157,000,000
May	16,000,000,000	8,620,675,000	11,000,000,000	1,081,934,500	157,000,000
Jun	16,000,000,000	9,471,462,000	11,000,000,000	1,085,624,800	157,000,000
Jul	16,000,000,000	9,126,307,000	11,000,000,000	1,035,580,700	157,000,000
Aug	16,000,000,000	8,256,222,000	11,000,000,000	952,907,600	157,000,000
Sep	16,000,000,000	5,600,000,000	12,123,893,000	796,942,700	157,000,000
Oct	16,000,000,000	5,600,000,000	11,066,284,380	700,271,300	157,000,000
Nov	16,000,000,000	5,600,000,000	11,000,000,000	723,485,100	157,000,000
Dec	16,000,000,000	5,600,000,000	11,000,000,000	983,340,600	157,384,560

Table XXXVII

Irrigated Land Amount in Each District (L_{jsz}) in Model-2 without Restriction (ha)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
WHEAT	118,551.63	55,935.26	18,085.61	72,622.84	29,599	20,247.42
BARLEY						
LENTIL	141,971.12					
CORN	3,932.09	55,935.26	18,085.61	72,622.84	29,599	20,247.42
COTTON	69,871.30	9,564.74	29,282.39	87,482.16		32,782.58
TOTAL	215,774.52	65,500	65,453.61	232,727.84	59,198	73,277.42
Total Land Available	37,0246	146,500	47,358	160,105	29,599	53,030
Percentage of Irrigated Land	0.58	0.45	1.38	1.45	2.00	1.38

Table XXXVIII

Water Release for Irrigation ($R_{ir,\,jszt}$) in Model-2 without Restriction (Cubic meter/per month)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
Jan						
Feb						
Mar	161,047,000	32,699,750	10,572,850	42,455,310	17,303,580	11,836,640
Apr	321,408,000	77,447,960	25,041,330	100,553,600	40,982,780	28,034,580
May	321,408,000	178,338,400	57,662,330	201,441,900	46,446,750	64,554,830
Jun	183,188,800	326,608,700	105,602,800	348,099,400	51,913,690	118,225,700
Jul	321,408,000	416,597,800	134,699,000	402,417,900		150,799,900
Aug	321,408,000	597,273,200	193,117,000	643,015,800	105,191,900	216,200,700
Sep	226,770,500	432,370,700	139,798,900	468,280,300	80,601,040	156,509,300
Oct	79,984,740	123,226,000	39,842,780	126,182,000	11,383,780	44,605,270
Nov	160,325,700	34,422,560	11,129,880	44,692,100	18,215,220	12,460,260
Dec						

In Model-3, the highest water flow condition of the Euphrates River was chosen to analyze the water scarcity problem. Between 1937 and 2000, the highest water flow into the Keban Reservoir was in 1988. It is called "flood season" in the water year. Results of Model-3 with border restriction are shown in Table XXXIX through Table XLIII. Total net benefit is $1,850,830,000 and $1,014,665,559 of that amount comes from agriculture, while $836,163,828 is from hydropower generation benefit. The net benefit from irrigation, crop patterns and land distributions of the crops are the same as the results from Model-1 since water distribution canals from reservoirs have capacity limitations (Table XLIII). Primary crops are wheat, lentils and cotton. Corn is planted as a secondary crop (Table XLII). Under the assumption of Model-3, Turkey is able to irrigate 106% (cropping intensity) of available land; in addition, annual electricity generation of all reservoirs rises 11% more than annual average generating amount. However, Ataturk reservoir cannot reach average annual hydropower generation levels because more water from the reservoir is consumed by agricultural activity (Table XXXIX).

By the end of this period, more than the half of the storage volume of all reservoirs is full (Table XLI). However, only Ataturk reservoir stays its minimum storage volume because of its extensive irrigation areas. Water release in the border, which is 300 m3/per second, is provided until August, but in the last quarter of the year, the amount rises more than 1000 m^3/per second (Table XL). The water requirements for crop patterns are low in October, November and December.

Table XXXIX

Hydropower Generation (E_{st}) in Model-3 with Restriction (Kilowatt-hours / per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	406,693,900	420,047,800	463,935,800	89,349,610	27,709,400
Feb	507,438,700	215,245,100	243,770,000	109,124,400	34,960,000
Mar	818,748,000	312,737,600	243,202,200	109,754,100	34,960,000
Apr	818,748,000	428,481,400	248,677,100	109,755,100	34,960,000
May	818,748,000	540,857,400	261,011,700	109,756,600	34,960,000
Jun	818,748,000	686,096,900	279,413,300	109,758,500	34,960,000
Jul	818,748,000	1,108,080,000	293,128,600	109,760,300	34,960,000
Aug	818,748,000	1,108,080,000	318,849,300	109,759,800	34,960,000
Sep	818,748,000	1,108,080,000	108,198,600	307,966,600	104,596,500
Oct	818,748,000	1,108,080,000	1110,769,000	325,644,700	110,808,000
Nov	818748000	1,108080,000	1150,226,000	338640,500	110,808,000
Dec	818,748,000	995,011,100	1058,446,000	339,502,600	110,808,000
Total	9,101,612,600	9,138,877,300	6753,415,000	2168,772,810	709,449,900
Annual Average	6,200,000,000	7,400,000,000	8,200,000,000	2,518,000,000	699,840,000
Change	47 %	23%	-18%	-14%	1%

Table XL

Water Release for Hydropower Generation ($R_{hp, st}$) in Model-3 with Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	1,444,144,000	1,444,109,000	1,443,969,000	867,303,900	777,600,000
Feb	1,769,080,000	791,323,600	791,163,900	777,607,200	777,600,000
Mar	2,763,535,000	1,036,479,000	789,480,500	777,614,800	777,600,000
Apr	2,670,933,000	1,330,503,000	805,713,800	777,626,800	777,600,000
May	2,513,338,000	1,631,621,000	842,286,500	777,644,600	777,600,000
Jun	2,490,245,000	2,052,935,000	896,023,200	777,666,800	777,600,000
Jul	2,491,891,000	3,365,324,000	928,660,200	777,688,100	777,600,000
Aug	2,447,221,000	3,403,202,000	994,040,700	777,681,200	777,600,000
Sep	2,482,020,000	3,442,883,000	3,261,412,000	3,104,786,000	3,104,727,000
Oct	2,517,228,000	3,482,754,000	3,357,017,000	3,312,341,000	3,312,305,000
Nov	2,548,318,000	3,522,903,000	3,477,413,000	3,464,922,000	3,554,607,000
Dec	2,576,097,000	3,206,896,000	3,206,727,000	3,796,913,000	3,796,909,000

Table XLI

Total Storage Volume ($ST_{st} + K_{ds}$) in Model-3 with Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	16,000,000,000	5,600,000,000	11,000,000,000	630,000,000	156,700,000
Feb	16,000,000,000	5,600,000,000	11,000,000,000	1,176,657,300	156,700,000
Mar	16,000,000,000	6,577,716,300	11,000,000,000	1,190,200,000	156,700,000
Apr	16,774,652,400	8,304,683,000	11,000,000,000	1,190,200,000	156,700,000
May	23,454,714,000	9,644,948,000	11,000,000,000	1,190,200,000	156,700,000
Jun	29,461,600,000	10,526,356,000	11,000,000,000	1,190,200,000	156,700,000
Jul	30,616,800,000	10,963,179,000	11,117,136,400	1,190,200,000	156,700,000
Aug	29,784,200,000	10,089,096,000	12,139,682,000	1,190,200,000	156,700,000
Sep	28,454,700,000	9,132,519,000	12,661,805,000	1,190,200,000	156,700,000
Oct	26,982,700,000	8,171,269,000	11,483,050,800	1,190,200,000	156,700,000
Nov	25,620,357,000	7,205,519,000	11,205,317,800	1,190,200,000	156,700,000
Dec	24,479,917,000	6,230,839,500	11,000,000,000	1,190,200,000	67,000,000

Table XLII

Irrigated Land Amount in Each District (L_{jsz}) in Model-3 with Restriction (ha)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
WHEAT	118,551.63	55,935.26	18,085.61	61,129.8	11,301.21	20,247.42
BARLEY						
LENTIL	141,971.12					
CORN	3,932.09	55,935.26	18,085.61	61,129.8	11,301.21	20,247.42
COTTON	69,871.30	9,564.74	29,282.39	98,975.20	18,297.79	32,782.58
Irrigated Land	334,326.14	121,435.26	65,453.61	221,234.8	40,900.21	73,277.42
Total Land	370,246	146,500	47,358	160,105	29,599	53,030
Percentage of Irrigated Land	90 %	83 %	138 %	138 %	138 %	138 %

Table XLIII

Water Release for Irrigation ($R_{ir,\,jszt}$) in Model-3 with Restriction (Cubic meter/per month)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
Jan						
Feb						
Mar	161,047,000	32,699,750	10,572,850	35,736,480	6,606,690	11,836,640
Apr	321,408,000	77,447,960	25,041,330	84,640,310	15,647,660	28,034,580
May	321,408,000	178,338,400	57,662,330	194,900,100	36,031,650	64,554,830
Jun	183,188,800	326,608,700	105,602,800	356,939,900	65,988,340	118,225,700
Jul	321,408,000	416,597,800	134,699,000	455,285,900	84,169,820	150,799,900
Aug	321,408,000	597,273,200	193,117,000	652,740,100	120,673,600	216,200,700
Sep	226,770,500	432,370,700	139,798,900	472,523,600	87,356,580	156,509,300
Oct	79,984,740	123,226,000	39,842,780	134,669,600	24,896,690	44,605,270
Nov	160,325,700	34,422,560	11,129,880	37,619,280	6,954,767	12,460,260
Dec						

The results of **Model-3** without restriction case are slightly different from that with a restricted condition. The results of **Model-3** without restriction are shown in Table XLIV through Table XLVIII. Total net benefits rise to $1,855,262,000 because hydropower generation is increased by only .05% more than in the model with border restriction. However, during the first six months, hydropower generations of the Model-3 without restriction are broadly lower than the restricted case (Table XLIV). Irrigated land distribution of the crops and irrigated crop pattern stay the same as in the restriction condition case. Primary crops are wheat, lentils and cotton. Corn is also planted as a secondary crop. Therefore, Turkey is able to irrigate 106% (cropping intensity) of its available lands (Table XLVII).

The main observed difference between those two cases is the amount of water released across the border. The annual average water release on the border drops from 643 m^3 / per second to 633 m^3 / per second in the restricted case, but it is not a steady amount for each month. During the first half of the year, the total release is 59.8 m^3 /per second; therefore, half of the year-monthly average becomes 1256.6 m^3 /per second and there is no release in May and June (Table XLIX).

From both results from **Model-3**, it can be concluded that when the Euphrates River's main stream flow reaches highest flow, both countries water consumption would be satisfied. Nevertheless, in both cases Turkey releases more water than it is obligated to do.

Table XLIV

Hydropower Generation (E_{st}) in Model-3 without Restriction (Kilowatt-hours / per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	406,693,900	177,787,400	206,248,800	23,748,030	
Feb	507,438,700			49,337,380	13,734,070
Mar	818,748,000	100,112,500		48,327,940	13,379,190
Apr	818,748,000	665,122,400		46,113,100	12,600,700
May	818,748,000	841,150,100	9,353,588	43,526,010	
Jun	818,748,000	833,619,400	34,582,590	43,527,900	
Jul	818,748,000	1,108,080,000	807,886,100	235,522,200	79,143,790
Aug	818,748,000	1,108,080,000	1,180,903,000	325,648,500	110,808,000
Sep	818,748,000	1,108,080,000	1,152,623,000	325,646,700	110,808,000
Oct	818,748,000	1,108,080,000	1,110,852,000	325,644,700	110,808,000
Nov	818,748,000	1,108,080,000	1,150,254,000	338,640,500	110,808,000
Dec	818,748,000	1,091,253,000	1,156,666,000	353,030,000	110,808,000
Total	9,101,612,600	9,249,444,800	6,809,369,078	2,158,712,960	672,897,750
Annual average	6,200,000,000	7,400,000,000	8,200,000,000	2,518,000,000	699,840,000
% change	47 %	25 %	-17 %	-14 %	-3 %

Table XLV

Water Release for Hydropower Generation ($R_{hp,st}$) in Model-3 without Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	1,444,144,000	680,052,000	679,911,400	89,703,890	
Feb	1,769,080,000	80,183,220	68,288,670	68,274,600	68,267,400
Mar	2,763,535,000	303,552,100	68,288,670	56,422,990	56,408,150
Apr	2,670,933,000	1,983,533,000	58,506,010	30,419,000	30,392,200
May	2,513,338,000	2,512,996,000	64,686,540	44,551	
Jun	2,490,245,000	2,489,737,000	118,423,200	66,812	
Jul	2,491,891,000	3,355,318,000	2,405,204,000	2,254,232,000	2,254,143,000
Aug	2,447,221,000	3,392,773,000	3,528,745,000	3,312,386,000	3,312,305,000
Sep	2,482,020,000	3,432,014,000	3,468,990,000	3,312,364,000	3,312,305,000
Oct	2,517,228,000	3,471,425,000	3,357,017,000	3,312,341,000	3,312,305,000
Nov	2,548,318,000	3,511,096,000	3,477,413,000	3,464,922,000	3,554,607,000
Dec	2,576,097,000	3,498,123,000	3,497,954,000	3,796,913,000	3,796,909,000

Table XLVI

Total Storage Volume ($ST_{st} + K_{ds}$) in Model-3 without Restriction (Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	16,000,000,000	5,600,000,000	11,000,000,000	630,000,000	67,300,000
Feb	16,000,000,000	6,364,057,300	11,000,000,000	1,220,200,000	157,000,000
Mar	16,000,000,000	8,052,911,000	11,011,734,780	1,220,200,000	157,000,000
Apr	16,774,652,400	10,512,793,000	11,000,000,000	1,220,200,000	157,000,000
May	23,454,714,000	11,200,000,000	12,400,238,000	1,220,200,000	157,000,000
Jun	29,461,600,000	11,200,000,000	14,059,188,000	1,220,200,000	157,000,000
Jul	30,616,800,000	11,200,000,000	15,390,647,000	1,220,200,000	157,000,000
Aug	29,784,200,000	10,335,914,000	14,926,494,000	1,220,200,000	157,000,000
Sep	28,454,700,000	9,389,756,000	12,903,395,000	1,220,200,000	157,000,000
Oct	26,982,700,000	8,439,369,000	11,506,187,000	1,220,200,000	157,000,000
Nov	25,620,357,000	7,484,942,000	11,217,125,000	1,220,200,000	157,000,000
Dec	24,479,917,000	6,522,067,900	11,000,000,000	1,220,200,000	67,300,000

Table XLVII

Irrigated Land Amount in each District (L_{jsz}) in Model-3 without Restriction (ha)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
WHEAT	118,551.63	55,935.262	180,85.61	61,129.80	11,301.21	20,247.42
BARLEY						
LENTIL	141,971.12					
CORN	3,932.09	55,935.262	180,85.61	61,129.80	11,301.21	20,247.42
COTTON	69,871.30	9,564.738	29,282.39	98,975.20	18,297.79	32,782.58
TOTAL	334,326.15	121,435.262	65,453.61	221,234.80	40,900.21	73,277.42
Total Land Available	370,246	146,500	47,358	160,105	29,599	53,030
Percentage of Irrigated Land	90 %	83 %	138 %	138 %	138 %	138 %

Table XLVIII

Water Release for Irrigation ($R_{ir, jszt}$) in Model-3 without Restriction (Cubic meter/per month)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
Jan						
Feb						
Mar	161,047,000	32,699,750	10,572,850	35,736,480	6,606,690	11,836,640
Apr	321,408,000	77,447,960	25,041,330	84,640,310	15,647,660	28,034,580
May	321,408,000	178,338,400	57,662,330	194,900,100	36,031,650	64,554,830
Jun	183,188,800	326,608,700	105,602,800	356,939,900	65,988,340	118,225,700
Jul	321,408,000	416,597,800	134,699,000	455,285,900	84,169,820	150,799,900
Aug	321,408,000	597,273,200	193,117,000	652,740,100	120,673,600	216,200,700
Sep	226,770,500	432,370,700	139,798,900	472,523,600	87,356,580	156,509,300
Oct	79,984,740	123,226,000	39,842,780	134,669,600	24,896,690	44,605,270
Nov	160,325,700	34,422,560	11,129,880	37,619,280	6,954,767	12,460,260
Dec						

In sum, these three models define an efficient allocation of the Euphrates River between hydropower generation and irrigation under the three different flow conditions. The distribution of the net benefits between agriculture and hydropower are shown in the table XLIX.

