WATER RESOURCES ALLOCATION AND CONFLICTS: THE CASE OF THE EUPHRATES AND THE TIGRIS

DISSERTATION

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ABSTRACT

The Mesopotamia region, within the boundaries of Turkey, Iraq, and Syria, is populated by different ethnic, national, and religious groups (Turks, Arabs, Kurds, Sunnis and Shiites), which have long fought over the control of its fertile lands. Since the early 1970's, there has been an increase in tension among these three countries, primarily related to the sharing of the waters of the Euphrates and Tigris rivers. In particular, Turkey's development of Southeastern Anatolia, with water needed for agricultural and energy production projects, has been viewed as a threat to the well-being of Syria and Iraq. This water problem is likely to be exacerbated in the future, when water demand grows in both quantity and quality due to high population growth and urban development. This dissertation develops a water allocation optimization model that represents, in network form, the system made of the two rivers and their various consumption (agriculture, urban centers, hydropower plants) and transshipment nodes, including the possibility of transferring water from the Euphrates to the Tigris. The basic model maximizes the aggregate net benefits of the three countries, including the gross benefits from water uses in agriculture, urban functions, and hydroelectricity, minus the costs of water conveyance. The model is formulated as a linear program, and accounts for both evaporation and return flows from consumptive uses. In view of the uncertainty surrounding the values of several parameters (e.g., agricultural benefit derived from using a gallon of water), the model is used to carry systematic sensitivity analyses to identify the critical parameters. Next, cooperative game theory concepts (core, Shapley value) are used to identify stable water allocations, where all three countries find it beneficial to cooperate. These various analyses are carried out under different scenarios related to future energy prices, agricultural production efficiency, and total water availability. The policy implications of the results are discussed, and areas for further research are outlined.

Dedicated to My Daughters:

Muazzez Sara & Műşerref Rana

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CHAPTER 1

INTRODUCTION

"Water is not necessary to life but rather life itself."
Antoine de Saint-Exupery[1]

Mesopotamia is recognized as the cradle of civilization. Today, as in ancient times, life in Mesopotamia is centered predominantly on the resources of the Euphrates and the Tigris. For much of its history, this region has been the center of conflicts between different ethnic groups, primarily over the control of its fertile and irrigable agricultural lands. In the past, however, water was not seen as an explicit source of these conflicts because of its abundance. Today, because of the increasing scarcity of these resources due to population growth and urban development, their potential as a distinctive source of conflict is becoming more obvious.

Currently, the upper and lower Mesopotamia region - within the boundaries of Turkey, Iraq, and Syria - is occupied by different ethnic, national, and religious groups, such as the Turks, Arabs, Kurds, Sunnis, and Shiites. Since the beginning of the 1970s, there has been an increase in tension among these three countries, primarily because of the sharing of the water resources of the Euphrates and Tigris. The water problem is expected to become exacerbated by future water demands (in terms of both quantity and quality) due to high population growth rates. Indeed, the population in the region will double over a period of at most 20 years, assuming that the current population growth rate remains constant. The fact that water demand in the region is approaching inelastic supply constraints makes it essential to have a clear vision for solving the allocation of

tight water supplies. This vision must take into account the social and political nature of the region, as well as economic, technical, and legal factors.

As the world population expands rapidly, together with the global demand for water, water scarcity problems - and consequently water conflicts - are not going to be limited to the Middle East. Despite regional differences in social, political and economic dynamics, international issues, such as transboundary resources problems, inherently have the potential to generate similar kinds of conflicts elsewhere. It is not easy, for any international dispute, to find a solution or a legal framework that can satisfy every party and that can be perfectly applicable anywhere in the world.

1.1. Conflict versus Cooperation over Water Resources Allocation

Collins (1998), Turan & Kut (1997), Just & Netanyahu (1998), Postel (1996), LeMarquand (1977), Berthelot (1997), and Rogers (1993) try to formalize and categorize water resources conflicts, and underline the necessity and potential of cooperation. They also show that water resources allocation issues are not isolated from economic, political, historical, and international problems.

Reasons for Rivalries and Conflicts: The reasons for conflicts can be listed as follows: 1) Scarcity of water resources, 2) mistrust among parties involved, 3) relative power among parties,[2] 4) absence of a supreme authority to implement international agreements and vague international legal principles and terminology, and 5) unstable undemocratic regimes.[3]

Legal Doctrines and Guidelines for Water Apportionment:[4] Legal frameworks are insufficient to end conflicts, but they are initial steps to pursue. Therefore, a short review will clarify the legal arguments. Following Rogers (1993) and LeMarquand (1977), Just and Netanyahu (1998) summarize the six major principles of water resources allocation. These principles are applied in favor of the national interests as opposed to the interest of other parties. For example, while one party is in favor of absolute sovereignty, the other country can assert the application of prior appropriation rights. These six major principles are: 1) Prior Appropriation,[5] 2) Harmon Doctrine,[6] 3) Riparian Rights,[7] 4) Mutual Development Theory, [8]5) The Linkage Principle,[9], and 7) Helsinki Rule.[10] The Helsinki Rule and the relevant legal framework are further discussed.

Obstacles to Transboundary Water Resources Cooperation:[11] Just & Netanyahu (1998) lists seven barriers reducing the chance of cooperation. Some of those barriers are defined as the determinants of a country position in foreign policy by LeMarquand (1977), such as international law and sovereignty. They are as follows: 1) Asymmetric Information,[12] 2) Scientific Gaps and Technical Uncertainties Among the Parties,[13] 3) Enforcement Limitation,[14] 4) Sovereignty,[15] 5) Conflicts Between National and International Interests,[16] 6) Asymmetric Country Characteristics,[17] and 7) Upstream/Downstream Considerations:[18]

1.2. International Legal Framework

Although there are more than 300 major transboundary river basins, there is no international law governing the allocation of water among riparian countries (Just & Netanyahu, 1998, p.12). In the absence of any general enforcement mechanism or any international agreement, international law offers some guidelines for "equitable and reasonable" allocations. The most notable documents related to transboundary rivers are the Helsinki Rules and Draft Articles on the Law of Non-Navigational Uses of International Water Courses, which are not binding but provide a basis for legal rules (Just & Netanyahu, 1998, p.7). The Helsinki Rules state that:

> "Each basin state is entitled, within its territory, to a reasonable and equitable share in the beneficial uses of the water of an international drainage basin (Article VII). If the various states disagree upon the extent of their right of use, the disagreement shall be settled on the basis of equity, taking into consideration the respective needs of the states, as well as any other circumstances relevant to any particular case (Article IV). Each state may proceed with works or use of a river or watershed that may affect the possibilities of use of the same waters by other states, on condition of preserving for those states the benefit of the advantages to which they are entitled by virtue of Article III, as well as adequate compensation for any losses or damages incurred (Article IV)" (Allan & Mallat, 1995, p.42, 43).

The Draft Articles, which were approved by the International Law Commission in 1994, also give similar guidelines:

> "(Article 5) …(1) Watercourse states shall in their respective territories utilize an international watercourse in an equitable and reasonable manner. In particular, an international watercourse shall be used and developed by watercourse states with a view to attaining optimal utilization thereof and benefits therefrom consistent with adequate protection in the watercourse. (2) Watercourse states shall participate in the use, development and protection of an international watercourse in an equitable and reasonable manner. Such participation includes both the right to utilize the watercourse and the duty to cooperate in protection and development thereof, as provided in the present articles. (Article 7)…Watercourse states shall utilize an international watercourse in such a way as not to cause appreciable harm to other watercourse states" (Allan & Mallat, 1995, p.64, 65).

However, the ***vague definition*** about reasonable and equitable shares deprives these guidelines of any enforcement power over relevant countries. Although Article V to some degree clarifies the stated 'reasonable and equitable share' in Article IV using several additional factors, it is also ambiguous because the relative importance of each factor is not clearly defined (Dinar & Wolf, 1994, p.80). This means that every right-holder defines preferred factors with respect to his own benefits. For example, with regard to the Euphrates, Syria and Iraq base their water requests on their ***historical rights*** and on the increasing power of Turkey to control the water, in contrast to Turkey's efficiency concerns, which are based on the marginal value of water. All factors in Article V are listed below:

> "1. The geography of the basin, including in particular the extent of the drainage area in the territory of each basin State; 2. The hydrology of the basin, including in particular the contribution of water by each basin State; 3. The climate affecting the basin; 4. The past utilization of the waters of the basin, including in particular existing utilization; 5. The economic and social needs of each basin State; 6. The population dependent on the waters of the basin in each basin State; 7. The comparative costs of alternative means of satisfying the economic and social needs of each basin State; 8. The availability of other resources; 9. The avoidance of unnecessary waste in the utilization of waters of the basin; 10. The practicality of compensation to one or more of the co-basin States as a means of

adjusting conflicts among uses; and 11. The degree to which the needs of a basin State may be satisfied, without causing substantial injury to a co-basin State."[19]

1.3. Analysis and Solution Grounds

It is possible to search for agreement under three main grounds, which are not mutually exclusive: (1) legal grounds, (2) efficiency grounds, and (3) political grounds. These grounds are interrelated and should be integrated into a unique framework.

Legal Grounds: Although, current international law (UN International Law Commission, 1994), suggests (1) an equitable and reasonable utilization and participation (Article 5), (2) factors relevant to equitable and reasonable utilization (Article 6), (3) an obligation not to cause significant harm (Article 7), (4) a general obligation to cooperate (Article 8), (5) regular exchanges of data and information (Article 9), and (6) relationships between different kinds of uses,[20] the problems are the following: (1) the international law is not sufficiently clear to convince all parties with an international commission's or court decision; (2) there exists *no supreme authority* to implement this decision; and (3) the only international organization, the United Nations, does not offer a clear image of objectiveness and unbiasedness in solving world problems.

To pursue legal grounds, there is a need to have legally viable and well-developed cases applicable to the Euphrates and Tigris. This takes time and requires long-term discussions. The UN is not capable to be a supreme authority. Even in obvious cases, the UN have had difficulty making decisions for actions. There are still on-going discussions on transboundary waters such as on the Nile, the Euphrates and the Tigris; however, the multiplicity of stakeholders brings different views, which are mostly conflicting with each other. Even if there were a legal solution, the difficulty would be its application.

Efficiency Grounds: There are two critiques aimed by Turkey at the other riparian states, and a three-stage proposal to find out an efficient and equitable distribution of the Euphrates water. Regarding Syria, Turkey claims that (1) existing agricultural technology is far behind the best technology, and (2) the marginal productivity of land irrigated in Turkey is much higher than that in Syria. Based on these arguments, Turkey's proposal consists of (1) inventory studies for water resources, (2) inventory studies for land resources, and (3) evaluation of water and land resources. Technically, Turkey argues for an economically optimal allocation of water rather than a politically defined sharing of water. The Syrian argument is that (1) each riparian will notify the other riparian of its water demands on each river separately, (2) the total potential water supply of each river will be calculated, and (3) if the total demand exceeds the total supply of a given river, the "overdraft" amount will be deducted proportionally from the demand of each riparian state. Syria's criteria are not clear representations of efficiency and objectivity, because they do not clarify how each country demands will be measured. The requested demand is unlikely to represent an efficient allocation, which is Turkey's concern.[21]

Efficiency grounds are the theoretically-mature component of the solution search, because there exist models to allocate scarce water resources in an efficient manner. However, there are problems in the allocation of water resources when considering this framework, because it may be politically infeasible due to its neglecting the power of the stakeholders.

Political Grounds: In the region, *political stability* is in question. In 1990, Iraq entered Kuwait. Both Iraq and Syria have become countries ruled by dictatorship.[22] Turkey also cannot be considered as a completely democratic state. Diplomatic relations with democratic regimes are much easier than with authoritarian regimes. Mostly totalitarian and populism-based dictatorial regimes are comparatively less stable than democratic regimes. To pursue dictatorial regimes, heroic actions and controlling (even suppressing) minorities are important, so Iraq has had two wars (with Iran and Kuwait) in the last twenty years and has gained a bad reputation with regard to the Kurds living in Iraq. These events, which are not unique to Iraq, have eradicated the trust among the nations in the region. *Power* is the other important factor during the bargaining process, especially if there is no supreme and just authority. Turkey, having been a long-term ally of NATO and the USA, and more recently of Israel, is seen as a potential threat by most of the Arab countries.

1.4. Research Methodology and Outline

In view of the complexity of real-world international water allocation problems, there is a need to develop a methodology that defines technically feasible actions for each riparian country, and evaluates these actions economically. The literature presents various models that yield technically feasible and economically optimal water allocations for irrigation and other uses. Generally, these models goals are based on economic efficiency. The primary goal of this research is to develop a *methodological* approach and to apply it to the Euphrates and Tigris River Basin, using the best available data that could be gathered within the resources of this research effort. The modeling effort should therefore be viewed as a *proof-of-concept* effort, illustrating the answers that could be provided to various policy questions. However, there is no claim that the results obtained here could be directly used by the actual policy makers and stakeholders. This research thus provides a methodological framework for further research in both finding better data and incorporating new variables and parameters into the model. This model should lead to an efficient, equitable, and politically feasible utilization of the Euphrates and Tigris water resources. Based on a thorough analysis of the Euphrates and the Tigris River Basin (ETRB) system, the Euphrates and Tigris River Basin Model (ETRBM) is developed and formulated as a linear program. The ETRBM is then used in a series of analyses. First, sensitivity analyses are conducted, to identify the critical model parameters. Next, cooperative game theory concepts are used, together with the ETRBM applied to individual countries or coalition of countries, to define sustainable benefits and water resources allocations. The remainder of this dissertation is organized as follows.

Chapter 2 provides an overview of water resources at the world, regional, and local scales, and describes the regional dynamics in the ETRB.

Chapter 3 reviews the literature relevant to scarce water resources allocation. It first reviews basic concepts related to cooperative Game Theory and Spatial Price Equilibrium modeling, and then describes various applications of these methods to the optimum allocation of water resources in both national (U.S.) and international contexts.

Chapter 4 presents the ETRBM. The basic assumptions used to design the ETRBM, the data used to estimate its parameters, and its mathematical structure are reviewed. A benchmark application of the model is presented and analyzed.

Chapter 5 presents a sensitivity analysis of the ETRBM, focusing on the most critical parameters, both separately and simultaneously. Both graphical and curve-fitting methods are used, and the most important parameters are selected to design 27 alternative scenarios to be used in Chapter 6, namely energy prices, agricultural productivities, and resources availabilities.

Chapter 6 analyzes cooperation strategies among the riparian countries, using the tools of cooperative game theory. In particular, it determines whether a core exists, and what level of international subsidy is necessary to create such a core, when it does not exist naturally. These analyses are based on the results obtained by specific implementations of the ETRBM to individual or coalition of countries.

Chapter 7 concludes this dissertation by summarizing its major results and outlining directions for further research.

NOTES

[1] In eds., Cooley (1984) p. 3.

[2] With changes in the relative powers of the riparian countries, persisting mistrust leads to insecurity among them, especially when one riparian country gains power through water resources development projects (Collins, 1998).