Table XLIX

Net Benefits ($)

	Agriculture	Hydropower	Total
Model-1 R	1,014,665,559	535,846,441	1,550,512,000
Model-1 N-R	1,014,665,559	549,292,441	1,563,958,000
Model-2 R	0	293,751,300	293,751,300
Model-2 N-R	1,009,163,462	194,959,538	1,204,123,000
Model-3 R	1,014,665,559	836,163,828	1,850,830,000
Model-3 N-R	1,014,665,559	840,596,441	1,855,262,000

R: RESTRICTION, N - R: NO-RESTRICTION

The total net benefit of the model with three restriction cases is less than that without restriction cases. Value differences between the restriction and no-restriction cases have a positive correlation with the water scarcity. For example, when the flow condition of the Euphrates River is lowest, the net benefit of the non-restriction case is four times higher than the restricted one. When the flow condition of the Euphrates River is highest, the difference between both cases is only $4,432,000.00. Hence, the cost of the water release in the border rises for Turkey when the water amount decreases.

Table L

Water Release on the Border and Shadow Price for Turkey

	MODEL-1				MODEL-2				MODEL-3			
	Restriction		No Restriction		Restriction		No Restriction		Restriction		No Restriction	
	Water Release (m^3/sc)	Shadow Price (\$/ m^3)	Water Release (m^3/sc)	Shadow Price (\$/ m^3)	Water Release (m^3/sc)	Shadow Price (\$/ m^3)	Water Release (m^3/sc)	Shadow Price (\$/ m^3)	Water Release (m^3/sc)	Shadow Price (\$/ m^3)	Water Release (m^3/sc)	Shadow Price (\$/ m^3)
Jan	300			-0.002	300			-0.03	300			-0.00200
Feb	300		26.22		300			-0.028	300		26.34	
Mar	300		21.64		300			-0.025	300		21.76	
Apr	300		15.53		300			-0.022	300		11.73	
May	300		1.422		300			-0.019	300			-0.00028
Jun	300			-0.00056	300			-0.016	300			-0.00014
Jul	300			-0.00037	300			-0.014	300		869.64	
Aug	300			-0.00014	300			-0.011	300		1,277.89	
Sep	300		441.82		300			-0.008	1,197.80		1,277.89	
Oct	300		1,277.9		300			-0.004	1,277.89		1,277.89	
Nov	737.5		1,277.9		300			-0.002	1,371.37		1,371.37	
Dec	300		1,371.4		300		37.26		1,464.85		1,464.85	

Water release amount in the border and shadow price are shown in Table L. As seen in the table, all restriction cases have a shadow price of zero. In Model-1 without restriction, releasing one cubic meter water in the border reduces the benefit $0.002 in the month of January. In the summer, it costs Turkey less than that amount. However, in **Model-2** releasing one cubic meter water in the border costs Turkey the highest when compared to others because of the water shortage. The shadow price in model-3 increases in January, May, and June. Their values are 0.002, 0.00028, and 0.00014 respectively.

The results of the three cases conclude that there is not enough water to satisfy both countries' projects. The strategy for managing water shortages is not only the trade in the different utilization of the water, but also the trade between the users. Therefore, some policy changes regarding the water scarcity problem between Turkey and Syria may benefit both sides.

Water trade between hydropower generation and irrigation uses is a viable option for both countries that is being confronted with water scarcity. In addition, most of the water in the Middle East is used more in agriculture than in other areas because of the food security and self-sufficiency concerns of the each country. Such concerns make it difficult to trade-off water for agricultural purposes and hydroelectric purposes. Furthermore, both countries are using water scarcity as a political weapon against each other. Recent Kurdish insurgents in Turkey serve as a good example of the turmoil caused when water scarcity problems are coupled with political agendas. Furthermore, Turkey has threatened to cut Syria's water supply has if Syria does not give up supporting

Kurdish separatist guerrillas. Therefore, it is difficult to suggest policy that includes mutual agreements or joint committees.

On the other hand, Turkey is an upstream country and distributes 90% of its water potential from Euphrates River. It is difficult to convince Turkey to release more water for irrigation projects. However, if some value of the water provides more benefit than the above the models, it could be acceptable to Turkey, as an economic benefit. Virtual water value may be used as a trade value that makes Turkey transfer water out of agriculture for the conflict solution.

A “virtual water" represents the amount of water needed to raise a certain quantity of food. In other words, a ton of grain has one tone of "virtual water" embedded in it because that is how much water it takes to raise that amount of grain. Thus, The virtual water value of each indicator is derived from calculating the volume of water expressed in tonnage used to produce one ton of that crop (Allan, 1999). Moreover, "virtual water," is a hidden source of water: Virtual water is the water contained in the food that the region imports. More water flows into the river as virtual water each year than flows into agricultural areas. The use of this virtual water obtained in the global trading system has enabled the countries of the region to augment their respective inadequate water resources.

Model-1 with restriction case crops output is used for virtual water value calculation. The optimum land distribution for crops is shown in Table XXIV and per hectare yield is provided from Table XX. Therefore, multiplication of the per-hectare yield of each crop and optimum land uses for that a crop gives total amount of crop production. The virtual value of each crop in each district is shown in Table LI. Total virtual water value of producing wheat is 1,255,104.1 tone and cotton is 983,341.22 tons. The total virtual water value for lentils and corn is 283,942.24 tons and 1,313,861.7 tons, respectively.

Table LI

Virtual Water Value (ton)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
WHEAT	52,1627.181	246,115.15	79,576.675	268,971.102	49,725.342	89,088.644
BARLEY	0	0	0	0	0	0
LENTIL	28,3942.242	0	0	0	0	0
CORN	30,277.1084	430,701.52	139,259.18	470,699.429	87,019.348	15,5905.13
COTTON	26,5510.955	36,346.004	111,273.09	376,105.775	69,531.587	124,573.81

Table LII

Net Benefit of Irrigation (Billion $)

	URFA-MARDIN	SURUC-YAYLAK	BOZOVA	SIVEREK-HILVAN	KAHTA	BIRECIK
WHEAT	368.55	173.89	56.224	190.04	35.13	62.95
BARLEY	0.00	0.00	0.00	0.00	0.00	0.00
LENTIL	120.98	0.00	0.00	0.00	0.00	0.00
CORN	28.12	399.95	129.32	437.09	80.81	144.77
COTTON	487.05	66.67	204.12	689.92	127.55	228.52

The virtual water value of crops could be transformed to dollar amount, using the net benefit of each crop from Table XX. The net economic benefit of each crop multiplied by the virtual value of the crops is shown in Table XLI. Virtual water value transforms the dollar amount and it is shown in Table LII. The total Value is $1,803,829,332.04.

That amount can be used as a compensation amount for Turkey. Syria can pay that amount to Turkey for releasing more water. Turkey transfers water from agriculture to hydropower. In this scenario, Turkey uses all water potential of the Euphrates River only hydropower generation. Therefore, Turkey not only receives compensation, but also receives hydropower generation benefit.

It could be calculated Turkey's total net benefit of hydropower generation and release amount of water from border. Results of the model are shown in Table LIII through Table LV.

Turkey uses five reservoirs for one purpose that hydropower generation and there is not water consumption for irrigation, net total benefit is $652,920,500.00. Turkey release water at the Turkish-Syrian border is 20,202,708,600 m^3. Turkey's total irrigation value is $1,803,829,332.04. Therefore, the per cubic meter water release across the border is $ 0.089. Syria may use this price to receive more water.

This value is average, but is higher than the shadow prices shown in Table LI, so that by benefit maximizing agency, like Turkey, could encourage them to release more water and receive more benefits.

Table LIII

Hydropower Generation (E_{st})
(Kilowatt-hours / per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	210,336,100	214,997,700	250,341,400	57,737,960	23,129,250
Feb	265,160,900	272,247,800	309,970,600	66,865,320	30,379,850
Mar	574,450,000	351,026,800	386,598,900	89,454,500	34,960,000
Apr	818,748,000	227,946,400	239,222,100	109,755,100	34,960,000
May	818,748,000	254,013,900	239,239,800	109,756,600	34,960,000
Jun	527,830,100	273,382,300	239,262,000	109,758,500	34,960,000
Jul	231,698,900	279,998,000	239,283,200	109,760,300	34,960,000
Aug	437,434,300	489,710,300	247,809,800	111,538,600	35,584,940
Sep	818,748,000	899,752,300	1,095,620,000	325,646,700	110,808,000
Oct	818,748,000	1,108,080,000	1,094,210,000	325,644,700	110,808,000
Nov	204,130,400	1,108,080,000	1,144,036,000	338,235,500	110,808,000
Dec	214,978,100	1,003,318,000	1,054,957,000	338,621,500	110,808,000
Total	5941,010,800	6,482,553,500	6,540,550,800	2092,775,280	707,126,040

Table LIV

Water Release for Hydropower Generation ($R_{hp, st}$)
(Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	810,824,000	810,789,200	810,648,600	810,641,000	777,600,000
Feb	987,652,600	987,612,500	987,452,700	834,268,400	777,600,000
Mar	1,985,214,000	1,214,996,000	1,214,660,000	777,614,800	777,600,000
Apr	2,742,110,000	778,283,300	777,679,200	777,626,800	777,600,000
May	2,685,179,000	778,726,000	777,731,700	777,644,600	777,600,000
Jun	1,739,727,000	779,244,300	777,797,500	777,666,800	777,600,000
Jul	780,473,900	779,814,600	777,860,400	777,688,100	777,600,000
Aug	1,428,175,000	1,427,535,000	798,724,600	798,565,800	798,484,600
Sep	2,694,440,000	2,693,996,000	3,312,481,000	3,312,364,000	3,312,305,000
Oct	2,747,043,000	3,349,919,000	3,312,411,000	3,312,341,000	3,312,305,000
Nov	790,808,600	3,416,733,000	3,460,197,000	3,460,167,000	3,547,056,000
Dec	825,796,000	3,196,551,000	3,196,381,000	3,786,568,000	3,789,358,000

Table LV

Total Storage Volume (ST_{st} + K_{ds})
(Cubic meter/per month)

	KEBAN	KARAKAYA	ATATURK	BIRECIK	KARGAMISH
Jan	16,000,000,000	5,600,000,000	11,000,000,000	630,000,000	67,300,000
Feb	16,000,000,000	5,600,000,000	11,000,000,000	630,000,000	100,337,140
Mar	16,000,000,000	5,600000,000	11,000,000,000	783,175,500	157,000,000
Apr	16,000,000,000	6,370,137,200	11,000,000,000	1,220,200,000	157,000,000
May	18,499,448,000	8,333,823,000	11,000,000,000	1,220,200,000	157,000,000
Jun	20,583,063,000	10,239,995,000	11,000,000,000	1,220,200,000	157,000,000
Jul	20,879,994,000	11,200,000,000	11,000,000,000	1,220,200,000	157,000,000
Aug	21,032,554,000	11,200,000,000	11,000,000,000	1,220,200,000	157,000,000
Sep	20,234,744,000	11,200,000,000	11,627,020,300	1,220,200,000	157,000,000
Oct	18,102,280,000	11,200,000,000	11,007,155,052	1,220,200,000	157,000,000
Nov	16,000,000,000	10,596,847,000	11,043,818,940	1,220,200,000	157,000,000
Dec	16,000,000,000	7,970,802,000	11,000,000,000	1,220,200,000	70,095,061

CHAPTER VI

CONCLUSIONS

As an upstream state, Turkey has complete control over the source of the Euphrates River and therefore has the advantage in ability to use its water. The utilization of the Euphrates River on the Turkish side is outlined by the Southeast Anatolian project. However, implementation of the Southeast Anatolian project in the Euphrates River escalates historical political conflicts between Turkey and Syria. Currently, the water scarcity problem between these two countries is used as a political weapon.

In this study, the model is developed to maximize the economic benefits of the Euphrates water system on the Turkish side. The model is utilized to investigate the impacts of the various Euphrates flow conditions on the water scarcity problem of the Turkish-Syrian border. The annual flow of the Euphrates River has high variation. Therefore, three different flow rates –lowest, average, and highest - are used to determine whether or not there is water scarcity problem. Results in Chapter IV show that satisfaction of both countries water consumption depends on the variation of the Euphrates River. When the flow rates is the highest amount, water release in the Turkish-Syrian border is more than 300 m^3/ per second. In the case of the lowest level flow rate, Turkey gives up water for irrigation to compensate for the border requirement. On the other hand, Turkey consumes all water for its irrigation projects in the same way as it does without border restriction. Water release on the border is close to the border requirement in both cases –with and without restriction- of the average flow rates. However, the amount of hydropower generation is less than the annual average production. Turkey gives up hydropower generation for more profitable agricultural production. Consequently, Turkish irrigation projects consume more water and cause the water scarcity problem.

As an upstream country, Turkey has no voluntary intention to transfer water out of agriculture in order to solve the conflict. In addition, some level of hostility and political considerations, which are usually not cooperated in economic analysis, exist between both countries. Food security and national independence also block the most efficient arrangement. Therefore, some compensation amount, which is more beneficial than water use in agriculture, may change the upstream country's water policy. A virtual water value is used to define the trade value not only between countries but also between hydropower and agriculture uses. Per cubic meter of The Euphrates River value is calculated at $0.089.

This approach is trying to combine quantitative (economic) and qualitative (political) measures in the conflict analysis. Therefore, future investigations of international water allocation should focus on quantifying political and ideological considerations to be compatible with economic factors. It should also include mechanisms and institutions, such as joint committees for achieving the proposed economic solution.

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APPENDIX A

Mass Balance Equation

$$ST_{st} - ST_{st+1} - EV_{st} - R_{hpst} = -QF_{st} \qquad (A1)$$

The mass balance equations explicitly define storage volume at the beginning of the period (t). ST_{st} is the active storage volume in the reservoir at the beginning of period (t). Continuity or conservation of flow requires that the initial storage volume plus any inflow QF_{st} less the release R_{hpst} and evaporation loss EV_{st} must equal the final storage volume. Evaporation losses in each period t are the function of the storage volume in that period required for the estimation of evaporation loses is the reservior Storage Volume / Surface Area function. Also required is the average evaporation rate ev_{st} for each period. Multiplying the average Surface Area (SA_{st}) times the loss rate yields the volume of evaporation loss (EV_{st}) in the each period (Loucks et al, 1981).

Surface area / Active storage Volume function can be written :

$$SA_{st} = A_a (ST_{st}) + b \qquad (A2)$$

A_{sa} = Area per unit active storage volume above A_{s0}

A_{s0} = Surface area of Dead Storage volume

Total evaporation amount may be written as a function of active storage volume;

$$EV_{st} = ev_{st} (SA_{st}) = ev_{st} (A_a (ST_{st}) + A_0) \qquad (A3)$$

The Mass Balance Equation of the each reserviors in the system is calculated according to above the formulation.

Keban Reservoir:

The Keban reservoir approximation of Surface area per unit active Storage Volume is showed at the Figure 5.

$$SA_{1t} = 0.0171(ST_{1t}) + 200000000 \tag{A4}$$

A_{1a} = Area per unit active storage volume above A_{10} **=0.0171**

A_{10} = Surface area of Dead Storage volume **= 430 000 000 m^2**

$$\mathbf{EV_{11t} = ev_{1t}(SA_{1t}) = ev_{1t}\,(0.0171(ST_{1t}) + 430\,000\,000)} \tag{A5}$$

Equation A5 plugged into Equation A1 arranges terms so that mass balance equation for Keban is shown equation in A6.

$$(1 - 0.0171\, ev_{1t})ST_{1t} - ST_{1t+1} - 430\,000\,000\, ev_{1t} - R_{1hpt} = -QF_{1t} \quad (t = 1, \ldots, 12) \tag{A6}$$

Karakaya Reservoir:

The Karakaya reservoir approximation of the surface area per unit active storage volume is showed at the Figure 6.

$$SA_{2t} = 0.0168(ST_{2t}) + 100000000 \tag{A7}$$

A_{2a} = Area per unit active storage volume above A_{20} **= 0.0168**

A_{20} = Surface area of Dead Storage volume **= 175 000 000 m^2**

$$EV_{21t} = ev_{2t}(SA_{2t}) = ev_{2t}\,(0.0168(ST_{2t}) + 175\,000\,000) \quad (t = 1, \ldots, 12) \tag{A8}$$

Equation A8 plugs in to Equation A1 and arranging terms so that mass balance equation for Karakaya is shown equation A9.

$$(1 - 0.0168\, ev_{2t})ST_{2t} - ST_{2t+1} - 175\,000\,000\, ev_{2t} - R_{2hpt} = -R_{1hp\,t} \quad (t = 1, \ldots, 12) \tag{A9}$$

Figure 5. Keban Reservoir Active Storage Curve

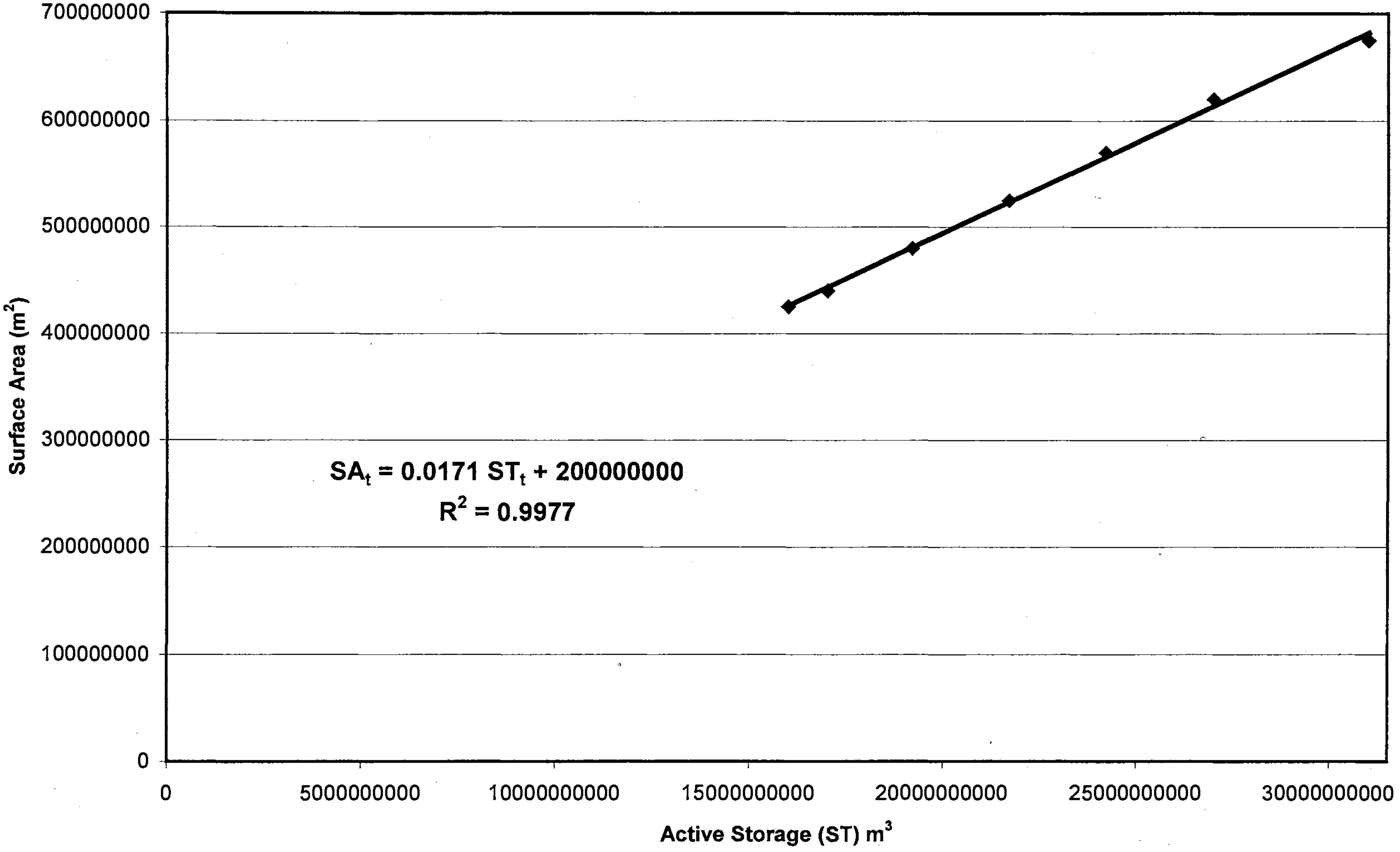
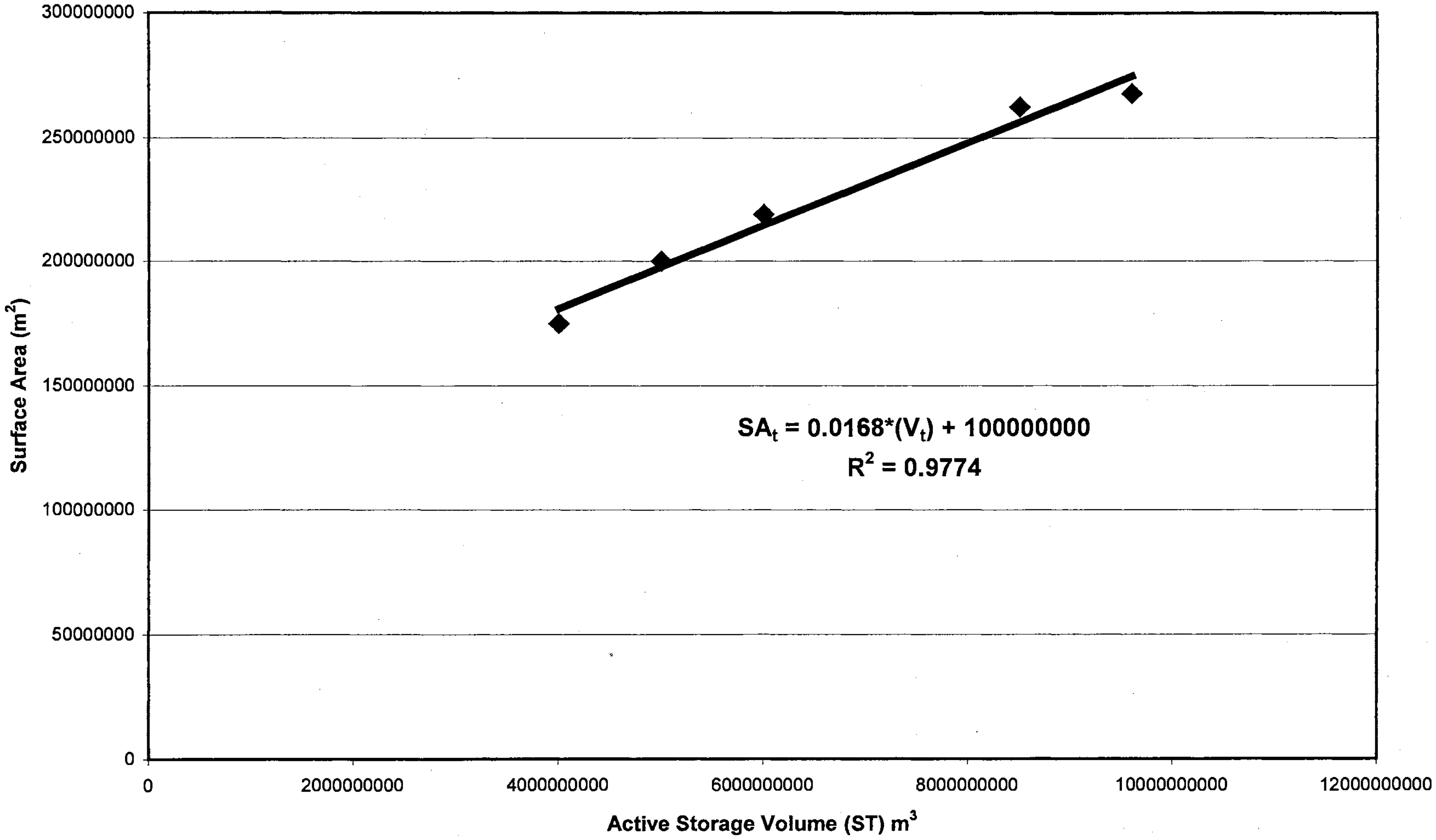


Figure 6. Karakaya ReservoirActive Storage Curve



Ataturk Reservoir:

The Ataturk reservoir approximation of the surface area per unit active storage volume is showed at the Figure 7.

$$SA_{3t} = 0.0122(ST_{3t}) + 200000000 \tag{A10}$$

A_{3a} = Area per unit active storage volume above A_{30} **= 0.0122**

A_{30} = Surface area of Dead Storage volume **= 685 700 000 m^2**

$$EV_{3t} = ev_{3t}(SA_{3t}) = ev_{3t}(0.0122(ST_{3t}) + 685\ 700\ 000) \quad (t = 1, \ldots, 12) \tag{A11}$$

Equation A11 plug in to Equation A1 and arranging terms so that mass balance equation for Ataturk is shown equation A12.

$$(1 - 0.0168\ ev_{2t})ST_{2t} - ST_{2t+1} - 175\ 000\ 000\ ev_{2t} - R_{2hpt} = -R_{1hp\,t} \quad (t = 1, \ldots, 12) \tag{A12}$$

Birecik Reservoir:

The Birecik reservoir approximation of the surface area per unit active storage volume is showed at the Figure 8.

$$SA_{4t} = 0.0353(ST_{4t}) + 1000000 \tag{A13}$$

A_{4a} = Area per unit active storage volume above A_{40} **= 0.0353**

A_{40} = Surface area of Dead Storage volume **= 35 000 000 m^2**

$$EV_{4t} = ev_{4t}(SA_{4t}) = ev_{4t}(0.0353(ST_{4t}) + 35\ 000\ 000) \quad (t = 1, \ldots, 12) \tag{A14}$$

Equation A14 plugs in to Equation A1 and arranging terms so that mass balance equation for Birecik is shown equation A15.

$$(1 - 0.0353\ ev_{4t})ST_{4t} - ST_{4t+1} - 35\ 000\ 000\ ev_{4t} - R_{4hpt} = R_{3hp\,t} \quad (t = 1, \ldots, 12) \tag{A15}$$

Figure 7. Ataturk Reservoir Active Storage Curve

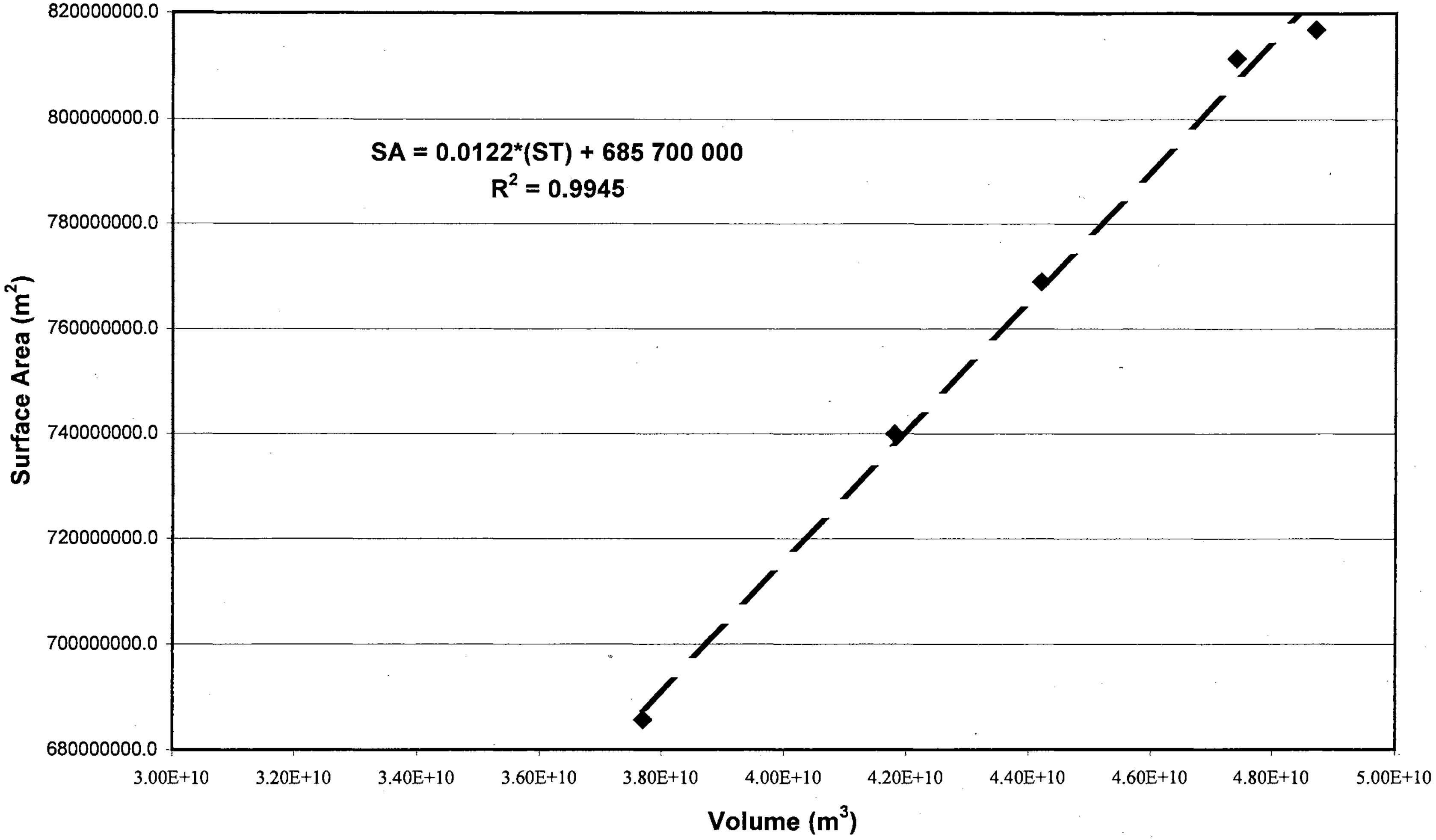
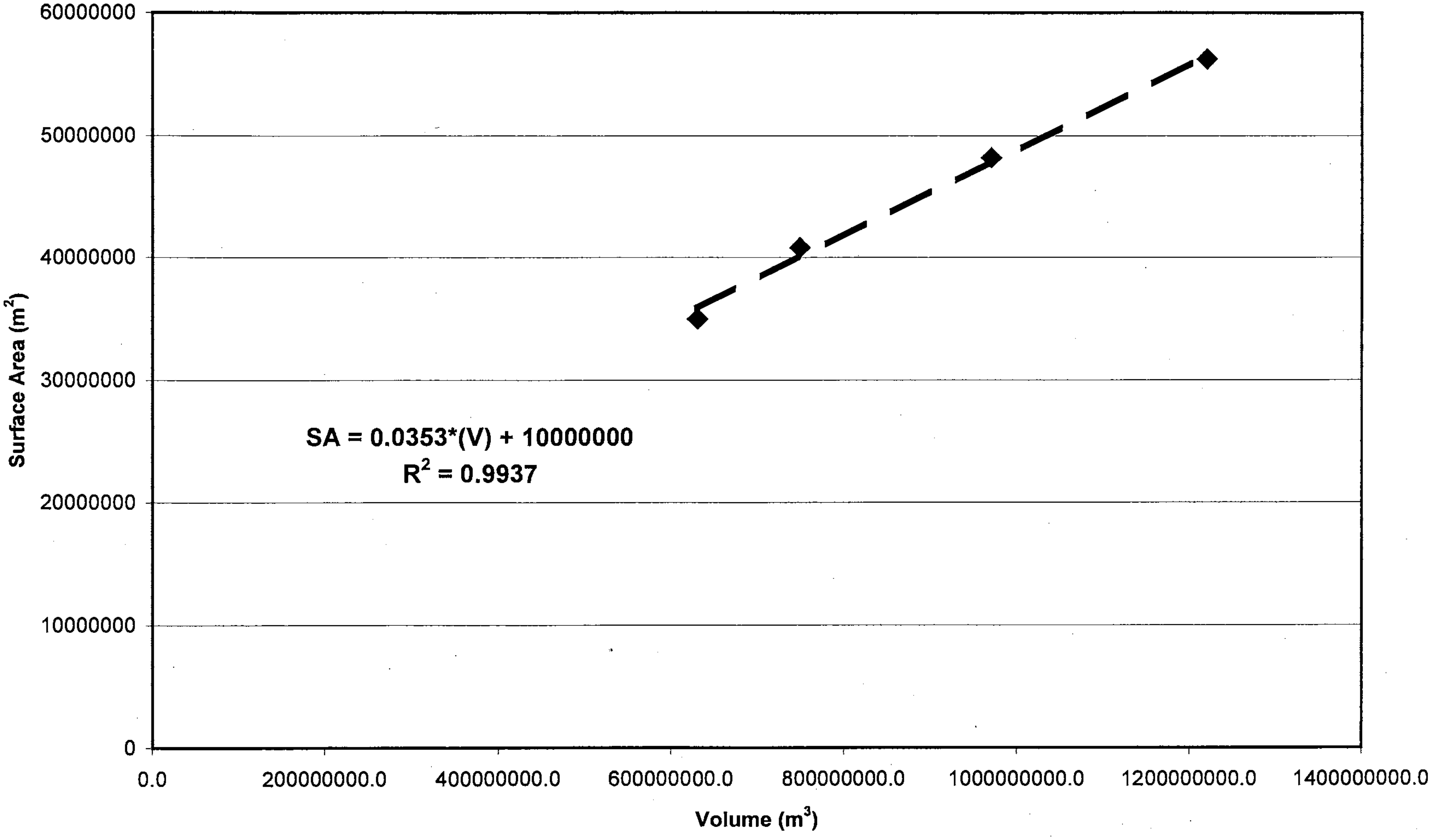