[3] Democratic and totalitarian regimes produce different problems, based on their underlying logic. In democratic systems, internal pressures shape foreign policies; in totalitarian regimes, arbitrary or totalitarian ideology shapes decisions. Democratic regimes must account for social pressures in order to be reelected; on the other hand, totalitarian regimes account for power relations in their society. Because there is no accountability for being reelected, they are relatively less sensitive to public decisions. Turan & Kut (1997) analyze the strong linkages between prevailing national ideologies and attitudes of totalitarian regimes on the intra-regional water disputes in the Middle East.

[4] Summary from Just & Netanyahu (1998, p. 7, 8), LeMarquand (1997, p. 7-23), and Rogers (1993, p. 119).

[5] It is principally based on the idea that the first user in time has the primary right of use of water resources. Naturally, all downstream countries, such as Egypt as opposed to Ethiopia, Iraq and Syria as opposed to Turkey, are inclined to put forward their water claims using this prior appropriation.

[6] Absolute *sovereignty* is the base for this doctrine. The relatively strong countries withdrawing water from the upper river basin utilizes this principle to justify their behavior.

[7] Absolute territorial integrity, which guaranties a certain amount of water for the lower riparian countries without any alteration. The clean up effort in the Danube is an illustration of this principle.

[8] Riparian states mutually develop the river drainage basins as a unique system for the benefits of all. For instance, the Mekong River Committee is established based on the mutual development theory.

[9] Water issues are discussed together with other issues that satisfy all parties. For example, while country A invests in water saving and productivity-increasing agricultural technology in country B, country B can minimize its water demand from the river basin, and even can sell or transfer the water saved.

[10] The 'reasonable and equitable utilization' of the water is the base for this rule. The underlying idea is the limited territorial sovereignty that is determined with respect to beneficial use of water without harming the other riparian countries.

[11] Summary from Just & Netanyahu, (1998, p. 8-12).

[12] Riparian countries consider the information they have as a potential bargaining chip over other riparian countries. This limits the cooperation and results in sub-optimum outcomes, rather than the global optimum. For instance, while Turkey defends its water withdrawal from the Euphrates in terms of the more productive land in Turkey, Syria can state that its agricultural land is as productive as Turkey's. Full information exchange requires mutual benefits; otherwise, there is a possibility of supplying misinformation or less information.

[13] In addition to asymmetric information due to strategic actions, there may be scientific gaps among the stakeholders. To achieve compromise requires that they have common knowledge of existing records and measurements. This scientific knowledge can be used strategically and pragmatically to increase benefits. However, having a scientific background and standards does not necessarily convince the other parties. Conflicting measurements, such as water reserves in the river basins and aquifers may not lead to agreements. For instance, during a reservoir filling period, Turkey claimed that there was an average 500 m^3/sec. water release at the Turkish border into Syria; however, Syria asserted that it was less than that amount.

[14] One of the major weaknesses of international law on water disputes is the lack of enforcement power. Although bilateral or multilateral agreements may exist among riparian countries, there is no authority to control and enforce the agreements.

[15] Sovereignty is the legal basis for the existence of a country; therefore, countries are not inclined to accept other party interventions unless it provides an absolute benefit for themselves. A third party intervention may be considered as an insult to the freedom of a country. For instance, Turkey has been building the Southeast Anatolia Development Project in spite of the reactions of Syria and Iraq.

[16] Even though the international interest of a country requires it to reach an agreement, its internal priorities may prevent such an agreement. For instance, if a country reaches an international agreement limiting the utilization of water resources, this is likely to create tensions in some water-related sectors, such as agriculture. Since countries face both internal and external pressures, they need to address national

dissatisfaction before signing an international treaty. Given the fact that most of the international water conflicts are among developing countries, where the discontent of the population plays an important role in politics, national economic priorities may create obstacles to an agreement at water negotiations.

[17] The stakeholder countries may have different characteristics that complicate the bargaining among the countries. To illustrate, Bangladesh, with its limited agricultural land on the Ganges Delta, needs to feed one of the most concentrated population in the world; therefore, there is not much room to negotiate the reallocation of the Ganges' water among Nepal, India, and Bangladesh.

[18] Being at the top of the stream is a significant advantage in water-related negotiations. Without the participation of upstream countries, an agreement does not have any practical meaning. However, geographic advantages and disadvantages are not the only factors, as there is a need to consider the relative powers of the countries. For instance, Turkey has both of these advantages - geographical upstream position and power - at the negotiation table. On the other hand, Ethiopia has the upstream position on the Nile, but its economic and military power is far behind Egypt.

[19] http://www.ce.utexas.edu/stu/akmanss/gap/paper.html

[20] For the details, see the source: Unite Nations International Law Commission (UN, 1994), "Draft articles on the law of the non-navigational uses of international watercourses." Natural Resource Forum, 21 (1997): 119-126.

[21] Turkish Ministry of Foreign Affairs 1995; and J. F. Kolars, "Problems of International River Management," in eds. A. K. Biswas, International Waters of the Middle East: From Euphrates-Tigris to Nile, (Bombay: Oxford University Press, 1994) 53.

[22] Both Syria and Iraq has been ruled respectively by Hafiz Esad and Saddam Huseyin, who are the members of extreme nationalist Bath Parties, more than 15 years.

CHAPTER 2

WATER RESOURCES: AN OVERVIEW

Water is the most important component of life in the world. It is used for supplying life, analogous to blood in the human body, and for solving pollution problems through dilution and cleaning, while satisfying quality standards and quantity requirements. It is also a transportation mode. The following sections provide an overview of water supplies and demands, first at a global level, next at the regional level, then within the Middle East, and finally in the Euphrates and Tigris basin.

2.1. Water Resources at the Global Level

2.1.1. Supply

The amount of water circulating in the world, while constant in the aggregate, displays seasonal, annual, and spatial variations. The water cycle starts with the evaporation of water from oceans, continents, and islands, and continues with the unequally distributed precipitations around the world, with some parts of the earth getting a large portion of the rainfall and others being deprived of it. Therefore, in some regions, water scarcity is seen as a major constraint on development. Table 2.1 shows that the total evaporation on the earth is 95,000 mi^3/year. However, only 25 % of this water returns to continents and islands in the form of precipitation, whereas the remainder returns directly to oceans. The surface runoff from continents and islands is only 9.47 % of all precipitations.

Table 2.1: Major Water Cycle Flows[1]

	Average rate (inch/yr.)	Total (mi^3/yr.)	% in total
Evaporation from ocean	36	80,000	84.21
Evaporation from continents and islands	19	15,000	15.79
Precipitation on oceans	32	71,000	74.74
Precipitation on continents and islands	30	24,000	25.26
Runoff from continents and islands	11	9,000	9.47

Source: Wüst (1936) p. 347-359.

Although there is a significant amount of water on the continents, not all rainfall can be used by humans, due to the uneven distribution of rainfalls and their mismatch with human settlements and population dynamics, leading to severe water constraints in some parts of the world. Table 2.2 shows that the water on land represents only 2.87 % of the total water supply on the earth. The shares of surface and subsurface waters are respectively 2.26 % and 0.61 %. However, a large portion of surface waters is in the form of ice caps and glaciers on the poles (2.24 %). After disregarding resources that are not appropriate for direct use, such as saline lakes and inland seas, only a small portion of the world's water can be counted as water supply (only .0091 % constitute rivers and lakes). The above shares are subject to change because of the construction of water reserves systems (dams) and global climatic changes. Climatic changes alter precipitations both spatially and temporally. Global warming may cause more evaporation and/or reduction in the amount of water in the North and South poles and high mountainous areas.

There are also subsurface water resources on the continents that are less renewable than surface water resources and more prone to deterioration due to excessive use (decreasing water tables) and environmental pollution coming from agriculture, industrial, and domestic uses. The share of ground water resources is around 0.61 % of total world water. This share is significantly larger than the one of mostly usable freshwater lake and river waters (0.0091 %).

Table 2.2: Water on the Earth[2]

Location	Surface area (1000 square mile)	Volume of water (1000 cubic miles)	Percentage of Total water
World (total area)	197,000		
Land area	57,000		
Surface water on the continents			
Polar icecaps and glaciers	6,900	7,300.00	2.2400
Fresh-water lakes	330	30.00	0.0090
Saline lakes and inland seas	270	25.00	0.0080
Average in stream channels	…	0.28	0.0001
Total surface water	7,500	7,350.00	2.2600
Subsurface water on the continents			
Root zone of the soil	50,000	6.00	0.0018
Groundwater above depth of 2640 feet	…	1,000.00	0.3060
Groundwater, depth of 2,640 to 13,200 feet	…	1,000.00	0.3060
Total subsurface water	50,000	2,000.00	0.6100
World ocean	139,500	317,000.00	97.1300
Total water on the land		9,350.00	2.8700
Atmospheric moisture		3.10	0.0010
Total world supply of water		326,000.00	100.0000

Source: Nace (1960) p.45.

2.1.2 Demand

Increasing population leads to increasing water use. Table 2.3 shows that there has been a parallel increase in population growth and water withdrawal. However, because of limited renewable water resources, per capita water is expected to decline in the future. There are parallel trends in expanding economic activities and technical capability in controlling water resources by dams and large transfer facilities. The water withdrawn in 1990 (3,000 km^3) represents only 7.3 % of the annual renewable water resources (41,000 km^3), due to the uneven distribution of precipitation and surface runoff, and their mismatch with population concentrations around the world.

Table 2.3: Global Trends in Population and Water Withdrawal[3]

	1900	Change %	1950	Change %	1990
Population (billion)	1.6	56.3	2.5	112.0	5.3
Water withdrawal per capita (m^3/year)	360	50.0	540	5.6	570
Water withdrawal total (km^3/year)	600	133.3	1400	114.3	3000

Source: Historic population from Biraben (1979): 1990 figure from UN (1992). Historic withdrawal estimates based on Shiklomanov (1993): 1990 figure from WRI (1994).

2.2. Water Resources at the Regional Level

2.2.1. Supply

Developed and underdeveloped countries are grouped along the classical North/South geographic division, where the North includes mostly developed countries in Europe and North America, and the South the relatively less developed Latin American, African, and Asian countries. Without any doubt, the climate at certain latitudes (between North and South 30^{o} latitudes) causes water shortages, particularly in North Africa and the Middle East.

Table 2.4 shows that the Middle East and Eastern Europe are the most disadvantaged regions in terms of per capita water availability (1,500 m^{3})). In terms of per land area water availability, again the Middle East region is the most deprived, with 340 m^{3}/ha. The other concern about uneven distribution is the accessibility to the water. For instance, the Amazon River carries 15 % of the earth's runoff, but is accessible to only 0.4 % of the world population (Postel, 1996, p.10). Monsoon rains received by tropical climate regions, such as Latin America and South East Asia, cannot be counted as stable water resources.

Table 2.4: Annual Water Resources by Region (1994)[4]

Region	Total (1000 km^{3})	Per person (1000 m^{3} per capita)	Per land area (1000m^{3}/ha)
Africa	3.8	6.0	1.3
China	3.5	2.9	3.1
Eastern Europe	0.15	1.5	1.7
FSU	4.4	15.2	2.0
Latin America	10.6	24.0	5.3
Middle East	0.22	1.5	0.34
North America	5.4	19.5	2.9
OECD Pacific	1.4	9.4	1.6
South and East Asia	9.3	6.0	10.9
Western Europe	2.1	4.7	4.7
World	40.9	7.8	3.1

2.2.2. Demand

Demand for water displays significant differences among regions. As discussed earlier, while the uneven distribution of water at the surface of the earth is the major reason for water shortages, high population growth rates are the major other factor aggravating the water problem. For instance, Middle East countries are among the fastest growing countries, with an annual population growth rate of around 3 %. Table 2.5 reveals that agricultural water use accounts for most of the consumption, especially in less developed areas. However, the industrial water share in developed regions (North America and Western Europe) points to the expected future water demands in developing countries, which are trying to achieve both food security and industrialization.

Table 2.5: Annual Withdrawals by Region[5]

Region	Total (km^3)	Per person (m^3 per capita)	Household and services (%)	Industry (%)	Agriculture (%)
Africa	150	230	8	7	84
China	500	410	7	7	86
Eastern Europe	60	600	9	60	32
FSU	360	1240	7	27	65
Latin America	180	400	12	11	76
Middle East	130	880	5	6	89
North America	510	1850	13	47	39
OECD Pacific	110	750	25	28	47
South and East Asia	680	440	4	6	90
Western Europe	300	660	14	49	37
World	2980	570	9	22	68

Table 2.6 shows projected water sufficiency levels in different regions of the world, using the "water barrier" measure. The water barrier concept is the most widely used method to determine water sufficiency. It considers a single measure of a country's water situation and identifies the areas approaching the limits of water resources availability. The water barrier approach uses ratios of annual renewable resources to population. Based on population projections, the method identifies the areas which might be hitting available water limits. Table 2.7 defines four major level of scarcity that may

be used to classify the index of water availability in Table 2.6: 1) absolute scarcity, which represents absolute shortage defined as a per capita share less than 500 m^3, 2) scarcity, which is defined as the interval between 500 – 1000 m^3/per capita, 3) stress, which indicates a potential prospective threat of water scarcity, defined between 1000 – 1700 m^3/per capita, and 4) no stress, which indicates abundance of water and no risk. The first two intervals point to severe water shortage as threat for basic human needs, health and food security. As can be seen from Table 2.6, the Middle East is the most disadvantaged region.

Table 2.6: Water Barrier Index in the Conventional Development Scenario (CDS)[6] (m^3 water resources per capita)[7]

Region	1990	2025	2050
Africa	6000	2500	1700
China	2900	2000	1900
Eastern Europe	1500	1300	1200
FSU	15200	13200	12600
Latin America	23900	15200	13100
Middle East	*1500*	*600*	*400*
North America	19400	16300	16700
OECD Pacific	9400	8400	8700
South and East Asia	5900	3500	2900
Western Europe	4700	4400	4500
World	7700	4900	4100

Table 2.7: Water Barrier Conditions[8]

Index (m^3 per capita)	Condition
> 1700	No stress
1000 – 1700	Stress
500 – 1000	Scarcity
< 500	Absolute scarcity

Source: Falkenmark and Widstrand (1992)

The "use-to-resource ratio" is also used as a water availability measurement. Using the ratio of water consumption to renewable water resources, the method predicts that countries withdrawing a large portion of their renewable resources are likely to be subject to water scarcity in the future. This approach suggests that, as the use-to-resource ratio increases, the possibility of experiencing water stress and/or scarcity also rises. A ratio of 25 % is indicative of water stress. Looking at Table 2.8, it is obvious that the Middle East is again the most disadvantaged region, followed by Eastern Europe and China.[9]

Table 2.8: Use-to-Resource Ratio in the CDS (%)[10]

Region	1990	2025	2050
Africa	4	5	7
China	14	19	24
Eastern Europe	41	60	66
FSU	8	10	11
Latin America	2	2	3
Middle East	*58*	*75*	*94*
North America	9	11	11
OECD Pacific	8	9	9
South and East Asia	7	9	12
Western Europe	14	16	16
World	7	9	11

2.3. Water Resources in the Middle East

While narrowed down to the Middle East, the following analysis is not limited to the "Euphrates and Tigris Basin". Rather, it aims at providing broader picture, that incorporates other transboundary river conflicts in the region.