Figure 8. Birecik Reservoir Active Storage Curve



Kargamish Reservoir:

The Kargamish reservoir approximation of the surface area per unit active storage Volume is showed in Figure 9.

$$SA_{5t} = 0.1175*(ST_{5t}) + 10000000 \qquad (A16)$$

A_{4a} = Area per unit active storage volume above A_{40} **= 0.1175**

A_{40} = Surface area of Dead Storage volume **= 18 000 000 m^2**

$$EV_{5t} = ev_{5t}(SA_{5t}) = ev_{5t}(0.1175*(ST_{5t}) + 18\ 000\ 000) \qquad (A17)$$
$$(t = 1, \ldots, 12)$$

Equation A17 plug in to Equation A1 and arranging terms so that mass balance equation for Kargamish is shown equation A18.

$$(1 - 0.1175\ ev_{5t})ST_{5t} - ST_{5t+1} - 18\ 000\ 000\ ev_{5t} - R_{5hpt} = R_{4hp\ t} \qquad (A18)$$
$$(t = 1, \ldots, 12)$$

Discharge of Euphrates River at Keban (QF)

Data of Discharge of Euphrates River at Keban is provided to resources; 1937-1972 data is provided from "The Global River Discharge Database" Home page at the addresses http://www.rivdis.sr.unh.edu/cgi-bin/ViewSite?SITE=00801. 1972 - 2000 annual discharge data provided by Turkish State Hydraulic Works. Monthly discharge of the 1973-2000 is calculated due to mean distribution of 1937-1972 data. All monthly data show at Table LVI.

Figure 9. Kargamish Reservoir Active Storage Curve

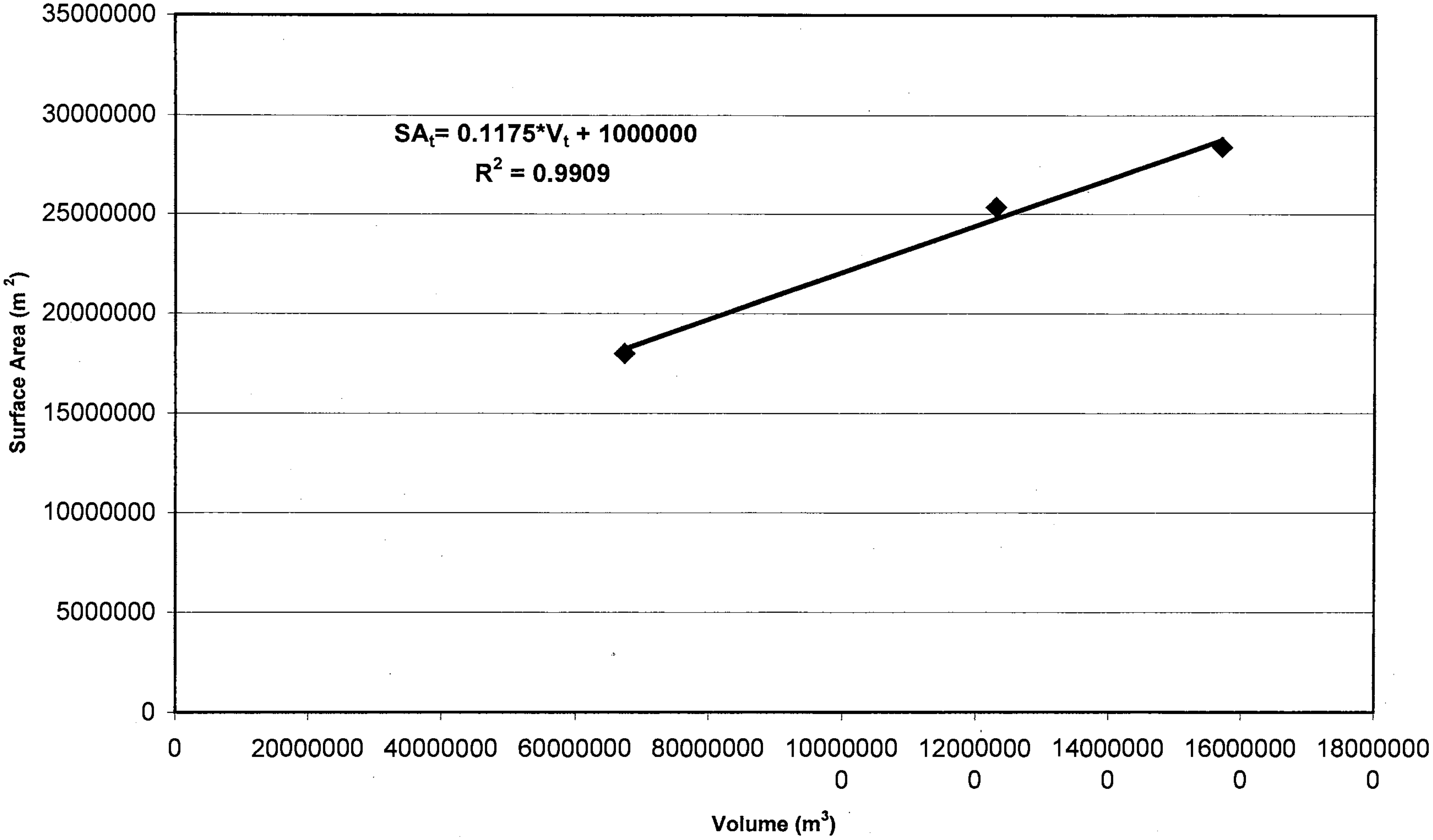


Table LIV
Historical annual water Income of the Euphrates River at Keban (hm^3)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1937	725.76	1034.208	2226.528	5438.016	3566.592	1863.648	1049.76	738.72	668.736	736.128	1153.44	1270.08	20471.62
1938	1057.536	997.92	1358.208	6951.744	5676.48	2337.984	1285.632	795.744	692.064	686.88	896.832	834.624	23571.65
1939	837.216	948.672	1744.416	4792.608	4408.992	1599.264	966.816	694.656	632.448	629.856	746.496	816.48	18817.92
1940	1360.8	1539.648	1607.04	8983.872	5806.08	2571.264	1365.984	780.192	648	917.568	1010.88	1340.064	27931.39
1941	1137.888	2288.736	4647.456	6780.672	5106.24	1811.808	969.408	684.288	603.936	655.776	756.864	684.288	26127.36
1942	738.72	878.688	1702.944	6575.904	6130.08	2138.4	896.832	642.816	578.016	717.984	1816.992	1557.792	24375.17
1943	917.568	811.296	1086.048	5953.824	5365.44	1827.36	850.176	611.712	549.504	616.896	676.512	756.864	20023.2
1944	673.92	1091.232	3473.28	4678.56	7156.512	2436.48	1132.704	772.416	699.84	720.576	1003.104	764.64	24603.26
1945	839.808	787.968	2384.64	3631.392	3833.568	1858.464	720.576	536.544	474.336	469.152	528.768	681.696	16746.91
1946	583.2	590.976	1539.648	4681.152	6088.608	2695.68	1148.256	793.152	609.12	1244.16	832.032	728.352	21534.34
1947	876.096	948.672	2892.672	3452.544	1925.856	1114.56	653.184	497.664	445.824	456.192	1249.344	637.632	15150.24
1948	627.264	961.632	881.28	6850.656	7239.456	3403.296	1174.176	710.208	588.384	588.384	635.04	598.752	24258.53
1949	518.4	588.384	992.736	3289.248	4655.232	1708.128	694.656	549.504	492.48	500.256	508.032	500.256	14997.31
1950	476.928	593.568	1316.736	4253.472	4815.936	1651.104	798.336	622.08	557.28	808.704	712.8	681.696	17288.64
1951	741.312	733.536	2001.024	3807.648	2877.12	1435.968	707.616	536.544	552.096	816.48	865.728	793.152	15868.22
1952	624.672	1342.656	1614.816	7397.568	5069.952	2055.456	917.568	624.672	572.832	565.056	593.568	653.184	22032
1953	663.552	990.144	1171.584	6137.856	5614.272	2610.144	1080.864	660.96	565.056	578.016	728.352	585.792	21386.59
1954	606.528	689.472	1967.328	7260.192	6324.48	2669.76	1226.016	686.88	598.752	603.936	676.512	842.4	24152.26
1955	741.312	813.888	1277.856	2288.736	2820.096	1093.824	653.184	552.096	489.888	497.664	546.912	668.736	12444.19
1956	624.672	1008.288	1073.088	5627.232	4802.976	2327.616	979.776	666.144	603.936	614.304	627.264	619.488	19574.78
1957	588.384	870.912	2791.584	3273.696	4885.92	2210.976	964.224	601.344	533.952	536.544	596.16	640.224	18493.92
1958	642.816	743.904	1741.824	3709.152	2731.968	1736.64	692.064	528.768	471.744	471.744	510.624	585.792	14567.04
1959	544.32	526.176	1080.864	3037.824	2532.384	1578.528	578.016	476.928	445.824	533.952	583.2	515.808	12433.82
1960	699.84	1008.288	1679.616	6225.984	4512.672	1754.784	920.16	653.184	593.568	588.384	632.448	590.976	19859.9
1961	598.752	668.736	956.448	2249.856	1726.272	741.312	476.928	391.392	352.512	383.616	541.728	894.24	9981.792

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1962	593.568	925.344	2441.664	3429.216	2742.336	1306.368	689.472	445.824	396.576	417.312	482.112	894.24	14764.03
1963	1308.96	1925.856	1876.608	7060.608	7677.504	5023.296	1879.2	1000.512	772.416	873.504	951.264	842.4	31192.13
1964	590.976	694.656	3180.384	5774.976	4033.152	1874.016	738.72	513.216	469.152	492.48	653.184	624.672	19639.58
1965	583.2	624.672	1967.328	5339.52	4186.08	1783.296	824.256	580.608	497.664	829.44	863.136	1111.968	19191.17
1966	2415.744	2166.912	2843.424	5819.04	5331.744	2392.416	1109.376	754.272	707.616	743.904	896.832	1179.36	26360.64
1967	1039.392	865.728	1620	6487.776	8794.656	2825.28	1438.56	878.688	756.864	977.184	1588.896	1617.408	28890.43
1968	1353.024	1321.92	3766.176	9727.776	6804	3035.232	1321.92	834.624	723.168	762.048	1321.92	1423.008	32394.82
1969	1308.96	1220.832	4131.648	8291.808	9276.768	2667.168	1280.448	912.384	780.192	909.792	863.136	987.552	32630.69
1970	842.4	1329.696	2661.984	4613.76	2579.04	1145.664	679.104	541.728	500.256	614.304	743.904	933.12	17184.96
1971	751.5148	920.6056	1841.211	4866.058	4433.937	1897.575	864.242	582.424	526.0604	601.2118	732.7269	770.3027	18787.87
1972	625	765.625	1531.25	4046.875	3687.5	1578.125	718.75	484.375	437.5	500	609.375	640.625	15625
1973	540.6556	662.3031	1324.606	3500.745	3189.868	1365.155	621.7539	419.0081	378.4589	432.5245	527.1392	554.172	13516.39
1974	666.5616	816.538	1633.076	4315.986	3932.713	1683.068	766.5458	516.5852	466.5931	533.2493	649.8976	683.2256	16664.04
1975	659.1552	807.4651	1614.93	4268.03	3889.016	1664.367	758.0285	510.8453	461.4086	527.3242	642.6763	675.6341	16478.88
1976	1059.0924	1297.388	2594.776	6857.623	6248.645	2674.208	1217.956	820.7966	741.3647	847.2739	1032.615	1085.57	26477.31
1977	796.1708	975.3092	1950.618	5155.206	4697.408	2010.331	915.5964	617.0324	557.3196	636.9366	776.2665	816.0751	19904.27
1978	888.7492	1088.718	2177.436	5754.651	5243.62	2244.092	1022.062	688.7806	622.1244	710.9994	866.5305	910.9679	22218.73
1979	762.8428	934.4824	1868.965	4939.407	4500.773	1926.178	877.2692	591.2032	533.99	610.2742	743.7717	781.9139	19071.07
1980	973.9208	1193.053	2386.106	6306.137	5746.133	2459.15	1120.009	754.7886	681.7446	779.1366	949.5728	998.2688	24348.02
1981	803.5772	984.3821	1968.764	5203.162	4741.105	2029.032	924.1138	622.7723	562.504	642.8618	783.4878	823.6666	20089.43
1982	844.3116	1034.282	2068.563	5466.918	4981.438	2131.887	970.9583	654.3415	591.0181	675.4493	823.2038	865.4194	21107.79
1983	629.5304	771.1747	1542.349	4076.209	3714.229	1589.564	723.96	487.8861	440.6713	503.6243	613.7921	645.2687	15738.26
1984	681.374	834.6832	1669.366	4411.897	4020.107	1720.469	783.5801	528.0649	476.9618	545.0992	664.3397	698.4084	17034.35
1985	585.0932	716.7392	1433.478	3788.478	3452.05	1477.36	672.8572	453.4472	409.5652	468.0746	570.4659	599.7205	14627.33
1986	592.4992	725.8115	1451.623	3836.432	3495.745	1496.06	681.3741	459.1869	414.7494	473.9994	577.6867	607.3117	14812.48
1987	1166.4828	1428.941	2857.883	7552.976	6882.249	2945.369	1341.455	904.0242	816.538	933.1862	1137.321	1195.645	29162.07
1988	1444.2168	1769.166	3538.331	9351.304	8520.879	3646.647	1660.849	1119.268	1010.952	1155.373	1408.111	1480.322	36105.42
1989	522.14	639.6215	1279.243	3380.857	3080.626	1318.404	600.461	404.6585	365.498	417.712	509.0865	535.1935	13053.5

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	710.9992	870.974	1741.948	4603.72	4194.895	1795.273	817.6491	551.0244	497.6994	568.7994	693.2242	728.7742	17774.98
1991	703.5928	861.9012	1723.802	4555.763	4151.198	1776.572	809.1317	545.2844	492.515	562.8742	686.003	721.1826	17589.82
1992	777.6552	952.6276	1905.255	5035.317	4588.166	1963.579	894.3035	602.6828	544.3586	622.1242	758.2138	797.0966	19441.38
1993	1014.6548	1242.952	2485.904	6569.89	5986.463	2562.003	1166.853	786.3575	710.2584	811.7238	989.2884	1040.021	25366.37
1994	555.468	680.4483	1360.897	3596.655	3277.261	1402.557	638.7882	430.4877	388.8276	444.3744	541.5813	569.3547	13886.7
1995	1022.0612	1252.025	2504.05	6617.846	6030.161	2580.705	1175.37	792.0974	715.4428	817.649	996.5097	1047.613	25551.53
1996	866.53	1061.499	2122.999	5610.782	5112.527	2187.988	996.5095	671.5608	606.571	693.224	844.8668	888.1933	21663.25
1997	725.925926	889.2593	1778.519	4700.37	4282.963	1832.963	834.8148	562.5926	508.1481	580.7407	707.7778	744.0741	18148.15
1998	910.9676	1115.935	2231.871	5898.515	5374.709	2300.193	1047.613	705.9999	637.6773	728.7741	888.1934	933.7418	22774.19
1999	585.09296	716.7389	1433.478	3788.477	3452.048	1477.36	672.8569	453.447	409.5651	468.0744	570.4656	599.7203	14627.32
2000	548.06176	671.3757	1342.751	3548.7	3233.564	1383.856	630.271	424.7479	383.6432	438.4494	534.3602	561.7633	13701.54

APPENDIX B

Hydroelectric Power Production

The production of hydroelectric energy during any period at any particular reservoir site is dependent on installed plant capacity; the flow through the turbines; the average head; the number of hours in the period; the plant factor; and a constant for converting the product of flow, head, and plant efficiency to kilowatt-hours of the electric energy (Loucks et. al., 1981). The kilowatt-hours of energy E_{st} produced in period t at reservoir s are proportional to product of plant efficiency e_{st}, the productive storage head h_{st}, and flow through the turbines R_{hpst}.

$$E_{st} = e_{st}\, k\, R_{hpst}\, h_{st} \tag{A19}$$

where k is reperesent The conversion factor which is equal to 0.0273 when the metric measurement is used for flow rate and head. In this research, plant efficiency e_{st} is equal to .855 for all reserviors. It was calculated as a product of turbine efficiency and generator efficiency, which are equal to 0.90 and 0.95 respectively.

Average head (h_{st}) in each period is approximated as a linear function of average active storage volume;

$$h_{st} = h_0 + 0.5\,(ST_{st} + ST_{st+1}) \tag{A20}$$

When the linear programming algorithm is used for solution of the model with hydroelectric power production, the nonlinear relationships in equation A19 involving the product of head and flow must be replaced by linear approximation. If the average heads h^0_{st} and flows R^0_{st} can be estimated for each period t and reservoir s, then these fixed constants can be used to obtain a linear approximation of flow-head product term (Loucks et al, 1981).

$$R_{st}\, h_{st} \approx R^0_{st}\, h_{st} + h^0_{st}\, R_{st} - R^0_{st}\, h^0_{st} \qquad (A21)$$

The calculation of all reservoir hydroelectric power production constraints follows;

Keban reservoir:

Gross Head (H) = Elevation of Water Surface – Elevation of the Tailrace

Elevation of Water Surface as a function of total volume is shown Figure 10.

Elevation = $(2*10^{-9} *(V_{1t}) + 783.17)$

Elevation of the Tailrace for KEBAN = 693 m

Step 1.

First period gross head calculation:

$ST_{11}= ST_{1jan96}=$ 6 977 466 197.94 m^3

$V_{11} = V_{1jan96} = ST_{1jan96} +16*10^9 =$22 977 466 197.94 m^3

$H_{11} = H_{1jan96} = (2*10^{-9} *(V_{1jan96}) + 783.17) – 693 = 131.1$ meter

$H_{12} = (2*10^{-9} *(V_{12}) + 783.17) – 693$

...

...

...

$H_{1t+1} = (2*10^{-9} *(V_{1t+1}) + 783.17) – 693$

Step 2:

Find Average Head as a Function of the average Active Storage Volume (**ST_t**);

Active Storage Volume (**ST_t**) = Total Storage Volume (**V_t**) – Dead Storage Volume (**K_d**)

Head as a function of storage volume is shown Figure 11:

$$h_t = h_0 + m(s_t) = 122.17 + 2*10^{-9}\, s_t \qquad (A21)$$

Figure 10. Keban Volume-Elevation Function

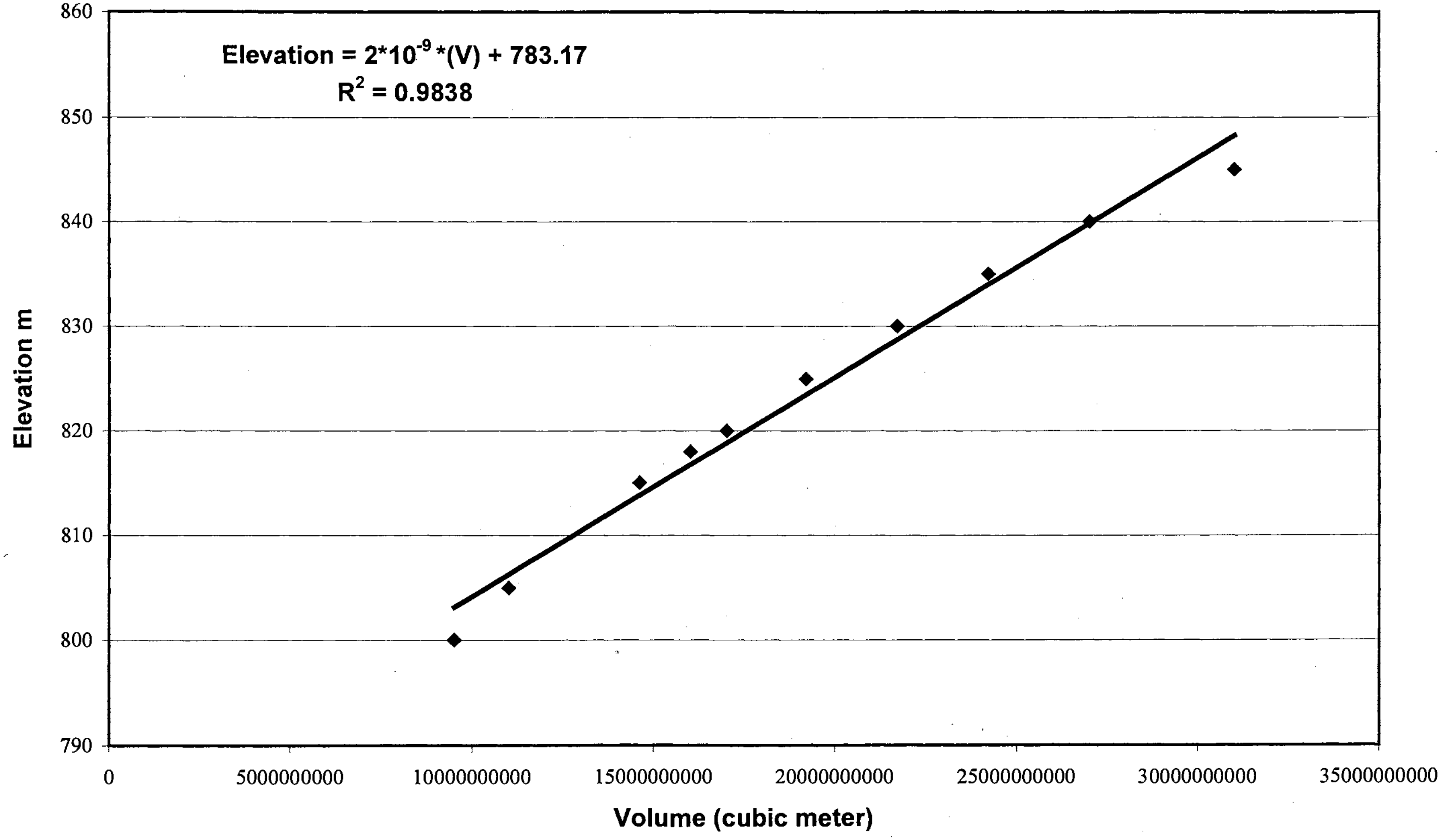
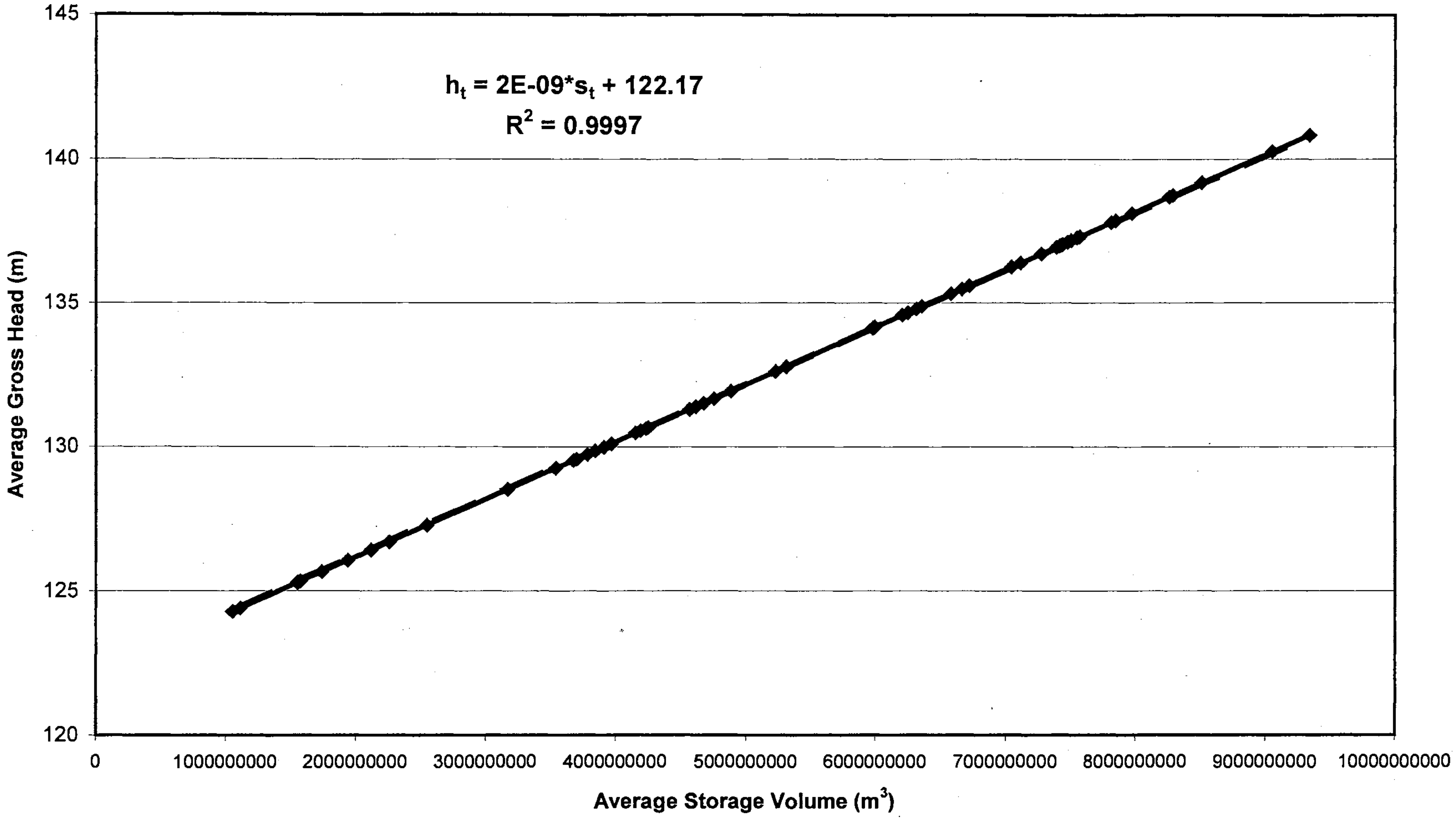


Figure 11. Keban Average Head-Active Storage Curve



Step 3:

Linear Approximation of the release-head product term:

Calculation of Water Release for given Monthly Power Production:

$R_{1hp1} = (E_{11}) / (0.00273^* (122.17 + 2^*10^{-9} {}^*(ST_{11})^* (0.855)$

$R_{1hp2} = (E_{12}) / (0.00273^* (122.17 + 2^*10^{-9} {}^*((ST_{11} + ST_{12}) / 2)^* (0.855)$

$R_{1hp3}= (E_{13}) / (0.00273^* (122.17 + 2^*10^{-9} {}^*((ST_{12} + ST_{13}) / 2)^* (0.855)$

...

...

$R_{1hp\ t+1}= (E_{1t+1}) / (0.00273^* (122.17 + 2^*10^{-9} {}^*((ST_{1t} + ST_{1t+1}) / 2)^* (0.855)$

Step 4:

Calculation of Average Water release for Power production:

$\mathbf{R^0_{hp1}} = (\Sigma_{t=1}{}^{T}\ R_{1hpt}\ )/\ T$

$=(99\ 031\ 341\ 256.51) / 60 = 1\ 650\ 522\ 354.28\ \text{m}^3/\text{per month}$

Calculation of Average Head:

$\mathbf{h^0_1} = (\Sigma_{t=1}{}^{T}\ h^0)/\ T = 7969.6 / 60 = 132.83\ \text{m}$

Calculation of Product term:

$\mathbf{R^0_{1hp\,t}} {}^*\mathbf{h^0} = 219\ 233\ 583\ 431$

Step 5:

$Z_t = h_{1t}{}^*\ R_{1hp\ t} \approx (1\ 650\ 522\ 354.28)\ h_{1t} + \ (132.83)\ R_{1hp\ t} - 219\ 233\ 583\ 431$

$h_{1t} = 122.17 + (2^*10^{-9})^*0.5^*\ [(ST_t) + (ST_{t+1})\ ]$

$Z_t \approx (1\ 650\ 522\ 354.28)\ (122.17 + (2^*10^{-9})^*0.5^*\ [(ST_t) + (ST_{t+1})]) + (132.83)\ R_{1hp\ t} - 219233583431$

$Z_t = 201644316021.80 + 1.65^*(ST_t + ST_{t+1}) + 132.83^*R_{1hp\ t} - 219\ 233\ 583\ 431$

$$h_{1t}{}^*\ R_{1hp\ t} = 1.65^*(ST_t + ST_{t+1}) + 132.83^*R_{1hpt} - 17589267409.2 \tag{A22}$$

For hydropower production funtion equation A22 plug into A19 ;

$$E_{1t} = 0.00273 * (1.65*(ST_t+ST_{t+1}) + 132.83*R_{1pt} - 17589267409.2)* 0.855 \qquad (A23)$$

Hydropower generation capacity constraint ;

$$E_{1t} \leq h_t N_{1t} \qquad (A24)$$

N_{1t} = Keban reservior capacity = 1330 MW
h_t = number of hours in season t =24*30 = 720 hours
N_{1t} = 1330*1000 = 1 330 000 KW
$E_{1t} \leq h_t N_{1t}$ = 957 600 000 KWh

Table LVII

Keban Hydropower Production (GWH)

	1995	1996	1997	1998	1999	2000	MEAN
JAN	670.9	797.2	489.1	567.4	696.6	680.6	658.3
FEB	497.7	714.8	430.4	501.7	624.6	321.6	487.2
MAR	543.5	598.2	619.6	742	522.7	272.7	535.7
APR	323.4	375.9	306.5	359.1	324.1	191.2	305.3
MAY	372.2	344.1	332.6	385	300.7	352.6	362.7
JUN	518.1	464.6	593.5	688.2	406	419	532.1
JUL	609.5	484.7	678.3	791	423.6	590.5	634.3
AUG	618.8	601.3	652.2	795.9	525.4	451.7	615.8
SEP	571	488.6	587.2	758.5	426.9	374.3	545.0
OCT	510.7	435.1	683.9	617.5	380.2	292.6	495.6
NOV	588.5	579.9	727.1	690.9	506.7	340	571.9
DEC	442.6	639.6	424.7	689.2	558.9	195.4	456.6
TOTAL	6266.9	6519.1	6524.9	7586.4	5696.4	4482.2	6200

Karakaya Reservoir:

Gross Head (H) = Elevation of Water Surface – Elevation of the Tailrace

Elevation of Water Surface as a function of total volume is shown Figure 12.

Elevation = $(-5*10^{-19}(V_{2t})^2 + 0.00000001*(V_{1t}) + 634.05$

Elevation of the Tailrace for KARAKAYA = 542 m at all discharges

Step 1.

First period gross head calculation:

$V_{21} = V_{2jan96} = 4\ 500\ 322\ 420.02\ m^3$

$H_{21} = H_{2jan96} = (-5*10^{-19}*(V_{2jan96})^2 + 0.00000001*(V_{2jan}) + 634.05) – 693 = 140.9$ m.

$H_{22} = (-5*10^{-19}(V_{22})^2 + 0.00000001*(V_{22}) + 634.05 – 693$

...