2.3.1. Water Supply and Demand

Table 2.9 shows the relative water capacity of the countries in the subject area (Turkey, Syria, and Iraq), and of the surrounding countries (Israel, Jordan, Saudi Arabia, Iran, Kuwait, and Lebanon). The data in Table 2.9 point to the relative superiority of Turkey, Iran, and Iraq, with water resources shares equal to 87.50, 53.68, and 15.18 %, respectively.[11]

One important concept to measure the water availability/sustainability of a country is the "*import dependence*", defined as the percentages of total renewable water resources originating outside a nation's border.[12] It is a measure of the reliability of water resources, indicating the vulnerability of countries to outside water resources. Transboundary water resources, especially lakes, rivers, and groundwater resources, are impacted by another country water consumption programs and projects. The other concept is the 'use-to-resource index,' which measures the periodical water requirements to available renewable water resources. Tables 2.10 and 2.11 provide a clear picture of the fragile water availability conditions in the Middle East, where significant portions of both Syria's and Iraq's water resources come from outside transboundary rivers, 78.6 and 66 %, respectively.

Table 2.12 presents the current water resource availability in the Middle East, using the "water barrier", " use-to resource ratio", and " import dependence" indicators of water availability.

Table 2.9: Current Water Resources in the Middle East Countries[13]

Region/Country	Resources		
	Internal (km^3)	% of the regional water share	River inflows (km^3)
Middle East	224	100.00	
Afghanistan	50	22.32	Na
Bahrain	0	0.00	Na
Cyprus	0.9	0.40	0
Iran	118	52.68	Na
Iraq	34	15.18	66
Israel	1.7	0.76	0.45
Jordan	0.7	0.31	0.4
Kuwait	0	0.00	0
Lebanon	4.8	2.14	0
Oman	2	0.89	0
Qatar	0.02	0.01	0
Saudi Arabia	2.2	0.98	0
Syria	7.6	3.39	27.9
United Arab E.	0.3	0.13	0
Yemen	2.5	1.12	0
Turkey[b]	196	87.50[c]	7

[a] Resources include river inflows.
[b] Turkey is classified in Western Europe, and the Middle East Totals do not include Turkey.
[c] Turkey's water resources are not included in the Middle East Region water resources total. Turkey's percent with respect to Regional total is computed in order to have a relative figure for Turkey.

Table 2.10: Major Water Import Dependent Countries in the World[14]

Country	Import component of renewable Water resources (%)
Egypt	97
Hungary	95
Mauritania	95
Botswana	94
Bulgaria	91
Netherlands	89
Gambia	86
Cambodia	82
Romania	82
Luxembourg	80
Syria	79
Congo	77
Sudan	77
Paraguay	70
Czechoslovakia (former)	69
Niger	68
Iraq	66
Albania	53
Uruguay	52

Source: Information is drawn from Table 2.[15] List is partial since imported water is not available for more than 50 countries.

Table 2.11: Current Water Constraints According to the Use-to-Resources Index[16]

Country	Index (%)[a]	Condition
Kuwait	Very high	Scarcity
Libya	374	↑
United Arab E.	300	
Saudi Arabia	164	
Yemen	136	
Egypt	97	
Israel	86	
Belgium	72	
Tunisia	53	
Afghanistan	52	
Korea Rep	44	
Iraq	43	
Spain	41	
Jordan	41	
Madagascar	41	
Iran	39	
Morocco	36	
Pakistan	33	
Singapore	32	
Germany	31	
Italy	30	
South Africa	29	
Poland	26	Stress

[a] The values exceeding 100 mean there is insufficient amount of country water resources to cover their annual needs with renewable water resources, implying the utilization of nonrenewable resources and imports. 100 means that there is exactly the amount of renewable water resources corresponding to the country demand.
Source: Information is drawn from Table 2.[17]

Table 2.12: Current Water Resources in the Middle East Countries[18]

	Resources		Withdrawals		Indicators		
Region/Country	Internal (km^3)	River inflows (km^3)	Total (km^3)	Per person (m^3/per capita)	Resources per person (m^3 per capita)[a]	Use/ resources (%)	Imports/ resources (%)
Middle East	224	[c]	130	1530	885	58	
Afghanistan	50	Na	26.1	3020	1580	52	na
Bahrain	0	Na	Na	0	na	na	na
Cyprus	0.9	0	Na	1290	na	na	0
Iran	118	Na	45.4	2150	831	39	na
Iraq	34	66	42.8	5290	2260	43	66
Israel	1.7	0.45	1.85	470	402	86	21
Jordan	0.7	0.4	0.45	270	112	41	36
Kuwait	0	0	0.5	0	245	na	0
Lebanon	4.8	0	0.75	1780	278	16	0
Oman	2	0	0.48	1330	320	24	0
Qatar	0.02	0	Na	50	na	na	00
Saudi Arabia	2.2	0	3.6	160	255	164	0
Syria	7.6	27.9	3.36	2830	267	9	79
United Arab E.	0.3	0	0.9	190	566	300	0
Yemen	2.5	0	3.4	210	291	136	0
Turkey[b]	196	7	23.8	425	3630	12	3

[a] Resources include river inflows.
[b] Turkey is included in Western Europe, and the Middle East Totals do not include Turkey.
[c] Information is not available.

2.3.2. Transboundary Surface Water Conflicts

With one of the most arid climate on the earth, water has always retained its importance in the Middle East. However, current water consumption levels are close to the water availability limit, due to rapid population growth in the region. As a consequence, conflicts over getting a larger share of water increase, most obviously in the case of transboundary surface waters. There is a tension over every international river in the region (Nile, Jordan, Euphrates and Tigris).

Moreover, ethnic (Arabs, Persians, Kurds, Turks, Jews, etc.), religious (Judaism, Christianity, Sunni and Shiite Islam), and political diversity in the region makes the problems much more complicated. There are also other concerns unique to the region that make the water allocation problems hard to solve:1) regional underdevelopment, with all riparian countries desperately needing agricultural and industrial development projects; 2) ethnic tensions that date backs to the collapse of the Ottoman Empire, which led to an authority vacuum (i.e., the nonexistence of unbiased, higher level, and strong authority) in the region; 3) desire for regional supremacy based on mostly nationalistic goals;[19] 4) since the beginning of this century, nationalism has been the rising value in the region; however, a strong religious affiliation is still one of the bases for regional conflicts; 5) arbitrarily drawn country borders (by Western countries after World War I), in which there are no homogenous ethnic and religious groups, are the bases for insecurity for both minorities and majorities in most of the Middle East countries.

Although the Middle East has been the place of petroleum-oriented conflicts since the beginning of the 20th century, the end of the century is witnessing another natural resource that can be reason for a regional conflict, *water*. Former General Secretary of the UN, Boutros Boutros Ghali, points out that

> "[t]he next war in our region will be over water, not politics" (in ed. Starr, 1995, p.47).

The major rivers that are subject to regional conflicts are: 1) The Nile River (riparian countries: Egypt, Sudan, and Ethiopia); 2) The Jordan and Litany Rivers (riparian countries: Israel, Jordan, Syria, and Lebanon); 3) The Euphrates and Tigris Rivers (riparian countries: Turkey, Syria, Iraq, and Iran). In the next section, the Euphrates and Tigris Rivers are the focus of analysis.

2.4. The Euphrates and Tigris Rivers

On October 5, 1998, Turkey and Syria came to the brink of a new war in the Middle East due to a water conflict. The reason of the conflict was, in Turkey's allegation, the open support of Syria for the Kurdish Worker Party, (PKK), which is an active military branch of separatist Kurds with terrorist activities in Turkey. On the Syrian side, the real problem was the increasing water holding and diverting capacity of Turkey in the southeastern part of Anatolia. However, Syria holds another standard on the allocation of the water of the Orontes River, which is considerably smaller than the Euphrates. Regarding the Orontes, the positions of Turkey and Syria are reversed: the current water entering Turkish territory represents only 10% of the river flow, which will be entirely (98% of Orontes water) diverted by Syria after two new projects are completed.[20] The other party associated with the water problem in the region is Iraq, which has been severely disabled by the actions taken before and after the Gulf War by the nationalist Bath Party. Therefore, since 1990, the Iraqi role in the water disputes has been significantly reduced. Nonetheless, in the long run, Iraq is also a part of the dispute over the allocation of the water of the Euphrates and Tigris. Finally, environmental issues (salinity, pesticides, and insecticides) are also reasons for concern, because the environmental impacts of the Southeast Anatolia Development Project[21] (GAP) are not yet clear.

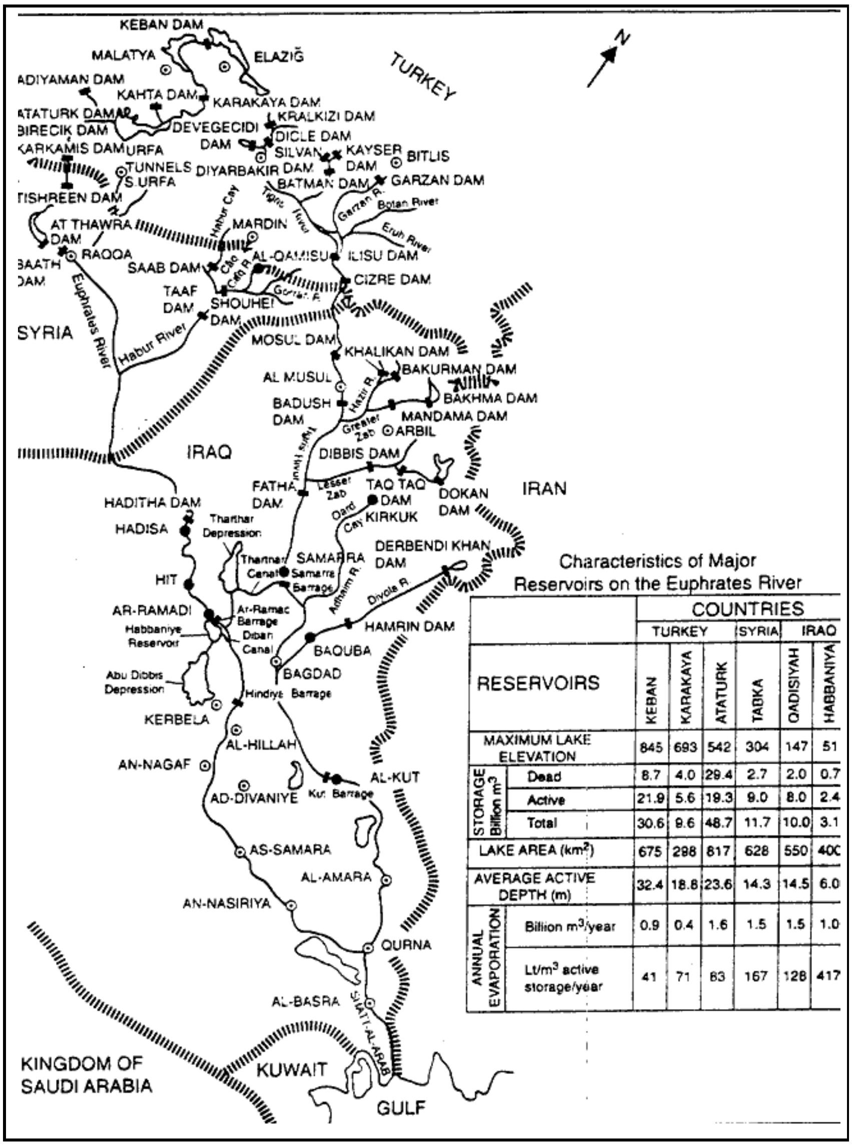
2.4.1. History[22]

Syria, Iraq, and Turkey are the countries founded on the ruins of the Ottoman Empire after the First World War. During the initial 4 - 5 decades of these countries, the emphasis was on the foundation of the state and its necessary institutions. In defining the international boundaries, there was no agreement about the two major rivers of Mesopotamia. In 1926, Turkey and Syria signed a treaty of Friendship and Good Neighborliness. In a similar treaty signed between Turkey and Iraq (1946), the only issue was flood control by Turkey and Iraq (Table 2.13). This treaty states that the most appropriate flood control work should technically be done in Turkey, and the Iraqi government pledged to contribute financial sources. Turkey, by this treaty, guaranteed 13 km^3 of water for the irrigation of approximately 1 million hectares of agricultural land in Iraq (Waterbury, 1994, p. 56).

After the 1960s, both Syria and Turkey started developing their own water resource potential for irrigation and energy purposes. After the oil shock of 1974, Turkey put more effort on the utilization of alternative energy sources, particularly hydroelectricity. Since then, Turkey has been building a series of dams and irrigation projects on the Euphrates and Tigris (named as the Southeast Anatolia Development Project), that give Turkey the power of controlling both. Consequently, the increasing Turkish control on the water, together with the increasing water demand by all three riparian countries, has become a serious concern for both Iraq and Syria. Of the two rivers, the Euphrates is the one from which the water will be diverted most because of the nature of the projects. However, flowing through Syria before entering Iraq, the Euphrates is the main source of water for Syria. On the other hand, the Tigris, which will be less affected by the projects, enters directly into Iraq, where it flows together with the Euphrates through Mesopotamia down to the Persian Gulf (Figure 2.1).

Increasing energy and irrigation needs have led Turkey and Syria to build dams over the Euphrates. In 1975, Iraq nearly came to the brink of a water-based war with Syria due to the reduced flow from the Syrian border. War was prevented by the mediation of both Saudi Arabia and the Soviet Union (Kolars, 1994, p. 49). In 1975-1976, Lake Assad, located behind the Tabqa (ath-Thawrah) Dam built by Syria, was being filled, coinciding with the filling of the Keban Dam reservoir (1974-1975), the first large-scale electric generating dam built by Turkey. The fact that the region had one of the driest years in decades worsened the situation. Turkey had informed all parties about the reduction of water from free flow to 500 m^3/sec in order to fill the reservoir of Keban Dam.

In 1987, Prime Minister Turgut Ozal of Turkey and Prime Minister Abdul Raouf el-Kassem of Syria signed an agreement over not only water but also trade, banking petroleum, gas, and power issues. Turkey was supposed to leave an average 500 m^3/sec from the Turkish Border. However, the political disagreements that developed during the Karakaya Dam filling period, and, especially, in 1990 during 27 days of interruption of the Euphrates flow, intensified during the reservoir filling period of the Atatürk Dam, which is the fifth largest in its scale category in the world (Waterbury, 1994, p. 56). During the filling of the reservoir of the Ataturk Dam with the unilaterally defined average 500 m^3/sec (nearly 50% of all the Euphrates's annual flow) water release by



Characteristics of Major Reservoirs on the Euphrates River

		COUNTRIES					
		TURKEY			SYRIA	IRAQ	
RESERVOIRS		KEBAN	KARAKAYA	ATATURK	TABKA	QADISIYAH	HABBANIYA
MAXIMUM LAKE ELEVATION		845	693	542	304	147	51
STORAGE Billion m³	Dead	8.7	4.0	29.4	2.7	2.0	0.7
	Active	21.9	5.6	19.3	9.0	8.0	2.4
	Total	30.6	9.6	48.7	11.7	10.0	3.1
LAKE AREA (km^2)		675	298	817	628	550	400
AVERAGE ACTIVE DEPTH (m)		32.4	18.8	23.6	14.3	14.5	6.0
ANNUAL EVAPORATION	Billion m^3/year	0.9	0.4	1.6	1.5	1.5	1.0
	Lt/m^3 active storage/year	41	71	83	167	128	417

Source: Altinbilek (1997) p. 313.