...

$H_{2T} = (-5*10^{-19}(V_{2T})^2 + 0.00000001*(V_{2T}) + 634.05 – 693$

Step 2:

Find Average Head as a Function of the average Active Storage Volume (ST_t);

Active Storage Volume (**ST_t**) = Total Storage Volume (**V_t**) – Dead Storage Volume (**K_d**)

Average Head as a function of Active Storage volume is shown Figure 13:

$$h_{2t} = h_0 + m(s_{2t}) = 128.09 + 3*10^{-9}\, s_{2t} \qquad (A25)$$

Step 3:

Linear Approximation of the release-head product term;

Calculation of Water Release for given Monthly Power Production:

$R_{2\,hp1} = (E_{21}) / (0.00273* (128.09 + 3*10^{-9} *(ST_{21})* (0.855)$

$R_{2\,hp2} = (E_{22}) / (0.00273* (128.09 + 3*10^{-9} *((ST_{21} + ST_{22}) / 2)* (0.855)$

$R_{2\,hp3} = (E_{23}) / (0.00273 * (128.09 + 3*10^{-9} *((ST_{22} + ST_{23}) / 2)* (0.855)$

...

...

$R_{2\,hpT} = (E_{1T}) / (0.00273 * (128.09 + 3*10^{-9} *((ST_{2T-1} + ST_{2T}) / 2)* (0.855)$

Step 4:

Calculation of Average Water Release for Power Production:

$\mathbf{R^0_{2hpt}} = (\Sigma_{t=1}^{T} R_{2\,hp\,t}) / T$

$= (114\,963\,960\,130.6) / 60 = 1\,916\,066\,002.2\ m^3$/per month

Calculation of Average Head:

$\mathbf{h^0} = (\Sigma_{t=1}^{T} h_{2t}) / T = 8322.8 / 60 = 138.71\ m$

Calculation of Product Term:

$\mathbf{R^0_{1hp\,t}\, h^0} = (1\,916\,066\,002.2)*(138.71) = 265\,783\,807\,482.65$

Step 5:

$Z_t = h_t * R_{1hp\,t} \approx (1\,916\,066\,002.2)\, h_t + (138.71)\, R_{1hp\,t} - 265\,783\,807\,482.65$

$h_t = 128.09 + (3*10^{-9})*0.5* [(ST_t) +(ST_{t+1})$

$Z_t \approx (1\,916\,066\,002.2)\, (128.09 + (3*10^{-9})*0.5* [(ST_{2t}) +(ST_{2t+1})]) + (138.71)\, R_{2\,hp\,t} -265783807\,482.65$

$$h_t * R_{1hp\,t} = 2.87*(ST_t+ST_{t+1}) + 138.71*R_{1hpt} - 20\,354\,913\,263.79 \qquad (A26)$$

For hydropower production funtion equation A26 plug into A19 ;

$$E_{2t} = 0.00273 * (2.87*(ST_{2t}+ST_{2t+1}) + 138.71*R_{2hp\,t} - 20\,354\,913\,263.79) * 0.855 \qquad (A27)$$

Hydropower generation capacity constraint :

$$E_{2t} \leq h_t N_{2t} \qquad (A28)$$

N_{1t} = Karakaya reservior capacity = 1800 MW

h_t = number of hours in season t = 24*30 = 720 hours in month

N_{2t} = 1800*1000 = 1 800 000 KW

$N_{2t}\ h_t$ = 1 296 000 000 KWh

Table LVIII

Karakaya Hydropower Production (GWH)

	1996	1997	1998	1999	2000	MEAN
JAN	802.8	868.1	892.2	828.6	852.6	848.9
FEB	694.7	713.9	772	650.8	550.1	676.3
MAR	850.3	785.7	945	640.2	386.3	721.5
APR	498.1	493.6	553.6	434.1	228.4	441.6
MAY	504.3	514.5	560.4	465.8	381.9	485.4
JUN	570.7	510.1	634.2	399	441.4	511.1
JUL	702.8	644.8	781	521	526.4	635.2
AUG	660.6	683.1	734.1	626.4	418.6	624.5
SEP	698.0	610.9	775.7	465	398.7	589.7
OCT	769.8	768.2	855.5	569.2	323.2	657.2
NOV	558.2	737.0	620.3	792.3	403.8	622.3
DEC	720.2	702.0	800.4	735.5	312.2	654.1
TOTAL	8030.3	8031.9	8924.4	7127.9	5223.6	7467.6

Figure 12. Karakaya Volume-Elevation curve

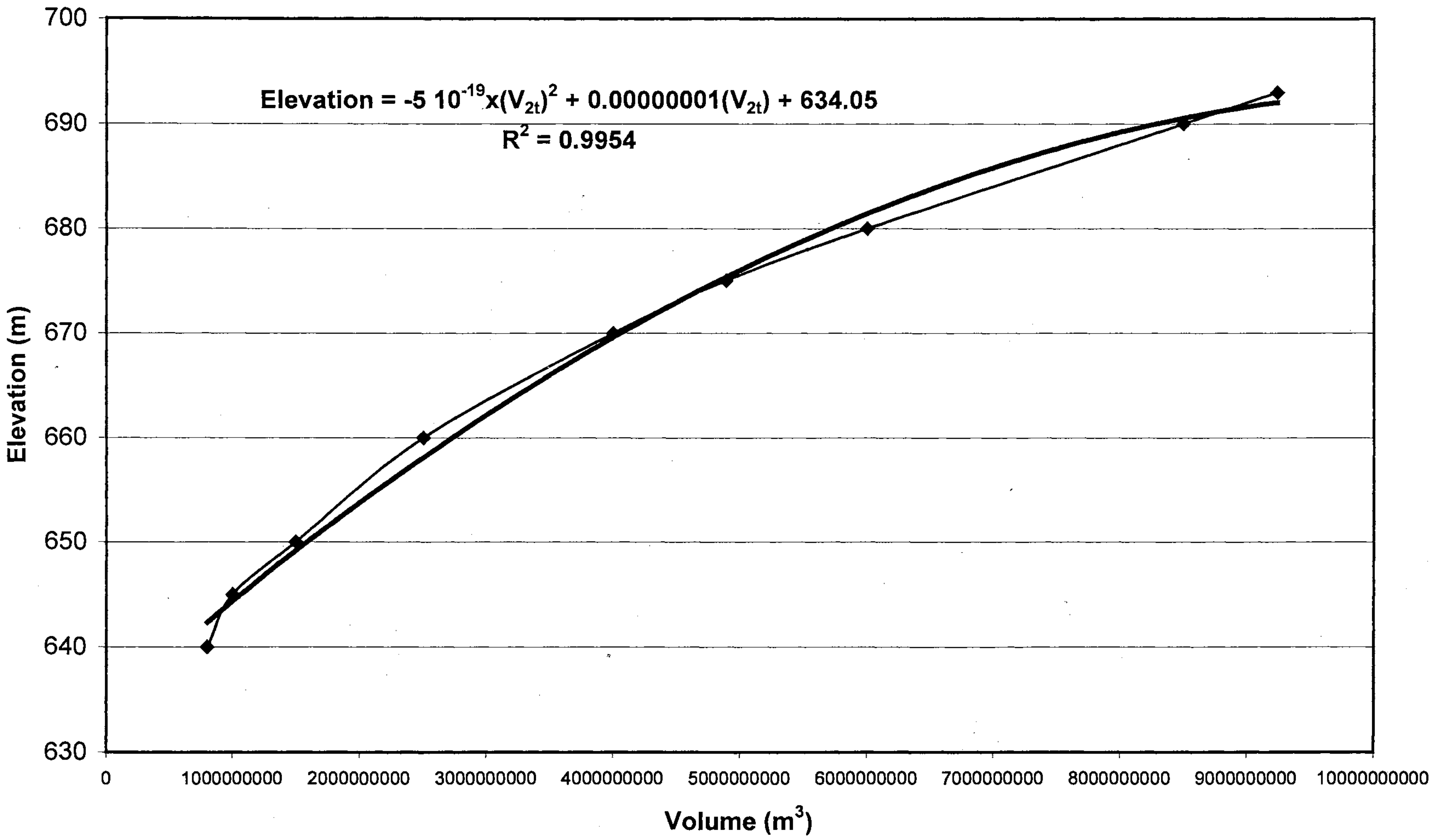
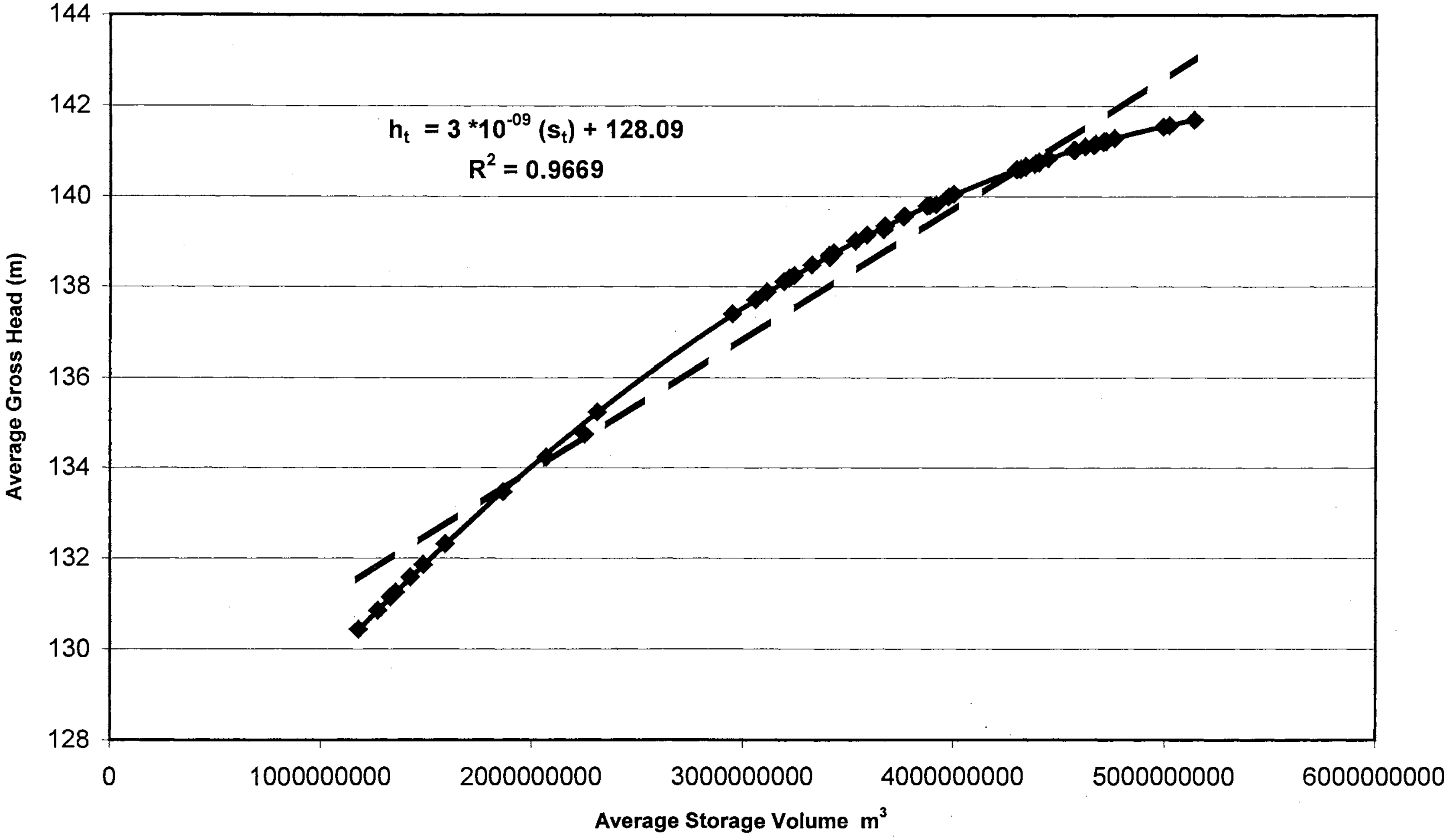


Figure 13. Karakaya Average Head-Active Storage Curve



Ataturk Reservoir:

Gross Head (H) = Elevation of Water Surface – Elevation of the Tailrace

Elevation of Water Surface as a function of total volume is shown Figure 14

Elevation = $(-6*10^{-20}(V_{3t})^2 + 0.000000006*(V_{3t}) + 386.33$

Elevation of the Tailrace for ATATURK = 385 m at all discharges

Step 1.

First period gross head calculation:

$V_{31} = V_{3jan96} = 44\ 388\ 638\ 941.4\ m^3$

$H_{31} = H_{3jan96} = (-6*10^{-20}*(V_{3jan96})^2 + 0.000000006*(V_{3jan}) + 386.33) - 385 = 146\ m$

$H_{32} = (-6*10^{-20}(V_{32})^2 + 0.000000006*(V_{32}) + 386.33 - 385$

...

...

$H_{3T} = (-6*10^{-20}(V_{3T})^2 + 0.000000006*(V_{3T}) + 386.33 - 385$

Step 2:

Find Average Head as a Function of the Average Active Storage Volume (ST_t);

Active Storage Volume ($\mathbf{ST_t}$) = Total Storage Volume ($\mathbf{V_t}$) – Dead Storage Volume ($\mathbf{K_d}$)

Average Head as a function of Active Storage volume shown Figure 15;

$$h_{3t} = h_0 + m(s_{3t}) = 140.12 + 9*10^{-10}\, s_{3t} \qquad (A29)$$

Step 3:

Linear Approximation of the Release-Head Product Term:

Calculation of Water Release for given Monthly Power Production:

$R_{3\,hp1} = (E_{31}) / (0.00273*(140.12 + 9*10^{-10}*(ST_{31})*(0.855)$

$R_{3\,hp2} = (E_{32}) / (0.00273*(140.12 + 9*10^{-10}*((ST_{31} + ST_{32}) / 2)*(0.855)$

$R_{3\ hp3} = (E_{33}) / (0.00273* (140.12 + 9*10^{-10} *((ST_{32} + ST_{33}) / 2)* (0.855)$

...

...

$R_{3\ hp\ T} = (E_{3T}) / (0.00273* (140.12 + 9*10^{-10} *((ST_{3T-1} + ST_{3T}) / 2)* (0.855)$

Step 4:

Calculation of Average Water release for Power Production:

$\mathbf{R^0_{3hpt}} = (\Sigma_{t=1}^{T} R_{2\ hp\ t}) / T$

$= (135\ 687\ 301\ 293.3) / 60 = 2\ 261\ 455\ 021.6\ m^3$/per month

Calculation of Average Head:

$\mathbf{h^0} = (\Sigma_{t=1}^{T} h_{3t}) / T = 8669.305 / 60 = 144.49$ m

Calculation of Product term:

$\mathbf{R^0_{3hp\ t}\ h^0} = (135\ 687\ 301\ 293.3)*(144.49) = 326\ 754\ 053\ 134.01$

Step 5:

$Z_{3t} = h_{3t}* R_{3hp\ t} \approx (2\ 261\ 455\ 021.6)\ h_t + (144.49)\ R_{1hp\ t} - 326\ 754\ 053\ 134.01$

$h_t = 140.12 + 9*10^{-10} *((ST_{3T-1} + ST_{3T}) *0.5)$ and plug into equation above,

$$Z_{3t} \approx (2\ 261\ 455\ 021.6)\ (140.12 + (9*10^{-10})*0.5* [(ST_{3t}) +(ST_{3t+1})]) + (144.49)\ R_{2\ hpt} -326\ 754\ 053\ 134.01$$

$$Z_t = 316\ 875\ 077\ 620.37 + 1.018*(ST_t+ST_{t+1}) + 144.49*R_{3hp\ t} - 326\ 754\ 053\ 134.01$$

$$h_{3t}* R_{3hp\ t} = 1.018*(ST_{3t}+ST_{3t+1}) + 144.49*R_{3hpt} - 9\ 878\ 975\ 513.64 \qquad (A30)$$

For hydropower production funtion equation A30 plug into A19 ;

$$E_{2t} = 0.00273* (1.018*(ST_{3t}+ST_{3t+1}) + 144.49*R_{3hpt} - 9\ 878\ 975\ 513.64)* 0.855 \qquad (A31)$$

Figure 14. Ataturk Volume-Elevation Curve

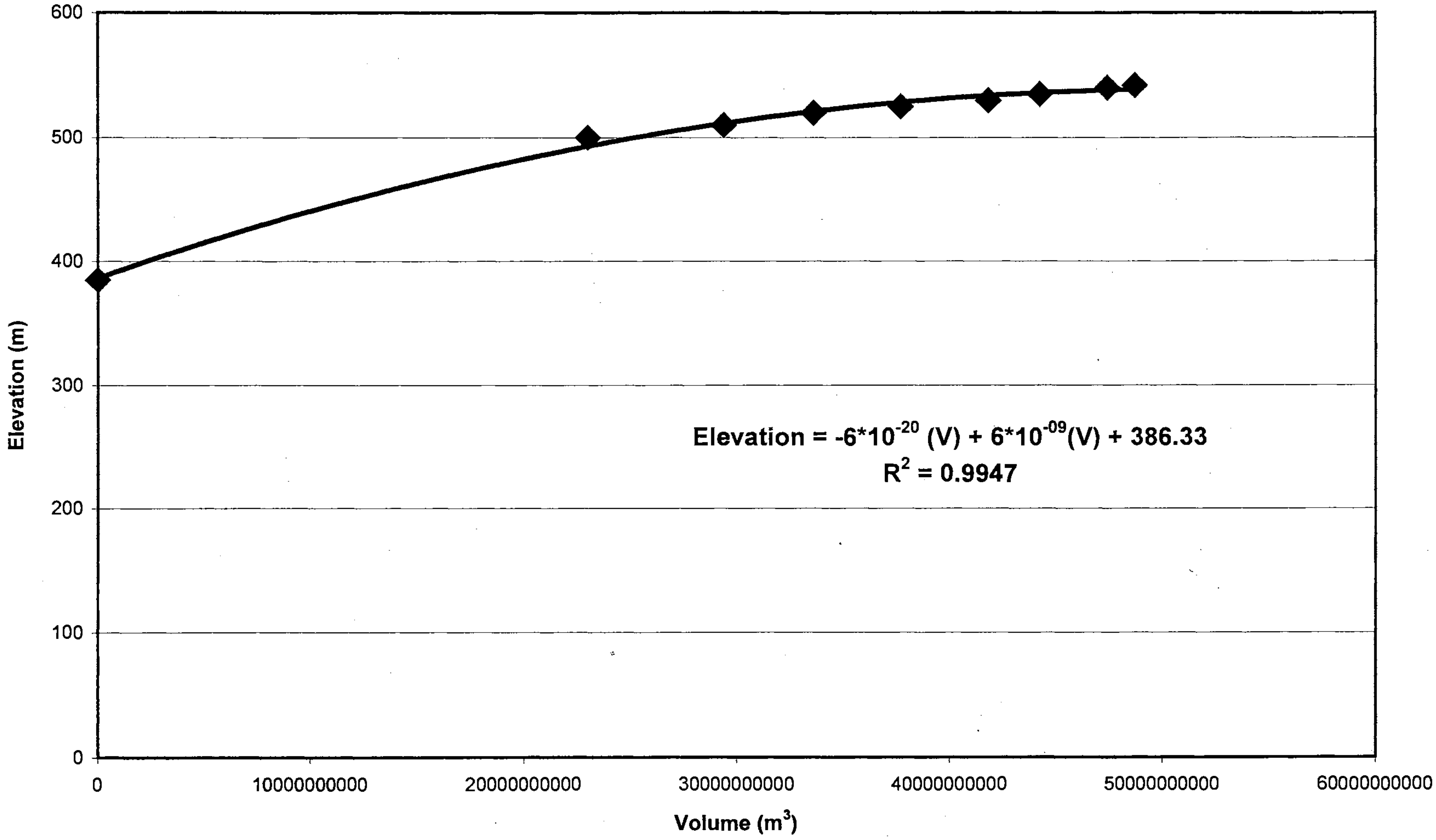
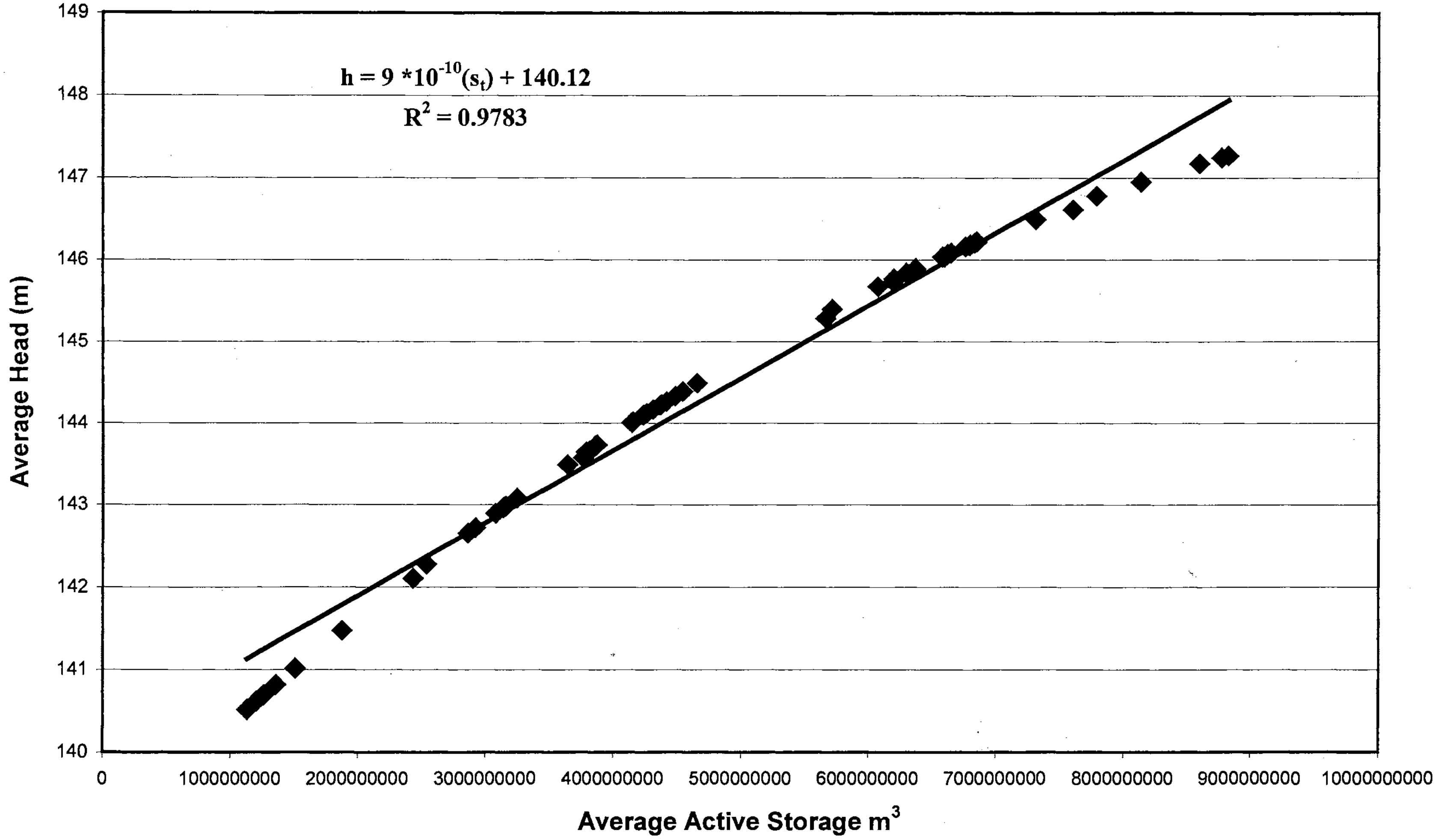


Figure 15. Ataturk Average Head-Active Storage Curve



Hydropower Generation Capacity Constraint (N) :

$$E_{3t} \leq h_t N_{3t} \tag{A32}$$

N_{3t} = Ataturk reservoir capacity = 2400 MW

h_t = number of hours in season t = 24*30 = 720 hours in month

N_{3t} = 2400*1000 = 2 400 000 KW

N_{3t} h_t = 1 728 000 000 KWh

Table LIX

Ataturk Hydropower Production (GWH)

	1996	1997	1998	1999	2000	MEAN
JAN	1138.5	973.1	1016.7	862.2	954	988.9
FEB	1132.8	1178.5	1185.2	733.3	993.2	1044.6
MAR	1046.0	1196.7	1203.5	598.8	713.5	951.7
APR	667.3	692.9	696.8	433	344.1	566.8
MAY	806.3	855.5	860.4	509.9	374.2	681.3
JUN	631.0	635.0	638.6	424	531.9	572.1
JUL	757.1	844.2	849	449.3	571.6	694.2
AUG	840.9	821.1	825.8	583.1	345.9	683.4
SEP	753.3	840.1	844.9	446.8	254.6	627.9
OCT	847.9	667.2	660.4	711.7	323	642.0
NOV	1123.5	843.7	829.8	975.5	423.7	839.2
DEC	1135.0	987.3	984.1	880.7	397.7	877.0
TOTAL	10879.7	10535.4	10595.2	7608.3	6227.4	9169.2

Birecik Reservoir:

Gross Head (H) = Elevation of Water Surface – Elevation of the Tailrace

Elevation of Water Surface as a function of total volume is shown Figure 16.

Elevation = $(2*10^{7}(V_{4t})^{2} + 0.0006*(V_{4t}) + 3.4265$

Elevation of the Tailrace for BIRECIK = 340 m at all discharges

Step 1.

First period gross head calculation:

$V_{41} = V_{4jan00} = 711.76\ hm^{3}$

$H_{41} = H_{4jan00} = (2*10^{7}(V_{41})^{2} + 0.0006*(V_{41}) + 3.4265)*100 - 340 = 35.22$ m.

$H_{42} = (2*10^{07}(V_{42})^{2} + 0.0006*(V_{42}) + 3.4265)*100 - 340$

...

$H_{4T} = 2*10^{7}(V_{4t})^{2} + 0.0006*(V_{4t}) + 3.4265)*100 - 340$

Step 2:

Find Average Head as a Function of the average Active Storage Volume (ST_t);

Active Storage Volume (**ST**$_t$) = Total Storage Volume (**V**$_t$) – Dead Storage Volume (**K**$_d$)

Average Head as a function of Active Storage volume is shown Figure 17.

$$h_{4t} = h_0 + m(s_{4t}) = 32.84 + 3*10^{-08}\, s_{4t} \qquad (A33)$$

Step 3:

Linear Approximation of the release-head product term:

Calculation of Water Release for given Monthly Power Production:

$R_{4\,hp1} = (E_{41}) / (0.00273* (32.84 + 3*10^{-08} *(ST_{41})* (0.855)$

$R_{4\,hp2} = (E_{42}) / (0.00273* (32.84 + 3*10^{-08} *((ST_{41} + ST_{42}) / 2)* (0.855)$

...

...

$R_{4\,hp\,T} = (E_{3T}) / (0.00273* (32.84 + 3*10^{-08} *((ST_{4T-1} + ST_{4T}) / 2)* (0.855)$

Step 4:

Calculation of Average Water release for Power production:

$\mathbf{R^0_{4hpt}} = (\Sigma_{t=1}{}^{T} R_{4\,hp\,t}) / T$

$=(7\ 961\ 321\ 728.7) / 6 = 1\ 326\ 886\ 954.8\ m^3$/per month

Calculation of Average Head:

$\mathbf{h^0} = (\Sigma_{t=1}{}^{T} h_{4t}) / T = 437.82878 / 12 = 36.49$ m

Calculation of Product term:

$\mathbf{R^0_{4hp\,t}\, h^0} = (1\ 326\ 886\ 954.8)*(36.49) = 48\ 412\ 441\ 752.4$

Step 5:

$Z_{4t} = h_{4t}* R_{4hp\,t} \approx (1\ 326\ 886\ 954.8)\ h_{4t} + (36.49)\ R_{4hp\,t} - 48\ 412\ 441\ 752.4$

$h_{4t} = 32.84 + 3*10^{08} *((ST_{4t+1} + ST_{4t}) *0.5)$ and plug into equation above,

$Z_{4t} = 43568333160.6 + 19.9*(ST_t+ST_{t+1}) + 36.49*R_{4hp\,t} - 48\ 410\ 716\ 672.1$

$$h_{4t}* R_{4hp\,t} = 19.9*(ST_{4t}+ST_{4t+1}) + 36.49*R_{4hpt} - 4\ 844\ 108\ 591.9 \qquad (A34)$$

For hydropower production funtion equation A30 plug into A19 ;

$$\mathbf{E_{4t} = 0.00273* (19.9*(ST_{4t}+ST_{4t+1}) + 36.49*R_{4hpt} - 4\ 844\ 108\ 591.9)* 0.855} \qquad \mathbf{(A35)}$$

Hydropower generation capacity constraint ;