Figure 2.1: The Euphrates and the Tigris Basin and Dams

Turkey to downstream countries, Syria and Iraq agreed on the allocation of the incoming water. Syria agreed to release 290 m^3/sec water to Iraq, using 48% of the incoming water from Turkey (Waterbury, 1994, p. 56; Scheumann, 1998, p.124). As the Euphrates

downstream flow diminished, Iraq and Syria attended tripartite ministerial meetings held in Ankara regarding the crisis. At those meetings, in contrast to the Turkish claim that the subject matter was technical, the Iraqis and the Syrians insisted that it was political. Without reaching any constructive agreement, the ministers left the talk. Shortly thereafter, the invasion of Kuwait took place and the situation was put on hold (Kolars, 1994, p. 49).

Table 2.13: Agreements and Conflicts among Turkey, Syria, and Iraq

Year	Agreements	Conflicts	Parties
1946	Flood control structures		Turkey and Iraq
1956		Syrian dam on the Orontes	Turkey versus Syria
1964	Minimum release of 350 m^3/sec. (filling period Keban Dam)		Turkey and Iraq
1974/75 1975/76		Filling period for Keban Dam Filling period for Tabqa Dam	Iraq versus Syria mediated by Soviet Union and Arab countries
1983		Water level dropped in Lake Assad	Syria versus Turkey
1986	Minimum release of 500 m^3/sec. (filling period Karakaya Dam)		Turkey and Iraq
1987	Minimum release of 500 m^3/sec. at the Turkish-Syrian border (filling period of Atatürk Dam and until trilateral - Turkey, Syria, and Iraq - agreement)		Turkey and Syria
1990	Proportional shares for Syria (42%) and Iraq (58%) from Turkish release	Iraq demands 700m^3/sec water release from Turkish border instead of 500 m^3/sec.	Syria and Iraq Syria/Iraq versus Turkey
1991		Date and duration time of filing period of Atatürk Dam; minimum release not ensured	Syria/Iraq versus Turkey
1995/96		Start to construct a new dam on the Euphrates: Birecik Dam	Syria/Iraq, Arab League versus Turkey

Source: Scheumann, 1998, p.125.

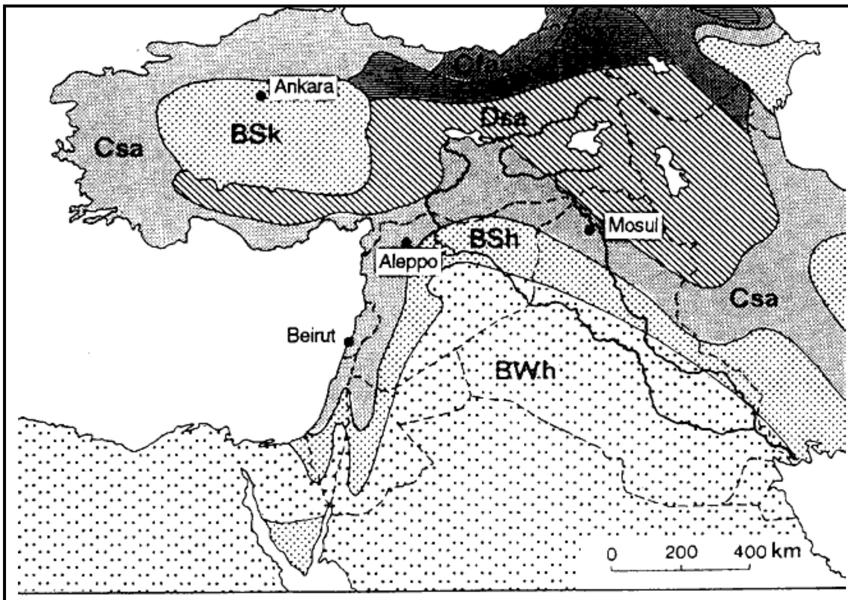
In addition to the GAP diversion of the Euphrates, Syria's total irrigation plan covers 600,000 hectares. An additional 300,000 ha is expected to be irrigated with water to be diverted from the Tigris (Waterbury, 1994, p. 58). As a response, Iraq would have to initiate a project diverting some parts of the Tigris water reserves to the Euphrates in order to alleviate the shortage of water due to flow reduction. With this diversion project, both the Euphrates and the Tigris are considered a combined water resource system that reduces the water stress in the region. Nevertheless, Iraq can be considered as the most disadvantaged country among the three riparian states (Waterbury, 1994, p. 59). With the destruction during the Gulf War of Iraq's military power, Turkey has become by far the dominant economic and military power in the region. It is a fact that Turkey is, currently, nearly a pure hegemon in the basin (Waterbury, 1994, p. 54).

2.4.2. Physical Descriptions

The Euphrates and the Tigris rivers follow two separate basins before their confluence near Basra to form the Shatt al-Arab and their drainage into the Persian Gulf (Figure 2.1). Kolars (1994, p. 51) considers these two river basins as 'twin river system'. After confluence, the Shatt meets the last tributary, the Karun, 32 km below Basra. The total average annual flow of the Shatt is around 81.9 billion m^3/s, with significant annual variations (Kolars, 1994, p. 51).

2.4.2.1. The Climate of the Euphrates and Tigris Basins

The Tigris-Euphrates basin is in a sub-tropical Mediterranean climate regime, characterized by wet winters and dry summers (Figure 2.2). According to the Koeppen System of Climate Classification, there are four different sub-climatic regions in the basin: From North to South, (1) Dsa – Temperate cold and humid climate with warm summers and 600 – 1000 mm of rainfall; (2) Csa – Mediterranean climate with dry summers, and 400 – 800 mm of rainfall; (3) BSh – Semi arid climate with 200-400 mm of rainfall; and (4) BWh – Semi arid climate with cold and dry summers, and 400-800 mm of rainfall (Kliot, 1994, p. 104, 105). The main water source of the Euphrates and Tigris is in the Dsa climatic area, which constitutes the northeastern part of Iraq, the northwestern part of Iran, and the eastern Anatolia region of Turkey, which is also the catchment area of the main winter rainfalls. The Csa climatic area, where the precipitation is barely sufficient for rain-fed agriculture but not enough for intensive agriculture, covers most of the southeastern portion of the Anatolian peninsula in Turkey, as well as the western and northeastern corners of Syria, and a narrow climatic belt in the northern part of Iraq. The Bsh climate is dominant on almost one-third of Syrian land, and a little more than one-tenth of Iraqi land. The BWh climatic area covers another one third of Syria and more than 60% of Iraq. Substantial amount of agricultural lands,



LEGEND:
Bsh - Semi Arid Climate 200-400 mm of Rainfall
BWh - Semi Arid Climate Cold and Dry 200-400 mm of Rainfall
Csa - Mediterranean Climate Dry Summers 400-800 mm of Fainfall
Dsa - Temperate Cold and Humid Climate with Warm Summers 600-1000 mm of Rainfall
Dfb - Temperate Cold and Humid Climate, Rainfall in all seasons 1000-2000 mm

Source: Kliot, 1994, p. 105.

Figure 2.2: Climatic Regions of Turkey, Syria, Iraq

particularly in Syria and Iraq, are classified as arid and semi-arid, and are dependent on the waters of the Euphrates and Tigris. When the total areas of the riparian countries are considered, the annual rainfall is less than 250 mm in 59% of Syria, and less than 400 mm in 70% of Iraq. Iran, which is the other minor riparian to the Tigris basin in the upper parts of the Lesser Zab and Diyalah tributaries, also has a mostly arid and semi-arid climate with precipitation ranging between 100 and 200 mm. In the Euphrates and Tigris basin, the other climatic feature carrying significant importance is high temperature and, therefore, high evaporation. Despite Turkey's somewhat lower summer temperatures, the mean annual potential evaporation ranges between 570 and 1,140 mm for all four riparians. The water loss due to evaporation is consequently high especially in the manmade lakes of the region: Keban and Ataturk in Turkey, Assad in Syria, Lakes Habbaniya and Tharthar in Iraq (Figure 2.1). In Iraq, heavy evaporation also reinforces salination processes in the Mesopotamian plains (Kliot, 1994, p. 105, 108). Thus, the lower basin riparian countries are highly dependent on the rivers and are in desperate need of water for irrigation, as opposed to Turkey, which is well endowed with winter precipitation and has many rich perennial rivers (Kliot, 1994, p. 108).

2.4.2.2. The Euphrates

The Euphrates is the longest river in southwest Asia west of the Indus. Its basin lies for 28% in Turkey, 17% in Syria, 40% in Iraq, and 15% in Saudi Arabia. The river is 3,000 km long, divided between Turkey (1,230 km), Syria (710 km), and Iraq (1,060 km) (Naff & Matson, 1984, 83). On the other hand, the catchment area that produces water inputs to the river is located for 62% in Turkey and 38% in Syria. It is estimated that Turkey contributes 89% of the annual flow, whereas Syria's contribution is 11%.[23] According to another estimation, the percentage of the Euphrates flow originating in Turkey is as high as 98% (Kolars, 1994, p. 51; Kolars, 1986, p. 250-258). Table 2.15 shows the water contributions of the three riparian countries to the Euphrates.[24]

In Turkey: The Euphrates is formed in Eastern Anatolia, where the annual rainfall is around 1,000 mm (Naff, 1984), by the union of both the Karasu and the Murat

Rivers, 45 km northwest of Elazig. From the confluence point, it goes down towards the Syrian border, south of Birecik. According to Kolars (1992), the observed average annual flow across the Turkish/Syrian border is 29.8 billion m^3. The natural flow, prior to river development in Turkey, had been estimated as 31.5 billion m^3 (Kolars, 1992, p. 107). Syrian sources indicate an annual average flow of 28 billion m^3. Nevertheless, the annual flow varies from 86% above the average in 1969, to 62% below the average in 1973 (Robins, 1991, p. 88). In addition, the flow of the Euphrates varies seasonally from a minimum of 181 m^3/s to a maximum of 5200 m^3/s at the Hit (Iraq) station (Kolars, 1994, p. 51).

In Syria: After entering Syria, the Euphrates flows through an entrenched valley, first towards the south, and then southeast into Iraq. In Syria, two tributaries, the Balikh and Khabur, join the Euphrates on its left bank, and are the only contribution of Syria to the flow of the river. However, these tributaries receive most of their water from a catchment area immediately north of the Turkish/Syrian border. Therefore, the tapping of aquifers on the Turkish side can influence their flow. Kolars (1994) estimates that as much as 98 per cent of the Euphrates waters therefore originate in Turkey, rather than the usually accepted 88% (Kolars, 1994, p. 51).

In Iraq: Except for the confluence of the Khabur river with the Euphrates at Deir es-Zor in Syria, there is no remarkable addition of water to the Euphrates, with the exception of irregular and infrequent hydrologic events in Iraq, which may add some Tigris water to its flow. At Hit, located 360 km downstream from the Syrian border, the Iraqi alluvial plain starts. From Hit to the Gulf (735 km), the river loses only 53 m in elevation. During this long trip, the Euphrates loses much of its water to a series of natural and manmade distributaries. Near Nasirya, a portion of the river feeds Lake Hammar, and the rest of the water is drained into the Shatt and then the Persian Gulf (Kolars, 1994, p. 51). Peak flows recorded at Hit, Iraq, during the period 1924-1973, were as high as 7390 m^3/sec in 1969 and as low as 850 m^3/s in 1930 (Kolars & Mitchell, 1991, p. 90-97).

2.4.2.3. The Tigris

The Tigris basin spreads over Turkey, Syria, Iraq, and Iran, with shares of 12%, 0.2%, 54%, and 34% of total basin area, respectively. The catchment area creating the water flow of the Tigris is located in Turkey (21%), Syria (0.3%), Iraq (31%), and Iran (48%). The river is 1,850 km long, with the Turkish, Syrian, and Iraqi portions equal to 400, 32, and 1418 km, respectively (Kliot, 1994, p. 112, 113). While Turkey is providing 51% of the annual water volume, Iraq and Iran contribute 39% and 10%, respectively. Table 2.16 shows the three riparian countries' water contributions to the Tigris.[25]

In Turkey and Iraq: The Tigris River emerges in the southeastern part of Anatolia in Turkey near Lake Van, and, before entering Iraq, it passes through Cizre, which is a southeastern city in Turkey, and constitutes the border between Turkey and Syria for 32 km. Unlike the Euphrates, the Tigris receives water from numerous left-bank tributaries, some of which originate in Iran in the Zagros Mountains to the east. The Greater Zab, the Lesser Zab, the Adhaim and the Diyala are the major streams contributing nearly 28.7 billion m^3 annually to the river, about 58 per cent of its natural flow at Qurna.

The main streams, the Tigris in Turkey and the Khabur River[26] (emerging in Turkey and confluencing at the border with the main stream of the Tigris), make up the remaining annual flow of 20.5 billion m^3 (Kolars, 1994, p. 52, 53). The Tigris reaches its alluvial plain midway between Tikrit and Samarra in Iraq. The Tigris tributaries coming down from the Zagros Mountains are the main sources of water in Spring, and the Greater Zab alone may contributes 65% of the seasonal flow, in April and May. Furthermore, the main stream flow displays great annual and seasonal variations. In addition, the diversion of water to the Tharthar Reservoir and to the Euphrates also significantly impacts the flow further downstream. The flow of the main river, combined with the Diyala, may reach 14,000 m^3/s. However, further downstream at Qurna, the flow may decrease to 179 m^3/s. The minimum flow recorded at Baghdad is 158 m^3/s, the maximum 13,000 m^3/s, and the average 1236 m^3/s (Kolars, 1994, p. 53).