$$E_{4t} \leq h_t N_{4t} \qquad (A36)$$

N_{4t} = Birecik reservoir capacity = 672 MW

h_t = number of hours in season t= 24*30 = 720 hours in month

N_{4t} = 672*1000 = 672 000 KW

$N_{4t}\, h_t$ = 483 840 000 KWh/ per month

Figure 16. Birecik Volume-Elevation curve

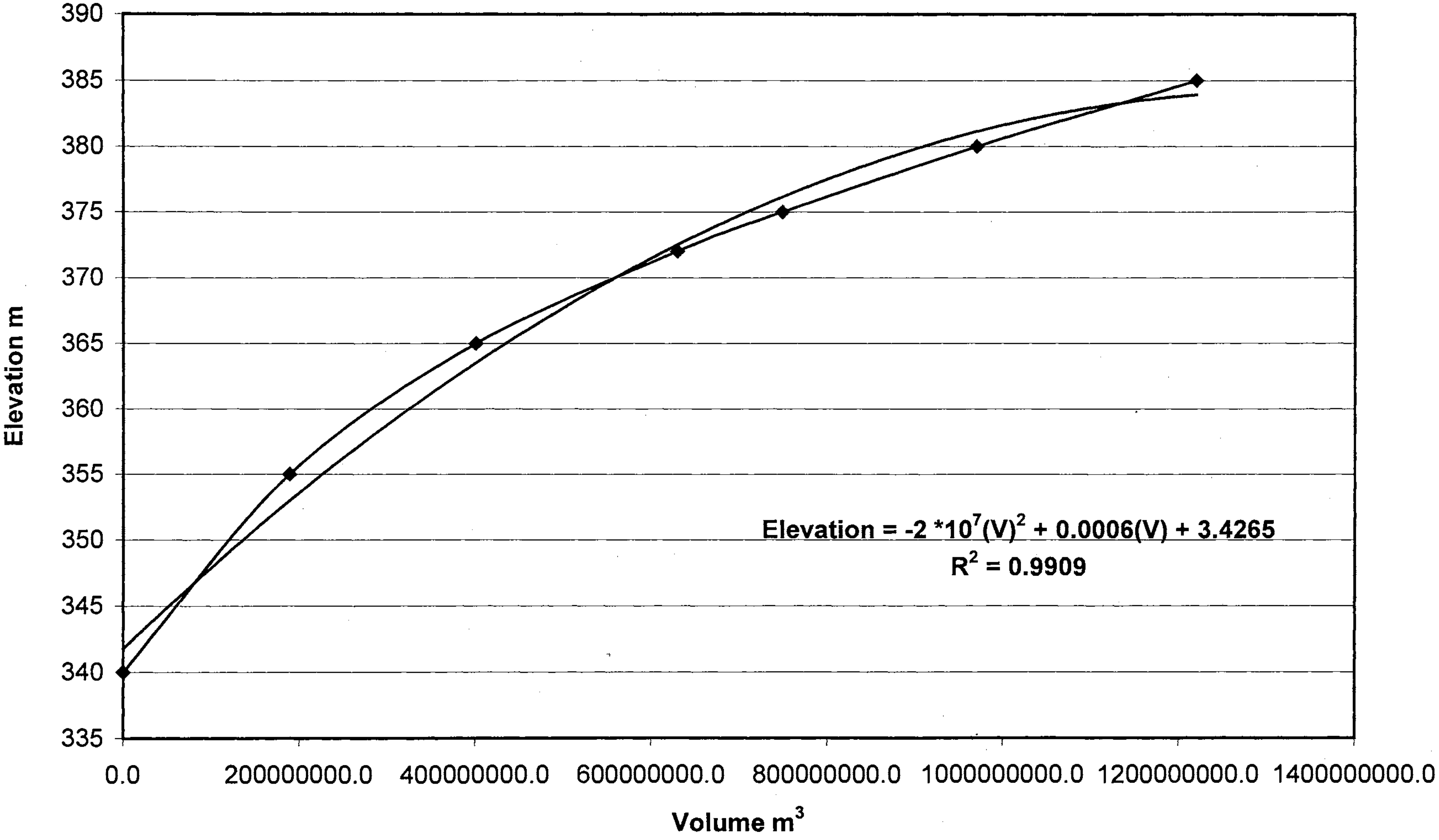
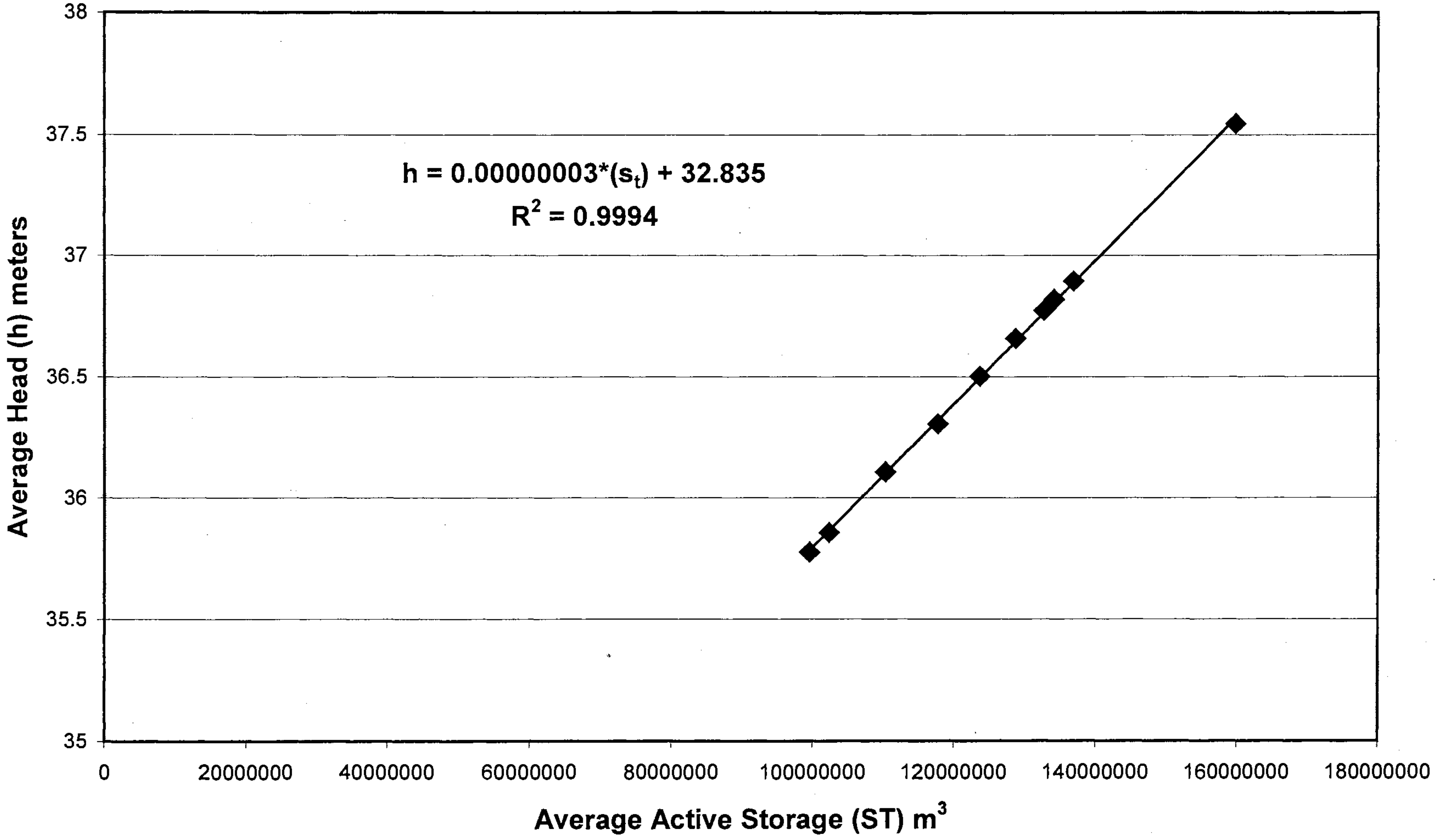


Figure 17. Birecik Average Head-Active Storage Curve



Kargamish Reservoir:

Gross Head (H) = Elevation of Water Surface – Elevation of the Tailrace

Elevation of Water Surface as a function of total volume is shown figure 18.

Elevation = $(-6*10^{-6}(V_{5t})^2 + 0.0019*(V_{5t}) + 3.32602$

Elevation of the Tailrace for KARGAMISH = 325 m at all discharges

Step 1.

First Period Gross Head Calculation:

$V_{51} = V_{5jan00} = 80.90 hm^3$

$H_{51} = H_{5jan00} = (-6*10^{-6}(V_{51})^2 + 0.0019*(V_{51}) + 3.32602)*100 - 325 = 12.46428m.$

$H_{42} = (-6*10^{-6}(V_{52})^2 + 0.0019*(V_{52}) + 3.32602)*100 - 325$

...

$H_{4T} = (-6*10^{-6}(V_{5T})^2 + 0.0019*(V_{5T}) + 3.32602)*100 - 325$

Step 2:

Find Average Head as a Function of the average Active Storage Volume (ST_t);

Active Storage Volume (**ST_t**) = Total Storage Volume (**V_t**) – Dead Storage Volume (**K_d**)

Average Head as a function of Active Storage volume is shown Figure 19.

$$h_{5t} = h_0 + m(s_{5t}) = 11.25 + 9*10^{-08} s_{5t} \qquad (A37)$$

Step 3:

Linear Approximation of the Release-Head Product Term:

Calculation of Water Release for given Monthly Power Production:

$R_{5\,hp1} = (E_{51}) / (0.00273* (11.25 + 9*10^{-08} *(ST_{51})* (0.855)$

$R_{5\,hp2} = (E_{52}) / (0.00273* (11.25 + 9*10^{-08} *((ST_{51} + ST_{52}) / 2)* (0.855)$

...

...

$R_{5\,hp\,T} = (E_{5T}) / (0.00273 * (11.25 + 9*10^{-08} *((ST_{5T-1} + ST_{5T}) / 2) * (0.855)$

Step 4:

Calculation of Average Water Release for Power Production:

$\mathbf{R^0_{5hpt}} = (\Sigma_{t=1}^{T} R_{5\,hp\,t}) / T$

$=(12\ 312\ 340\ 938.8) / 16 = 769\ 521\ 308.7\ m^3$/per month

Calculation of Average Head:

$\mathbf{h^0} = (\Sigma_{t=1}^{T} \hat{h}_{5t}) / T = 153.78 / 12 = 12.82$ m

Calculation of Product term:

$\mathbf{R^0_{5hp\,t}\,h^0} = (769\ 521\ 308.7)*(12.82) = 9\ 861\ 724\ 503.8$

Step 5:

$Z_{5t} = h_{5t} * R_{5hp\,t} \approx (769\ 521\ 308.7)\ h_{5t} + (12.82)\ R_{5hp\,t} - 9\ 861\ 724\ 503.8$

$h_t = 11.25 + 9*10^{-8} *((ST_{5t+1} + ST_{5t}) *0.5)$ and plug into equation above,

$$Z_{5t} \approx (769\ 521\ 308.7)\ (11.25 + (9*10^{-8})*0.5* [(ST_{5t}) +(ST_{5t+1})]) + (12.82)\ R_{5\,hp\,t} - 9\ 861\ 724\ 503.8$$

$$h_{5t} * R_{5hp\,t} = 34.63*(ST_{5t}+ST_{5t+1}) + 12.82*R_{5hpt} - 1\ 203\ 840\ 259.9 \qquad (A38)$$

For hydropower production funtion equation A38 plug into A19 ;

$$E_{5t} = 0.00273 * (34.63*(ST_{5t}+ST_{5t+1}) + 12.82*R_{5hpt} - 1\ 203\ 840\ 259.9)*0.855 \qquad (A39)$$

Hydropower generation capacity constraint :

$$E_{5t} \leq h_t N_{5t} \qquad (A40)$$

N_{5t} = Kargamish reservoir capacity = 180 MW

h_t = number of hours in season t = 24*30 = 720 hours in month

N_{5t} = 180*1000 = 180 000 KW

$N_{5t}\ h_t$ = 129 600 000 KWh/ per month

Figure 18. Kargamish Volume-Elevation curve

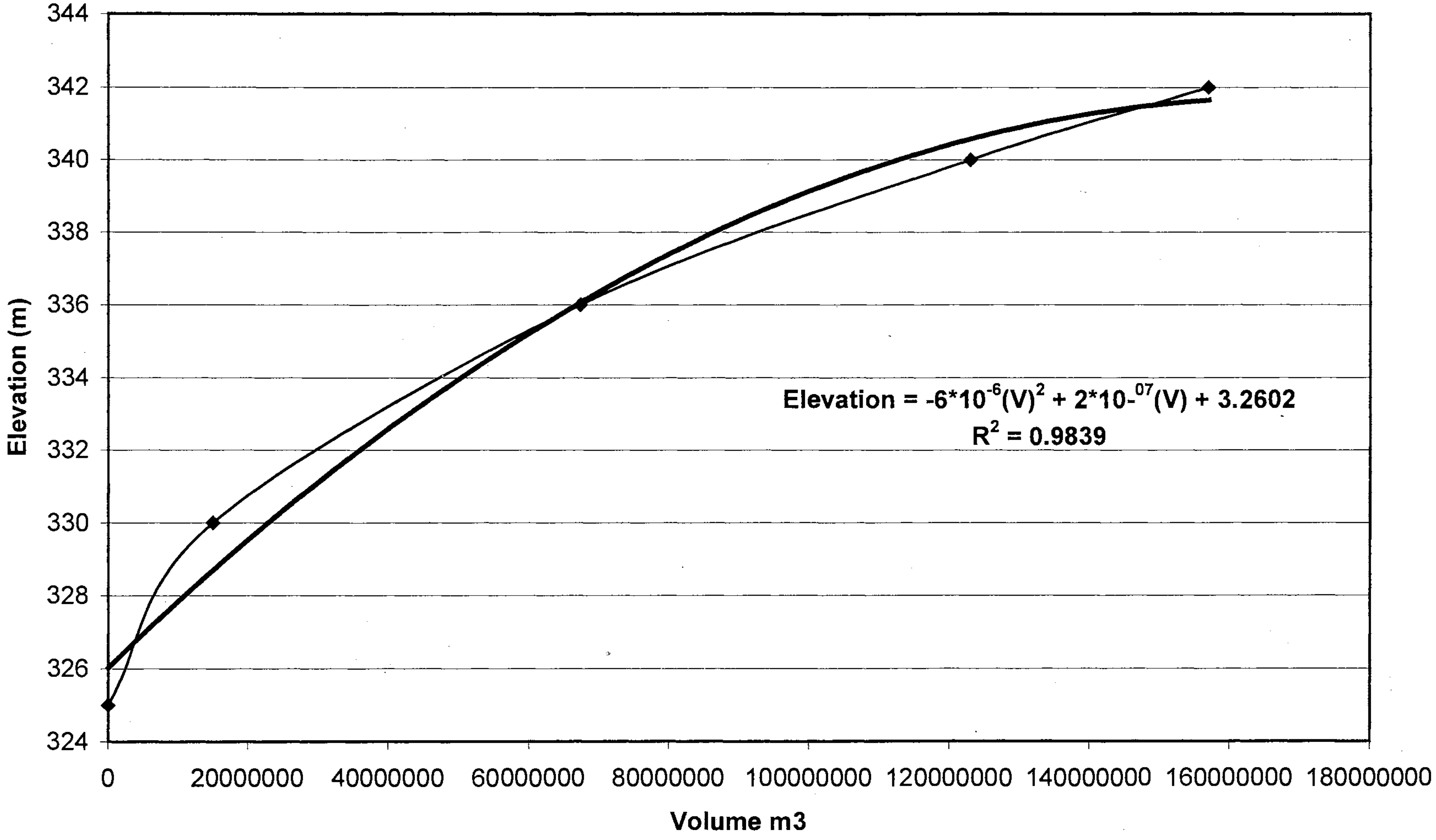
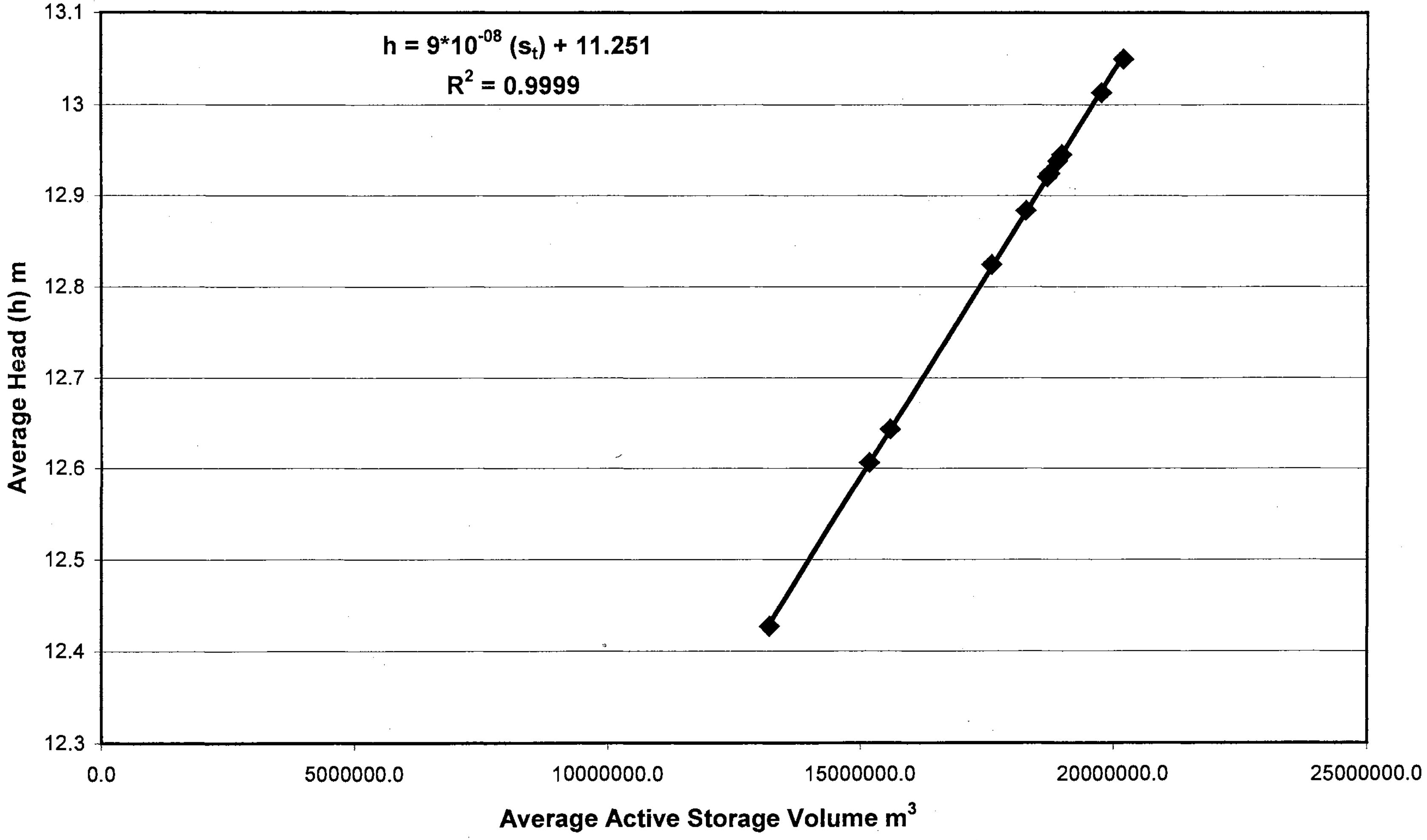


Figure 19. Kargamish Average Head-Active Storage Curve



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VITA

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