Table 2.15: Sources and Uses of the Euphrates (Mm^3/yr)

Natural Flow			% of natural flow at Hit
	Observed at Hit, Iraq	29,800	91
	Removed in Syria (pre-Tabqa)	820	3
	Removed in Turkey (pre-GAP)	2,100	6
	Natural flow at Hit	32,720	100
Pre-Keban Dam (<1974)			
	Flow in Turkey	30,670	94
	Removed in Turkey	-820	-3
	Entering Syria	29,850	91
	Added in Syria	+2,050	6
	Removed in Syria	-2,100	-6
	Entering Iraq	29,800	91
	Added in Iraq	---	0
	Iraqi irrigation	-17,000	-52
	Iraqi return flow (est.)	+4,000	12
	To Shatt Al-Arab	16,800	51
Full Use Scenario (2040)			
	Flow in Turkey	30,670	94
	Removed in Turkey	-21,600	-66
	Entering Syria	9,070	28
	Removed in Syria	-11,995	-37
	RF. & Tributaries (Turkey/Syria)	9,484	29
	Entering Iraq	6,559	20
	(Removed in Iraq)	(-17,000)	-52
	(RF in Iraq)	(+4,000)	12
	(Deficit to the Shatt Al-Arab)	(-6,441)	-20

Source: Kolars (1992 and 1994)

Flow irregularity and variations, from severe drought to destructive flooding, is one of the strongest justifications, on the Turkish side, for developing the GAP. The opportunities for supply-augmentation policies, storage facilities (dams), and optimal run-off regulations in the basin, are some of the main reasons for GAP (Bilen, 1994, p. 96; Tekeli, 1990, p. 214). Nevertheless, the Syrian and Iraqi sides have not been convinced by this argument. According to Kolars (1994), Turkey carried out the GAP not to intimidate its neighbors, but in order to satisfy its own energy, agricultural and foreign exchange needs, which required a new vision, particularly the development of its major river resources (Kolars, 1994, p. 54). The scale of GAP is unquestionably large and certainly gives Turkey the power of controlling the water.

Table 2.16: Sources and Uses of the Tigris (Mm^3/yr)

	Pre-project	% of total natural flow	2000 +	% of total natural flow	Natural Flow	% of total natural flow
Flow from Turkey	18,500	38	18,500	38	18,500	38
Removed in Turkey	---		-6,700	-14		
Entering Iraq	18,500	38	11,800	24		
Inflows to Mosul	2,000	4	2,000	4	2,000	4
Greater Zab	13,100	27	13,100	27	13,100	27
Lesser Zab	7,200	15	7,200	15	7,200	15
Other	2,200	4	2,200	4	2,200	4
Subtotal	43,000	87	36,300	74	43,000	87
Reservoir Evaporation	---	0	-4,000	-8		
Irrigation (to Fatha)	-4,200	-9	-4,200	-9		
Return Flow	+1,100	2	+1,100	2		
Adhaim River	+800	2	+800	2	800	2
Irrigation (to Baghdad)	-14,000	-28	-14,000	-28		
Return flow	+3,600	7	+3,600	7		
Domestic Use	-1,200	-2	-1,900	4		
Diyala River	+5,400	11	+5,400	11	5,400	11
Irrigation	-5,100	-10	-5,100	-10		
Return Flow	+1,300	3	+1,600	3		
Subtotal	30,700	62	19,200	39	49,200	100
Reservoir Evaporation	---	0	900	2		
Irrigation (to Tokut)	-8,600	-17	-8,600	-17		
Return Flow	+2,200	4	(2,200 to Outfall Drain)	4		
Total to Shatt Al-Arab	24,000	49	9,700	20	49,200	100

Source: Kolars (1992 and 1994)

2.4.3. Dynamics in the Region

There are several dynamics in the region that must be considered in order to understand the nature of the problem: population, development, and political dynamics.

2.4.3.1. Population Dynamics

The populations of all three countries (Iraq, Syria, and Turkey) have significantly high annual growth rates, around 3%. Although Turkey's national growth rate is lower than 1.6%, the regional rate for Southeastern Anatolia is higher than 3%, implying a population doubling every 24 years (Table 2.17). Furthermore, as can be seen in Table 2.17, the population compositions of the three riparian countries are similar, with significantly young population: (1) The youngest age range (0-15) make up 31% of the population in Turkey, 44% in Iraq, and 46% in Syria; (2) In all three countries the working-age population (15-65) represents more than 50% of the total population; and (3) The retirement-age population represents 6% of the population in Turkey and 3% in Syria and Iraq. Turkey's population is close to twice the sum of both Syria's and Iraq's population (16.7 and 21.7 million, respectively).

Table 2.18 shows the levels of urbanization in 1995. Iraq is the most urbanized country, with 74.6% of its population in urban areas, followed by Turkey (68.8%) and Syria (52.4%). Thus, Syria is the most agriculture-dependent state. Table 2.20 in the next section provides the number of people employed in agriculture, with 40% in Syria and 30% in Turkey and Iraq. Despite low precipitations and lack of technology before the GAP implementation, agriculture remained the primary economic activity in the southeastern portion of Turkey.

Table 2.17: Demographic Characteristics (1998)

	Population	Population Structure			Population Growth Rate	Net Migration Rate	Total fertility rate
		0-14	15-64	65 +		(per 1000)	
		%	%	%	%		
Primary Countries							
Iraq	21,722,287	44	53	3	3.20	-	5.23
Syria	16,673,282	46	51	3	3.23	-	5.55
Turkey	64,566,511	31	63	6	1.60	-	2.47
SAR*	3,500,000				3.8**		
Secondary Countries							
Iran	68,959,931	43	53	4	2.04	(4.79)	4.31
Israel	5,643,966	28	62	10	1.91	5.25	2.71
Jordan	4,434,978	43	54	3	2.54	(5.92)	4.79
Kuwait	1,913,285	32	66	2	4.10	22.31	3.44
Lebanon	3,505,794	30	64	6	1.62	-	2.28
Saudi Arabia	20,785,955	43	55	2	3.41	1.44	6.38

Source: http://www.odci.gov/cia/publications/factbook/country-frame.html.
*Southeast Anatolia Region (SAR).
**Value is in 1980.

Table 2.18: Urban and Rural Population (1995)

	Urban	Percent	Rural	Percent	Total	Density
	1995	%	1995	%	1995	inh./sq. km
Primary Countries						
Iraq	15,258,000	74.6	5,191,000	25.4	20,449,000	47
Syria	7,676,000	52.4	6,985,000	47.6	14,661,000	79
Turkey	42,598,000	68.8	19,347,000	31.2	61,945,000	79
Secondary Countries						
Iran	39,716,000	59.0	27,567,000	41.0	67,283,000	41
Israel						
Jordan	3,904,000	71.5	1,559,000	28.5	5,463,000	61
Kuwait	1,501,000	97.0	46,000	3.0	1,547,000	87
Lebanon	2,622,000	87.1	387,000	12.9	3,009,000	289
Saudi Arabia	14,340,000	97.8	321,000	2.2	14,661,000	8

Source: Food and Agricultural Organization of the United Nations (1997).

2.4.3.2. Development Dynamics

All three riparian countries are developing countries that are desperately in need of water for their urbanization, industrialization, and agricultural development. Iraq, after the Gulf War, lost its major infrastructures not only in industry but also in agriculture.

The data in Table 2.19 illustrate the actual size of the Iraqi economy, formerly a major oil-exporting country. The real GDP growth rates indicate that Turkey is the most dynamic country in the region. The demand for energy and raw materials can be inferred from population size and growth. The same growth could be restored to Iraq if stability and trade relations are reestablished. The purchasing power parity GDP measure shows that the Syrian and Turkish living standards are very close. The GDP composition by sector shows that Turkey has a relatively more advanced economy, with a larger industrial sector. However, agriculture still plays a major role in the economy of Turkey, where it is still a major export base (mainly textile).

Table 2.19: Country Profiles: Economy (1997)

	GDP Purchasing Power Parity	GDP Real Growth Rate	GDP Per Capita Purchasing Power Parity	GDP Composition by Sector			Inflation Rate (CPI)
	Billion			Agriculture	Industry	Service	
Primary Countries				%	%	%	%
Iraq	42.8	0	2,000	NA	NA	NA	NA
Syria	106.1	4.6	6,600	28[e]	14[e]	58[e]	15 - 20
Turkey	388.3	7.2	6,100	15[f]	28.4[f]	56.6[f]	99
Secondary Countries							
Iran	371.2	3.2	5,500	21[d]	37[d]	42[d]	23[f]
Israel	96.7	1.9	17,500	2	17	81	9
Jordan	20.7	5.3	4,800	6	30	64	3
Kuwait	46.3	1	22,300	0[f]	53[f]	47[f]	3.2[f]
Lebanon	15.2	4	4,400	4	23	73	9
Saudi Arabia	206.5	4	10,300	6[f]	46[f]	48[f]	0

Source: http://www.odci.gov/cia/publications/factbook/country-frame.html.
*: It is aggregated for the purpose of table. a: 1988, b: 1989, c: 1993, d: 1994, e: 1995, f: 1996, g: 1998.

Although the data for Iraq in Table 2.20 pertain to 1989 (pre Gulf War), they provide sectoral information missing in Table 2.19, although in terms of labor force rather than GDP composition. Table 2.20 also shows that, among the three riparian countries, Turkey's industrial sector has the highest share (23%), followed by Iraq (22%) and Syria (20%) in 1996. Turkey has the lowest unemployment rate among the three countries, half the Syrian unemployment rate.

Table 2.20: Country Profiles: Economy (1997)

	Labor force					Unemployment rate
	Total	Services	Agriculture	Industry	Construction**	
Primary Countries	Million	%	%	%	%	%
Iraq	4.4[b]	48[b]	30[b]	22[b]		NA
Syria	4.7[e]	40[f]	40[f]	20[f]		12
Turkey	21.6[f]	34.5[f]	42.5[f]	23[f]		5.9
Secondary Countries						
Iran	15.4[a]	33[a]	21[a]			30[a]
Israel	2.3	69.7[f]*	2.6[f]*	20.2[f]*	7.5	7.7
Jordan	1.15	71.2*	7.4	11.4	10	20 – 25
Kuwait	1.1[f]	90[f]	0 – 10*	0 – 10*		1.8[f]
Lebanon	1[f]	62[g]	31	7		18
Saudi Arabia	7[g]	70 (40% gov)	5[g]	25[g]		NA

Source: http://www.odci.gov/cia/publications/factbook/country-frame.html.
*: It is aggregated for the purpose of table.
**: If there is a detailed data exist about construction sector, percentages added.
a: 1988, b: 1989, c: 1993, d: 1994, e: 1995, f: 1996, g: 1998.

2.4.3.3. Political Dynamics

Among the three riparian countries, there has been mistrust going back to the First World War, when nation states were established after the collapse of the Ottomans. In addition, Turkey is a member of NATO, a long-term ally of the USA, and a close trade and military partner of Israel (for at least the last two years), and is being considered a threat by the Arab nations in the region. Therefore, none of the riparian countries would like to be dependent on the others, especially for water. All the riparian countries scrutinize changes in the relative power of their neighbors. In this respect, GAP is a relative advantage for Turkey in terms of (1) development and growth in the region, and (2) a possible weapon to control water flow. In contrast, the Iraqi and Syrian concerns about GAP, especially over the Euphrates, are (1) the damage to be created by the shut-off of the flow during the dam filling periods, (2) future problems due to further expected shut-offs and ultimately to changes in the volume and nature of the water flow, and (3), most profoundly, the impact of control over the water on the power relationship within and among the three states (Robins, 1991, p. 92, 93). Syria has been accused by Turkey of opening its borders to Kurdish[27] separatists (PKK) in order to increase its bargaining power with Turkey on water.[28] In spite of Turkey's efforts to solve the PKK problem during the last 20 years, the accelerating increase in PKK activities in the last ten years has been the basis for Turkey accusing Syria of abetting terrorists. On the 5th of October 1998, Turkey initiated a military action against Syria, forcing it to deport the leader of the PKK. In line with Turkish policies aimed at ameliorating Kurdish living standards in Southeastern Anatolita, Iraq had implemented an agricultural development project improving the living standards of Shias in the Southern part of the country, with the goal of increasing their loyalty or at least quiescence. Thus, the potential high volumes of water withdrawals by the upstream countries (Turkey) endanger Iraqi internal policies and constitutes an internal threat to Iraq. The other problematic issue between Turkey and Syria is the Syrian claim on Hatay, a city that became part of Turkey years after its establishment, based on a public referendum in 1939, and is now within the border of Turkey. Iraq, after the Kuwait invasion and Gulf War, lost control over its territory, and its military strength to challenge Turkey. Therefore, the water problem has mostly remained an issue between Turkey and Syria since then.

Ethnic Composition: Table 2.21 provides the ethnic compositions of the major Middle Eastern Countries. Arabs, Turks, and Kurds constitute the major ethnic groups in the region. In Turkey the share of Kurds is around 20%. In Iraq, Arabs make up 75-80% of the country population, with Kurds (15-20%), Turkomans, Assyrians and others (5%) making up the remainder in Iraq.[29] On the other hand, Syria is relatively more homogenous, compared to Turkey and Iraq; 90.3% of its population is Arab, and the rest (9.7%) Kurds, Armenians and others.

Religious Composition: Since the Middle East is the cradle of many religions, the ethnic composition alone fails to grasp the sociological structure of the region. As can be seen in Table 2.22, Islam is the dominant religion in all three riparian countries, adhered to by more than 90% of the populations. All three countries have Christian populations with the highest share in Syria (10%). There is a negligible Jewish population in Syria. However, the prominent Muslim majority in the region is divided into several competing,

even fighting, factions, such as Shi'a, Sunni, Alawite, and Druze. While the Sunni sect constitutes the majority in both Turkey and Syria, the Shi'a sect constitutes the majority in Iraq (Table 2.22).

Table 2.21: Ethnic Composition (1998)

	Ethnic Groups
Primary Countries	
Iraq	Arab 75%-80%, Kurdish 15%-20%, Turkoman, Assyrian or other 5%
Syria	Arab 90.3%, Kurds, Armenians, and other 9.7%
Turkey	Turkish 80%, Kurdish 20%
Secondary Countries	
Iran	Persian 51%, Azerbaijani 24%, Gilaki and Mazandarani 8%, Kurd 7%, Arab 3%, Lur 2%, Baloch 2%, Turkmen 2%, other 1%
Israel	Jewish 82% (Israel-born 50%, Europe/Americas/Oceania-born 20%, Africa-born 7%, Asia-born 5%), non-Jewish 18% (mostly Arab) (1993 est.)
Jordan	Arab 98%, Circassian 1%, Armenian 1%
Kuwait	Kuwaiti 45%, other Arab 35%, South Asian 9%, Iranian 4%, other 7%
Lebanon	Arab 95%, Armenian 4%, other 1%
Saudi Arabia	Arab 90%, Afro-Asian 10%

Source: http://www.odci.gov/cia/publications/factbook/country-frame.html

Table 2.22: Religious Composition (1998)

	Religions Groups
Primary Countries	
Iraq	Muslim 97% (Shi'a 60%-65%, Sunni 32%-37%), Christian or other 3%
Syria	Sunni Muslim 74%, Alawite, Druze, and other Muslim sects 16%, Christian (various sects) 10%, Jewish (tiny communities in Damascus, Al Qamishli, and Aleppo)
Turkey	Muslim 99.8% (mostly Sunni), other 0.2% (Christian and Jews)
Secondary Countries	
Iran	Shi'a Muslim 89%, Sunni Muslim 10%, Zoroastrian, Jewish, Christian, and Baha'I 1%
Israel	Judaism 82%, Islam 14% (mostly Sunni Muslim), Christian 2%, Druze and other 2%
Jordan	Sunni Muslim 96%, Christian 4% (1997 est.)
Kuwait	Muslim 85% (Sunni 45%, Shi'a 40%), Christian, Hindu, Parsi, and other 15%
Lebanon	Islam 70% (5 legally recognized Islamic groups—Alawite or Nusayri, Druze, Isma'ilite, Shi'a, Sunni), Christian 30% (11 legally recognized Christian groups—4 Orthodox Christian, 6 Catholic, 1 Protestant), Judaism NEGL%
Saudi Arabia	Muslim 100%

Source: http://www.odci.gov/cia/publications/factbook/country-frame.html

2.4.4. Problem Identification

Ethnicity–based conflicts and shortage of rainfall, and therefore water scarcity, are the main problems in the region.

2.4.4.1. Shortage of Rainfall in the Middle East

According to Postel (1996), the Syrian and Iraqi water situations are defined as 'water scarce' (per capita water availability is less than 1000 cubic meter/year) and 'water stressed' (1700 cubic-meter/year), respectively. According to the same author, these definitions do not perfectly define the relative situations of the countries when considering agricultural and industrial technologies (Postel, 1996, p. 15,16.). It is clear that both countries would like to have more water for their prospective needs.

2.4.4.2. Under-Development, Regional Disparities, and Ethnic and Religious Concerns

Most of the Euphrates water (89%) originates in Turkey, and Turkey would like to use these water resources for the benefit of the most underdeveloped parts of the country, Southeastern Anatolia. This is also crucial for the development of Turkey in terms of reducing the interregional disparities and ethnic tensions coming from the Kurdish population, neglected for a long time due to economic and technical difficulties and historically wrong policies. The Southeast Anatolia Development Project (GAP) is a kind of compensation for this history and an opportunity for the development of Turkey. Furthermore, Turkey, as opposed to Syria and Iraq, is an energy poor country. For Turkey's industrial development, the constructed dams are more crucial and the agricultural development is a complementary part, which disseminates the generated wealth to local farmers (mostly Kurds), formerly farming once in two years due to water shortage. With irrigation, it is possible to have three different crops in the same year from the same land. Together with the increasing productivity, the expected production will be at least six times larger than before. In summary, GAP is a large-scale project planned to solve both ethnic and underdevelopment problems in the region. As Kolars (1994, p. 49) states, the Ataturk Dam and, in general, the GAP have a significant importance for Turkey:

> "From the Turkish point of view, the stakes have been raised, for the Ataturk Dam is not only intended to produce large amounts of electricity…, but also as many as a million hectares of land are to be irrigated in the south-east with water from its reservoir. This is expected to generate large amounts of foreign exchange from the sale of new crops. High priority is also given to the potential that GAP has for raising the standard of living in south-east Anatolia, which in turn is seen as a way to ameliorate the discontent of the local Kurds who form a majority in the region."

NOTES

[1] Thomas (1965), p. 437.

[2] Thomas (1965), p. 436.

[3] Raskin, Hansen, & Margolis (1996) p. 1.

[4] Raskin, Hansen, & Margolis, 1996, p. 3-5. Raskin et al. add in their table-footnote the following: Population and average resource data from Gleick (1993b), except Germany and Yemen from WRI (1994). Total withdrawals from WRI (1994). Land areas from FAO (1990).

[5] Raskin, Hansen, & Margolis (1996) p. 3-6. Raskin et al. add in their table-footnote the following: Population and average resource data from Gleick (1993b), except Germany and Yemen from WRI (1994). Sectoral percentages and total withdrawals are from WRI (1994).

[6] Conventional Development Scenario (CDS) by Raskin et al. P. D. Raskin, E. Hansen, and R. M. Margolis, "Water and Sustainability: Global Patterns and long-range Problems," Natural Resources Forum 20 (1996) 8: "Here the focus is on a single reference, or 'business as usual', scenario, which tries to capture the effects of current trends, policies and development goals. The purpose of the Conventional Development Scenario (CDS) is to give a rough indication of water conditions under mainstream assumptions about long-run development, and to provide a point of departure for generating alternative and perhaps more desirable future."

[7] Raskin, Hansen, & Margolis (1996) p. 13.

[8] Raskin, Hansen, & Margolis (1996) p. 6.

[9] Raskin, Hansen, & Margolis (1996) p. 7.

[10] Raskin, Hansen, & Margolis (1996) p. 13. Conventional Development Scenario (CDS).

[11] Turkey's water resources are not included in the Middle East Region water resources total. Turkey's percent with respect to Regional total is computed in order to have a relative figure for Turkey.

[12] Raskin, Hansen, & Margolis (1996) p. 8.

[13] Raskin, Hansen, & Margolis (1996) p. 3-5.

[14] Raskin, Hansen, & Margolis (1996) p. 8.

[15] Table 2 is from the study of Thomas (1965) p. 3-5.

[16] Raskin, Hansen, & Margolis (1996) p. 8.

[17] Table 2 is from the study of Thomas (1965, p. 3-5).

[18] Thomas (1965) p. 3-5.

[19] For instance, the Peace Water Project - an international water distribution project covering several countries from Israel to Saudi Arabia, and originally suggested by the Ozal administration (The late President of Turkey from 1982-1993) - was rejected because of suspicion that it would give significant power to Turkey.

[20] http://www.ce.utexas.edu/stu/akmanss/GAP/paper.html#PartI

[21] Southeast Anatolia Development Project is the largest of regional projects in Turkey and in the Middle East Region (Turkish acronym: GAP). The GAP is made up of total 21 dams and 19 hydropower plants on the Euphrates and Tigris Rivers. Around one million hectares of land are scheduled to be irrigated with water from the Euphrates and 625,000 ha with water from the Tigris. The GAP will have a total of 7500 MW installed capacity with an average annual production of 26 billion kWh. This area corresponds to 19 per cent of the 8.5 million ha of economically irrigable land in Turkey, and 20.5 % of the county's hydropower. (Kolars, 1994; 48).

[22] Table 2.13 summarizes the history of the water issues between Turkey, Syria, and Iraq, (Scheumann, 1998, p. 125).

[23] Ibrahim Kaya, "The Euphrates-Tigris basin: An overview and opportunities for cooperation under international law." http://ag.arizona.edu/OALS/ALN/aln44/kaya.html.

[24] Negligible numerical differences come from different sources.

[25] Negligible numerical differences are related to different data sources.

[26] The Khabur river in Iraq is different from the Khabur river at Deir es-Zor, in Syria.

[27] Kurds are an ethnic group, which lives mostly in Turkey, Iraq, and Iran. Syria compared to these countries does not have large number of Kurds in their country; therefore, Kurds do not pose any threat to Syria.

[28] http://www.ce.utexas.edu/stu/akmanss/GAP/paper.html#PartI

[29] Turkey considers the Turkoman population as a sub-branch of Turks.

CHAPTER 3

LITERATURE REVIEW

This literature review focuses on the basic concepts of *game and spatial price equilibrium theories* and their applications to water resource issues. The scope of the analysis is transboundary water resources and their allocation among the riparian countries by means of efficiency, equity, and political criteria. Efficiency refers to the optimum allocation of resources, which has a strong relationship with the spatial equilibrium model. Equity is ethical and political in nature, and can be formalized within the game theory framework. In the following sections, theoretical reviews of game theory and spatial equilibrium modeling are first presented. Next, the literature on their applications to water resources is discussed.

3.1. Cooperative Games Methodologies

According to Heaney & Dickinson (1982), there are three types of cooperative games with respect to the characteristics of cooperation. The first is the *value game,* which maximizes the profit or revenue functions; the second is the *cost game,* which aims at minimizing the costs; third is the *saving game,* which aims at reducing costs. Cost games can be converted into savings games. By participating in a cooperative cost game, each participant tries to save by reducing his cost. If he does not participate, the savings will be zero. The first subsection provides a general definition of cooperative cost games, whereas specific cost allocation techniques are presented in the next subsection. The third subsection presents applications to water allocation problems.

3.1.1. Cooperative Game Theory Concepts

In this subsection, we define first sub-additive games, next imputations, and then the core of the game. Equation (3.1) defines the necessary conditions for sub-additive games, in which cooperative behaviors reduce the cost coming out of independent actions of any sub-groups coalitions. Equation (3.1) shows that, for any subsets of N, named S and T, individual behaviors must be more costly than or equal to the cost of the coalition of these subsets; otherwise, a coalition cannot be the outcome. When the inequality becomes an equality, cooperation is possible but not essential. Note that there is no intersecting element between sub-group S and T.

$$c(S) + c(T) \geq c(S \cup T) \quad S \cap T = \emptyset \quad S, T \subset N \tag{3.1}$$

In order to clarify Equation (3.1), consider a set of n individual players $\{1,2,\ldots,i,\ldots n\}$. Let $x(i)$ be the cost allocated to player i when all players cooperate, i.e., join the grand coalition, $c(i)$ be the cost incurred by player i when he acts independently, i.e., out of the coalition, and $c(N)$ be the cost incurred by the grand coalition. In order to make participation in the grand coalition advantageous to all players, the cost of the participants' independent behaviors must not be less than the cost of their cooperative behaviors. The inequality (3.2), represents this condition, and Equation (3.3) states that the total cost of the grand coalition is fully allocated among all the participants. These two relationships define all the feasible ***imputations***.

$$x(i) \leq c(i) \quad \forall i \in N \text{ (individual rationality)} \tag{3.2}$$

$$\sum_{i \in N} x(i) = c(N) \text{ (allocation of cost in the grand coalition)} \tag{3.3}$$

Next, consider a subset *S* of at least two players *(S⊂N)*. Let *c(S)* be the cost of the subset *S* if it acts independently. Equation (3.4) states that the aggregate cost of subset *S* when all its participants are in the grand coalition is less than the cost that the subset would incur when acting independently:

$$\sum_{i \in S} x(i) \leq c(S) \quad \forall S \subset N \text{ (sub-group rationality)} \tag{3.4}$$

All these equations define a solution set area, named the core, over which all rational players agree to join the grand coalition. The lower the cost of the grand coalition, the higher the probability of obtaining a non-empty core and achieving the grand coalition.

3.1.2. Review of Cost Apportionment Techniques

This section first reviews four well-known cost apportionment methods: The 'Separable Cost Remaining Benefit' (SCRB) method, the 'Shapley method', the linear programming method (LP) and, and the 'Minimum Cost Remaining Saving' (MCRS) method. These are widely used approaches to allocate *costs* or *benefits* among participants in common projects (Heaney & Dickinson, 1982). Next, Giglio & Wrightington's (1972) model, which includes a regional authority as a participant, is discussed.

Appropriate cost allocation among cooperating participants in different types of activities, such as irrigation, flood control, and energy production, is an essential prerequisite to establish a coalition. If these participants are private firms instead of branches of the same firm, achieving the coalition requires an absolutely rational allocation of costs and benefits among the participants. Heaney & Dickinson (1982), in their article "Methods for Apportioning the Cost of a Water Resource Project," study cost allocation models. After introducing the separable cost remaining benefits (SCRB) method, they review the LP and Shapley methods, and develop a new model named the minimum cost and remaining saving method (MCRS), in order to eliminate weaknesses

in the Shapely, LP, and SCRB methods. In the presence of a core, the LP, Shapley, SCRB, and MCRS methods do not differ significantly. If there is no core, the first three methods do not produce a rational allocation of cost. However, the MCRS method utilizes an additional LP technique that relaxes the core constraints to find a core solution. In many cases of public goods, independent participants or local governments are not willing to take regional cooperative actions. The role of a regional authority is to collect funds and allocate them in order to establish a stable solution. Giglio & Wrightington (1972), introduce a new participant into cooperative games to find a core solution (stable solution) and to convince the non-cooperating players to participate by means of side payments. This participant can be either a regional government or a regional authority or any other organization having funds and trying to implement regional projects (such as wastewater treatment). In some cases, there is a possibility that the grand coalition implies a more costly solution for the participants than individual or sub-coalition alternatives. If this is the case and if the regional authority sees an overall benefit in the implementation of the grand coalition, it intervenes in the game as a participant, with its funds and side-payment strategies. The study provides an optimization framework clearly defining the role of such authority in cost allocation, and analyzes the expected results of the authority's strategies in terms of the sufficiency or insufficiency of the collected funds.

3.1.2.1. The Separable Cost Remaining Benefit (SCRB) Model

The separable cost and remaining benefit (SCRB) model allocates the costs of activities, which are not necessarily of the same type. For instance, while one group may be working on flood control, another group may be working on electric generation activities, on the same river system. In Equation (3.5), *b(i)* and *c(i)* are the benefit and cost, respectively, resulting from the separate actions of player *i* (out of coalition). Therefore, the minimum of *b(i)* and *c(i)* will determine the cost allocated to group (player) *i*, *x(i)*:

(1) If $b(i)$ is less than $c(i)$, the allocated cost to group i, $x(i)$, must be less than $b(i)$ in order to convince group i of participating in the coalition. Otherwise, group i would never participate and would not do the project alone. Therefore, the cost allocated to group i cannot exceed the benefit generated out of coalition.

(2) If $c(i)$ is less than $b(i)$, the allocated cost to group i, $x(i)$, must be less than $c(i)$ in order to convince group i of participating in the coalition. Otherwise, group i would do the project out of coalition. Thus:

$$x(i) \leq \min[b(i), c(i)] \qquad \forall i \in N \qquad (3.5)$$

Equation (3.6) computes the separable cost of each participant in the grand coalition (N). When group i is removed from the coalition, the change in the total cost represents the separable cost $sc(i)$ for group i, with:

$$sc(i) = c(N) - c[(N) - \{i\}] \qquad \forall i \in N \qquad (3.6)$$

Equation (3.7) finds the non-separable part, nsc, of the total cost for all participants. Equation (3.8) computes the proportion $\beta(i)$ of nsc (non-separable cost) to be allocated to each participant. $Min(b(i), c(i))$ determines the maximum amount that can be charged to group i, and the difference between $Min(b(i), c(i))$ and $sc(i)$ is used to allocate the joint costs nsc by computing the prorated share $\beta(i)$ of the nonseparable costs (Heaney & Dickinson, 1982, p. 477). While the numerator in Equation (3.8) indicates the remaining costs (positive) or benefits (negative) for group i, the denominator represents the sum of these remaining cost or benefits. The sum of all shares is necessarily equal to 1 (Equation 3.9). Equation (3.10) finalizes the cost apportionment procedure, including both the separable and non-separable portions of the costs.

$$nsc = c(N) - \sum_{i \in N} sc(i) \qquad (3.7)$$

$$\beta(i) = [[\min(b(i), c(i))] - sc(i)]\left\{\sum_{i \in N}\{[\min(b(i), c(i))] - sc(i)\}\right\}^{-1} \quad (3.8)$$

$$\sum_{i \in N}\beta(i) = 1.0 \quad (3.9)$$

$$x(i) = sc(i) + \beta(i)(nsc) \quad (3.10)$$

The allocation may be out of the core.

3.1.2.2. Shapley Method

The Shapley method is one of the methods used to find a unique apportionment for each coalition member. The idea behind this method (represented in Equation 3.12) is that the cost allocated to the ith player, $x(i)$, is the sum of incremental costs times the probability of various coalition formations (Heaney & Dickinson, 1982, p. 478).

The incremental cost for player i of joining coalition S is:

$$c(S) - c(S - \{i\}) \quad (3.11)$$

The charge to player i, x(i), is:

$$x(i) = \sum_{s \subseteq N}\alpha_i(S)[c(S) - c(S - \{i\})] \quad (3.12)$$

where:

$$\alpha_i(S) = \frac{(S-1)!(n-S)!}{n!} = \left[1\Big/\binom{n}{s}\right][1/(n-s)] \quad (3.13)$$

$\alpha_i(S)$: Probability that a player (participant) joins coalition S;

$(n - S)$: Number of free players who may join coalition S;

$1 \Big/ \binom{n}{S}$: Probability for a coalition of size S to be chosen;

$1/(n - S)$: Probability that the given player i will choose coalition S.

The allocation may be out of the core.

3.1.2.3. Linear Programming (LP) Method

A cooperative game has solution(s) if there is a core satisfying the conditions defined by Equations (3.2) - (3.4). If there is no feasible solution, Heaney & Dickinson (1982) introduce an LP formulation (Equations 3.14 – 3.18) providing an optimum relaxation to the constraints, and requiring a decrease in the allocated costs for some (or all) members of the coalition.[1] With this relaxation, the authors redefine an acceptable core area. This change affects the minimum cost constraints. The changed minimum cost constraints are used in the MCRS model, which is presented in the next section. The LP model computing the minimum relaxation to find the core solution is:

Minimize $\quad Q \qquad (3.14)$

subject to:

$$x(i) \le c(i) \qquad \forall i \in N \tag{3.15}$$

$$\sum_{i \in S} x(i) - Qc(S) \le c(S) \qquad \forall S \subset N \tag{3.16}$$

$$\sum_{i \in N} x(i) = c(N) \tag{3.17}$$

$$x(i) \ge 0 \tag{3.18}$$

Because there is no core, a new variable, *Q*, is introduced in order to extend the core constraints at a minimum rate. All coalition costs *c(S)* are expanded by the amount *Qc(S)*, which may be viewed as an imposition of a tax on these costs, and minimizing *Q* implies searching for the minimum tax. The set of Equations 3.14 – 3.17 makes up a linear program with, as unknowns, the variables *x(i)* and *Q*.

3.1.2.4. Minimum Cost Remaining Saving (MCRS)

Heaney & Dickinson (1982) summarize the computation procedure of the MCRS model in three steps: ***First***, if there is core solution, find the minimum $x(i)_{\min}$ and maximum $x(i)_{\max}$ costs that satisfy the core conditions by solving respectively *Max x(i)* and *Min x(i)* optimization problems which are subject to the constraints defined by Equations (3.2) – (3.4). The maximum cost $x(i)_{\max}$ can be automatically seen from the individual non-cooperative costs (i.e., $x(i)_{\max} = c(i)$). Alternatively, if there is no core solution, apply the procedures shown by Equations (3.14) – (3.18) in order to extend the cost constraints for all sub-coalitions, and then derive the necessary $x(i)_{\min}$ and $x(i)_{\max}$. ***Second***, obtain the value of the non-separable costs (*nsc*) and prorate them by the application of the following Equations (3.19) and (3.20):

$$nsc = c(N) - \sum_{i \in N} x(i)_{\min} \tag{3.19}$$

$$\beta(i) = [x(i)_{\max} - x(i)_{\min}] \left\{ \sum_{i \in N} [x(i)_{\max} - x(i)_{\min}] \right\}^{-1} \qquad \forall i \in N \tag{3.20}$$

Third, determine the fair solution *x(i)* for each group using Equation (3.21):

$$x(i) = x(i)_{\min} + \beta(i)(nsc) \tag{3.21}$$

Equation (3.19) computes the non-separable part, *nsc*, of the costs for all the participants. Equation (3.20) computes the proportion $\beta(i)$ of *nsc* which can be allocated to each participant, in a way similar to the SCRB method. The last Equation (3.21) finalizes the cost apportionment procedure, including both the separable and non-separable costs.

To summarize, the advantage of the MCRS model over the SCRB model is the utilization of the $x(i)_{\min}$ value, which is defined as an alternative to the separable costs *sc(i)* used in the SCRB model. The separable costs in the SCRB model do not always lead to a core solution, due to not incorporating subcoalition constraints (Equation 3.4[2]) into the method. On the other hand, the MCRS method optimally (minimally) relaxes the minimum cost boundaries of *x(i)*, and therefore it always leads to a core solution with a controlled relaxation, which always satisfies the constraints shown in Equation (3.4).

3.1.2.5. Apportioning Costs in a Regional System: Participating Regional Authority

Giglio & Wrightington (1972), in their article "Methods for Apportioning Costs among Participants in Regional Systems," present five alternative ways to allocate water pollution treatment costs among community participants. The listed cost allocation models are based on:

(a) ***Cost sharing based on the measure of pollution:*** This method allocates all costs in proportion to the amount of pollution produced by each participant;

(b) ***Cost sharing based on single plant costs with a rebate proportional to the measure of pollution:*** Every participant is required to pay treatment costs as if solving the problem alone (out of coalition). Then the collected funds are used to pay for the grand coalition project. The remainder (surplus) of the collected funds is then allocated among the participants, in proportion to their pollution or their financial contribution to the common project. (The higher cost payers get the higher rebates).

(c) ***Cost sharing based on the SCRB method:*** This is an incomplete version of the 'Shapley' solution. Both the SCRB and Shapley methods have been previously discussed.

(d) *Cost sharing based on free market bargaining:* This is essentially the concept of the core.

(e) *Cost sharing based on bargaining, including a regional authority as participant (player):* In order to make all members participate in the grand coalition, nonnegative payoffs to all the participants are a necessary condition. Therefore, in cases of negative payoffs (meaning that solving the problem out of the grand coalition is cheaper) for some participants, the regional authority must subsidize these participants. The amount that will be paid to each such participant is determined by solving an LP problem. In this LP, the regional authority estimates the minimum rebates ($P_{\min}$ in total) to be distributed.

The indices, variables, and parameters are defined below:

i: index of players $i=1,2,...N$;

K_i: savings (side payments) returned to user i;

P(S): minimum total rebate for coalition S;

$c(i)$: cost for user i treating his waste alone, $i=1,2,...N$;

C_r: total cost of the optimal regional plan (exogenously determined);

$P_{\min}$: total rebate.

The model is then:

$$\textit{Minimize} \ \ P_{\min} = \sum_{i=1}^{N} K_i \tag{3.22}$$

subject to:

$$\sum_{i \in S} K_i \geq P(S) \qquad \left(P(S) = \sum_{i \in S} c(i) - c(S)\right) \tag{3.23}$$

$$K_i \leq c(i) \tag{3.24}$$

$$K_i \geq 0 \tag{3.25}$$

When solving the LP for K_i, the solutions are the minimum payoffs (rebates) to each participant (their total is equal to P_{min}). The solution, which the regional authority wants to pursue, must satisfy the intermediate sub-coalition rebate constraints in Equation (3.23). Equation (3.24) simply states that the rebate cannot exceed the cost of treating alone. $\sum c(i) - P_{\min}$ refers to the funds that can be raised from the participants. In other words, it is the sum of the expected costs of all participants, when they treat their wastes out of coalition, minus the minimum total rebate making them participate in the regional project.

After solving the LP, three specific situations emerge regarding the total cost of the regional project (C_r), which the regional authority is trying to implement, and the funds collected from all necessary participants for the same regional project ($\sum c(i) - P_{\min}$):

(a) $C_r > \sum c(i) - P_{\min}$: Here, the regional authority cannot obtain sufficient funds to pursue the grand coalition. In other words, the necessary fund for the regional project, C_r, is greater than the collectable funds, $\sum c(i) - P_{\min}$. Therefore, the authority needs an outside subsidy to run the project.

(b) $C_r = \sum c(i) - P_{\min}$: In this case, the regional authority is at the breakeven point to realize the regional project (after rebates are paid). In other words, the necessary fund for the regional project, C_r, is equal to the collected fund, $\sum c(i) - P_{\min}$.

(c) $C_r < \sum c(i) - P_{\min}$: In this case, the regional authority has more than sufficient funds to implement the project, i.e., the collected funds ($\sum c(i) - P_{\min}$) are more than the necessary funds for the regional project, C_r. Thus, the regional authority has a surplus, which can be used for other activities needing funds.

3.1.3 Application of Cooperative Games to Water Allocation Problems

There is a number of studies analyzing international water allocation problems as non-cooperative zero sum games, in which the water withdrawn by one player is the loss of the other(s) (Postel, 1996; Ohlsson, 1995; Wolf & Dinar, 1994; Rogers, 1969, 1993;

Naff 1994; Thomas and Matson, 1984; Berthelot, 1997; Turan & Kut, 1997; Postel, 1997). These studies emphasize the importance of and benefits from cooperative attitudes. However, there are few quantitative approaches. Among them, three cooperative game theory studies are reviewed in this section. The first two are by P. Rogers (1969 and 1994) about the Ganges River and its basin, and the last one is by Dinar & Wolf (1994) about the Nile. The differences between the two Rogers's articles are in the use of game theory. The first article, defines alternative strategies (six cooperative and non-cooperative alternatives), next computes the returns using LP, and then analyzes the cooperative and noncooperative returns. In his second article, Rogers utilizes the results of Quinn's (1991) study to find a core solution among the three riparian nations (Nepal, India, and Bangladesh), and then summarizes the difficulties of implementing the core solution. In the Dinar & Wolf (1994) study, the emphasis is on the potential of water markets. They examine the political nature of the problem that prevents the implementation of the cooperative solution: Trading the Nile water among two countries and four stakeholder regions (Egypt, Israel, West Bank, and Gaza Strip). An optimization technique (LP) is used to compute the expected maximum benefits for the different game strategies (cooperative vs. noncooperative). The inclusion of nonriparian countries into the water allocation model can be considered as exemplary for further water allocation studies utilizing water markets.

3.1.3.1. Game Approach Only

In Rogers's (1969) article, "A Game Theory Approach to the Problems of International River Basins," there are two major players, India and East Pakistan (Bangladesh). His optimization model (LP) incorporates power generation, irrigation benefits, costs of ground and surface water storage, and costs of embankment. Also navigation control, salinity control, and flood control, for which there is no benefit function, are incorporated into the model simply through constraints. Based on combinations of 'do', 'not do', 'do together by separate budgets', and 'do together by

common budget' strategies, he derives six game strategies, four of which are non-cooperative (1 - 4) and two of which are cooperative (5 and 6):

Game strategies:

(1) Both India and East Pakistan do nothing;

(2) India makes an optimal plan for its parts of the region and East Pakistan does nothing. East Pakistan suffers from large flood damages, but smaller than in Case 1 due to the complementarity of the Indian action;

(3) India does nothing, and East Pakistan makes its own optimal plan on the unregulated rivers.

(4) India makes an optimal plan for its part of the region, and then East Pakistan makes its own optimal plan based upon the physical outputs of the Indian plan.

(5) A joint optimal development plan is made for the region by both India and East Pakistan, subject to the proviso that their budgets are allocated each to its own region

(6) A joint plan is made in which the separate budgets are summed together as a single regional budget.

For each game strategy, a benefit value is generated. Alternatives 5 and 6 give the highest maximum returns. Considering the results, the author concludes that, although the data are limited and not reliable, and the model is too crude to comprehend the real nature of the complex system, there is a potential to work on cooperative action by the two countries about the utilization and control of the Ganges-Brahmaputra. The game theory application is used to show the potential of the cooperative actions (non-zero sum games) rather than finding a core solution.

In Rogers's (1993) second article, "The Value of Cooperation in Resolving International River Basin Disputes," the emphasis is set on water resources allocation disputes among riparian countries, rather than on the optimum utilization of the river basin. The study reviews the political reasons for the conflicts and the international legal framework for international water allocation problems. Regarding the 'reasonable and

equitable share' principle proposed by the Helsinki Rule (Article 5) and by the UN International Law Commission (ILC – Article 6), the author outlines the contents of the analyses based on the principles of 'Pareto-Admissibility,' 'Superfairness' and 'Game Theory' criteria. Then he applies this framework to the Ganges-Brahmaputra case. Later he makes three different allocation analyses based upon (1) 'Reasonable and Equitable' sharing, (2) Pareto-Admissibility, and (3) Game theory.

Analysis Criteria:

Pareto-Admissibility: **For every riparian county, if the new allocation *x* brings higher net benefits than the net benefit from former allocation *y* ($NB_i(x) \geq NB_i(y)$), *x* is superior (preferred) to y. Pareto-Admissibility for *x* is satisfied if there is no allocation plan *y* which is preferred over *x*.**

Superfairness: **This criterion is based on the fair division of a stake, so that "[a] distribution is called (nonstrictly) superfair if each class of participants prefers its own share to the share received by another group, that is, if no participant envies the other" (Roger, 1994, p. 117-31). Actually, Pareto superiority does not necessarily satisfy Superfairness. For instance, one could choose an allocation inferior to the Pareto optimum allocation.**

Game Theory:

Let $v(i)$ and $v(S)$ be the benefits to player *i* and coalition *S*, and p_i the unknown imputations of the benefits of the grand coalition $v(N)$. The core is defined by the following equations (similar to Equations 3.2 - 3.4, but with benefits functions instead of costs):

$$p_i \geq v(i) \quad \text{for } i=1,2,\ldots,n \quad \text{(individual rationality)} \tag{3.26}$$

$$\sum_{i \in N} p_i = v(N) \quad \text{(allocation of grand coalition)} \tag{3.27}$$

$$\sum_{i \in s} p_i \geq v(S) \quad \text{for all } S \subset N \quad \text{(coalition rationality)} \tag{3.28}$$

Models and Their Applicability

(1) **Allocation Analyses Based upon 'Reasonable and Equitable' Sharing: The analyses are prepared with respect to a series of scenarios of percentage allocation of the potential water supply among the three riparian countries, based alternatively on the shares of land area, cultivated area, population, total runoff, irrigation potential, and hydroelectric potential. The allocation of water proportional to these shares is seen as potentially unacceptable, due to the high shares of India (70-85%). Therefore, the 'Reasonable and Equitable' sharing criterion does not properly deal with the Ganges-Brahmaputra issues.**

(2) **Allocation Analyses Based upon Pareto-Admissibility: the global maximum is obtained by maximizing the sum of all the benefits generated by allocation x_i (*i=1,2, 3:* India, Bangladesh, Nepal) (Equation 3.29). When using Equation (3.30) all solutions are Pareto Admissible. To generate a Pareto-Admissible solution, a weighted ($w_i \geq 0$, at least one $w_i > 0$) sum of the benefits is maximized, (Equation 3.30):**

$$Max[NB1(x_1) + NB2(x_2) + NB3(x_3)] \qquad x \in X \qquad (3.29)$$

$$Max[W_1 NB1(x_1) + W_2 NB2(x_2) + W_3 NB3(x_3)] \qquad x \in X \qquad (3.30)$$

The author plots the Pareto frontier, using 17 weight cases, and evaluates the allocations considering the Superfairness criterion. Although all of the alternatives are Pareto-Admissible, political reasons may prevent such an allocation. For instance, Bangladesh may prefer a less favorable alternative over a Pareto-Admissible one that requires a dam construction in India, thus enhancing India's power to control water flows. This means that Pareto-admissibility is not a sufficient criterion to satisfy all players.

(3) **Allocation Analyses Based upon Game Theory: Roger (1994, p. 128) checks the existence of a core solution. He initially derives the seven necessary constraints coming from the theory (Equation 3.26 - 3.28). These constraints are: *v(1)*: Maximum**

net benefits available to India assuming that there is no development in the other parts of the basin. Solve the basin model with separate budget for India and virgin inflows from Nepal. (Rs 4184 per year); *v(2)*: Maximum net benefits available to Bangladesh assuming that Nepal and India are trying to maximize their joint net benefits. Use a separate budget for Bangladesh and the border flows derived from the Nepal-India coalition solution (Rs 2754 per year); *v(3)*: Maximum net benefits available to Nepal. Since Nepal is upstream of India and Bangladesh solve the problem with a separate budget for Nepal and no constraints on the border flow (Rs 23 per year); *v(12)*: Maximum net benefits for a coalition of India and Bangladesh. Joint budget for these countries and the inflows from Nepal set at the level of no development in Nepal (Rs 8265 per year); *v(13)*: Maximum net benefits for a coalition of India and Nepal. Joint budget for the two countries. No constraints on the downstream flows in Bangladesh (Rs 4409 per year); *v(23)*: Maximum net benefit for a coalition of India and Bangladesh. Joint budget for the two countries. Assume no development in India (Rs 3729 per year); and *v(123)*: Maximum net benefits to the 'Grand Coalition' of the three countries. This is the optimum use of basin (Rs 8643 per year). With respect to these constraints, Rogers concludes that there exist core solutions.

Finally, in order to arrive at a Pareto-Admissible solution or one of the core solutions, Rogers suggests that river systems be managed under a single authority, and side payments be paid to the disadvantaged parties for externalities. In this way, a stable solution can be generated. However, the concept of the nation-state sovereignty makes such a cooperation difficult to pursue. Rogers concludes the article by stressing the importance of a consistent framework and methodology to develop and sort out potential solutions for water allocation problems, especially under population growth pressures.

3.1.3.2. Game Approach with Politics

Dinar & Wolf (1994), in their article "International Markets for Water and Potential for Regional Cooperation: Economic and Political Perspectives in the Western Middle East," incorporate three main aspects of water issues - political, economic, and technical - to find out an efficient solution for the water scarcity problem. The authors utilize water markets, optimization techniques, and game theory to find out the expected benefits of international water transfers and their justification in the Middle East. Unlike earlier models, this study addresses international (including non-riparian demanders) water allocation using water markets (WM). Dinar and Wolf state the potential of technical improvements in the utilization of water in different sectors, specifically agriculture, which is the dominant water consumer. The purpose of technical improvements is not only productivity increase in the sector, but also water savings in order to be able to transfer surplus amounts to other sectors and even to nonriparian international customers. In this study, Israel (IL) is being represented as a high irrigation technology holder, and Egypt (EG) is introduced as a country having a large water supply that can be sold in the region. The other stakeholders are the Gaza Strip (GS) and the West Bank (WB).

Dinar and Wolf list the distinctive features of their study by stating the weakness of the existing literature on international water transfers: (1) It is based on intercountry and interregional water transfers in riparian countries, but not in other countries; (2) There is no consideration of water saving technologies and potential improvements in agriculture; (3) It ignores the political, ideological, and cultural factors preventing the consideration of efficient alternatives. Their objectives are: (1) to analyze the potential welfare benefits of water markets and water-saving technologies; (2) to utilize game theory approaches with both cooperative and noncooperative strategies, leading to different overall welfare benefits; and (3) to clarify the political acceptability of water trade when including the other riparian countries, Ethiopia and Sudan, in the Nile basin.

Theory: In order to explain the potential of water trade and the advantage of better technology to save water, the paper presents two main theoretical analyses involving the nature of demand functions and the nature of welfare functions. The first analysis is akin to Samuelson's (1952) analysis, where he uses the interregional price differences as the basis for interregional trade and improvement in welfare. The second analysis is about the dilemmas of two different countries, where one is developed in high technology, and the other is an underdeveloped water-rich country. The developed country utilizes its technical capacity as a substitute for water, i.e., using technology to reduce water consumption and system losses, and to increase productivity in different water-using sectors. On the other hand, the relatively underdeveloped country consumes more water and uses less water-saving technologies due to their high economic costs. The authors use these differences as a base for water and technology trade. The underdeveloped country imports technology from the developed country in order to save water, which in turn to is exported to the technology-exporting country. Both trading countries can expect welfare benefits from these trades.

Optimization Model and Game Theory (Dinar & Wolf, 1994, p. 48, 49): Dinar and Wolf use a simple LP model to find the maximum benefits of the trade. All players are rational players in the economy. R^j is the payoff function for player j (j=*EG, IL, GS, WB*), and its maximization is subject to price and water quantity constraints. The quantities of water and technology sold are determined exogenously, and the prices are determined endogenously. The following optimization formulation is rerun for each stakeholder j.

$$\begin{aligned} Max \quad R^j = {} & F^j(W^j, T^j) \\ & + \sum_{i \neq j} W^j{}_{(s)\,j,i} P_{(s)}^{W^j_{j,i}} - \sum_{i \neq j} W^j_{(b)\,i,j} P_{(b)}^{W^j_{i,j}} \qquad \forall j \neq i \qquad (3.31) \\ & + \sum_{i \neq j} T^j_{(s)\,j,i} P_{(s)}^{T^j_{j,i}} - \sum_{i \neq j} T^j_{(b)\,i,j} P_{(b)}^{T^j_{i,j}} - \sum_{g} T^j_g P_g^{T^j} \end{aligned}$$

subject to:

$$W^j \le \overline{W}^j - \sum_{i \ne j} W^j{}_{(s)\,j,i}{}^j + \sum_{i \ne j} W^j_{(b)i,j} \qquad \forall j \ne i \qquad (3.32)$$

$$P_{(s)}^{W^j_{j,i}} \ge MC^j_{(s)\,j,i} + VMP^j_w \qquad \forall j \ne i \qquad (3.33)$$

$$P_{(b)}^{W^j_{i,j}} \le VMP^j_W \qquad \forall j \ne i \qquad (3.34)$$

$$P_{(b)}^{T^j_{k,j}} \le VMP^j_T \qquad \forall j \ne i; k = i, g \qquad (3.35)$$

***The endogenous decision variables*:**

R^j : **payoff of player j;**

$P_{(s)}^{K^j_{j,i}}$: **the price of resource sold by i to j (K = water W or technology T);**

$P_{(b)}^{K^j_{i,j}}$: **the price of resource bought by j from i (K = water W or technology T);**

***The exogenous parameters*:**

F^j : **the water welfare production function of player j;**

W^j : **the water utilized by player j;**

$K^j{}_{(s)\,j,i}$: **the resource sold by i to j (K = water W or technology T);**

$K^j_{(b)i,j}$: **the resource bought by j from i (K = water W or technology T);**

$T^j_{(g)}$: **the technology purchased out of the region;**

$T^j_{(b)}$: **the technology used by player j;**

$P_{(g)}^{T^j}$: **the cost of technology purchased out of the region (exogenously fixed in the international competitive market);**

$\overline{W}^j$: **water endowment;**

VMP^j_w: **the value of marginal productivity of water for j;**

VMP^j_T: **the value of marginal productivity of technology sold by either i or g to j; and**

$MC^j_{(s)\,j,i}$: **the marginal cost of water transfer from i to j.**

In the objective function (Equation 3.31), the stakeholder j is either water buyer & technology seller or water seller & technology buyer. Therefore, (1) the buyer maximizes R^j while decreasing water prices, $P_{(b)}^{W_{i,j}^j}$; and (2) the seller maximizes R^j while raising water prices $P_{(s)}^{W_{j,i}^j}$. In Equation (3.31), $F^j(W^j, T^j)$ is excluded under the conservative assumption that the welfare gains derived from the increase in yields by the application of new technology can be ignored, and that the total agricultural land is kept constant.[3] Because the technology can be supplied out of the region, the price of technology is constant and the quantity of technology demanded is exogenously determined. Hence, the first and third lines in the objective function (Equation 3.31) can be deleted, and the second line constitutes the basis for optimization. The quantity of water demanded is also exogenously determined. Equation (3.32) defines water resources constraints: the sum of water used and traded, sold (s) and bought (b), cannot exceed the total water endowment $\overline{W}^j$. The price of water sold must be equal to or greater than the marginal cost of water transfer plus the marginal productivity of water sold (Equation 3.33). On the other hand, Equation (3.34) indicates that the price of water bought must be equal to or less than the marginal productivity of water at the destination. In the same way, Equation (3.35) indicates that the price of technology must be lesser than or equal to the marginal productivity of technology.

N is the set of all players in the regional game, X represents the set of all feasible coalitions combinations in the game, and $x(x \in X)$ is one of these feasible coalitions. The individual players are j = *EG, IL, GS, WB*, and the grand coalition is N. Equation (3.36) represents the total return for coalition x from the noncooperative game, and provides the minimum return to be achieved by any cooperative game.

$$f^x = \sum_{j \in x} R^j \quad \forall x \in X, \tag{3.36}$$

Later the authors normalize the return from this noncooperative game by setting it equal to zero. This means that positive returns are only possible if there is trade. Regional cooperation is economically feasible if Equation (3.37) is verified (Dinar & Wolf, 1994, p. 49).

$$\sum_{j \in x} f^j - R^j \geq 0 \quad \forall x \in X. \tag{3.37}$$

The total number of possible games is $2^4 - 1 = 15$.[4] Dinar and Wolf list all possible games under three different categories: 1) non-cooperation, 2) partial cooperation, and 3) complete cooperation. Then they eliminate the cooperation alternatives not leading to any positive benefit by water or technology trade. Finally, they reduce the alternatives to two coalitions: *{EG;GS}* and *{EG;GS;IL;WB}*.

***The Political Environment and Its Impacts on Regional Arrangements:* Dinar and Wolf use the 'Political Accounting System' (PAS) method to identify the political acceptability of their scenarios. PAS is a conceptually simple evaluation system that allows for incorporating different concerns and for ranking policies, programs, and projects under three major categories: *position, power* and *salience.* In their study, position ranges from negative to positive, with scores from -3 to +3, and power and salience are scored from 0 to 3. After analyzing a stakeholder's position, power, and salience on a scenario, the produced scores are multiplied with each other, and the result represents the attitude of the participant on that scenario. The same procedure is completed for each relevant stakeholder. In order to compare the scenarios, individual responses to the scenarios are summed and a grand total is obtained for each scenario. The higher the total, the most likely is the implementation of the scenario.**

***The Regional Game:* Ignoring the agricultural benefits generated from the application of better irrigation technology in the water-exporting country, the regional benefit from water and technology trade is only the sum of consumers' benefit or**

exporters' (producers') benefits, which are derived from the multiplication of the quantity of water traded by the price difference before and after the trade.

Scenario 1: **All players try to optimize their resources unilaterally; therefore, there is no generated benefit. The regional trade benefits are zero for all players:**

$$R^{\{EG\}} = R^{\{IL\}} = R^{\{GS\}} = R^{\{WB\}} = 0 \qquad \textbf{(3.38)}$$

Scenario 2: **There is trade among *EG* and *GS*, but not with the other players, *IL* and *WB*. The benefits for *IL* and *WB* are zero due to lack of trade with the water-holding country *EG*.**

$$\textit{Maximize}_{P_1^{W_{EG}}}\ R^{EG\in\{EG;GS\}} + R^{\{IL\}} + R^{GS\in\{EG;GS\}} + R^{\{WB\}} \qquad \textbf{(3.39)}$$

subject to:

$$P_1^{W_{EG}} \geq .006 + .214,$$

$$P_1^{W_{EG}} \leq .300.$$

The objective function contains the following components.[5]

$$R^{EG\in\{EG;GS\}} = 100 \cdot 10^6 [P_1^{W_{EG}} - (.006 + .214)]$$

$$R^{GS\in\{EG;GS\}} = 100 \cdot 10^6 [.300 - P_1^{W_{EG}}]$$

$$R^{\{IL\}} = 0$$

$$R^{\{WB\}} = 0$$

The linear programming (LP) computes the equilibrium price $P_1^{W_{EG}}$.

Scenario 3: **All players participate into the grand coalition in which there is potential trade, if feasible, among all participants.**

$$\begin{aligned} Maximize_{P_2^{W_{EG}},\, P^{W_{IL}}}\ & R^{EG\in\{EG;GS;IL;WB\}} + R^{IL\in\{EG;GS;IL;WB\}} \\ & + R^{GS\in\{EG;GS;IL;WB\}} + R^{WB\in\{EG;GE,IL,WB\}} \end{aligned} \qquad (3.40)$$

subjet to:

$$P_2^{W_{EG}} \geq .006 + .198 + 21.4/500,$$

$$P_2^{W_{EG}} \leq .300,$$

$$P^{W_{il}} \leq .300,$$

$$P^{W_{il}} \leq .140.$$

The objective function contains the following components:[6]

$$R^{EG\in\{EG;GS;IL;WB\}} = 500 \cdot 10^6 (P_2^{W_{EG}} - .204) - 21.4 \cdot 10^6,$$

$$R^{IL\in\{EG;GS;IL;WB\}} = 400 \cdot 10^6 (.300 - P_2^{W_{EG}}) + 68 \cdot 10^6 + 26.4 \cdot 10^6 + .5 \cdot 10^6 (P^{W_{il}} - .170),$$

$$R^{GS\in\{EG;GS;IL;WB\}} = 100 \cdot 10^6 (.300 - P_2^{W_{EG}})$$

$$R^{WB\in\{EG;GE,IL,WB\}} = 50 \cdot 10^6 (.300 - P^{W_{il}}) - 1.5 \cdot 10^6$$

WM & PAS Results and Conclusions: **Before considering PAS analyses, the authors summarize the political concerns of each country in terms of sharing water of the Nile and of having good or bad relations with each other. For example, Ethiopia, contributing approximately 85% of the water of the Nile from its water catchment area, wants to use more water for its agricultural development by diverting water from the Nile; however, Egypt opposes any project significantly reducing the water coming downstream, based on rights it claims for historical reasons. Although Sudan has an agreement with Egypt to share water, Sudan needs more water for its own development and tends to object to a water-market based allocation, fearing that it will give no benefits**

to Sudan. There are other political factors, such as the conflict between Palestinians and Israelis.

The numerical solutions indicate that the beneficiary of the trade based on the grand coalition is IL, receiving 89% of all benefits. In terms of the Pareto-superiority criterion, when excluding the political aspects of the problem, the grand coalition, which has the highest return, is a theoretically viable alternative. However, it is unlikely to be realized. On the other hand, the subcoalition alternative providing water trade between EG and GS is practically much more realistic (with 45 positive points in the PAS analysis) than the grand coalition (with only 2 positive points). This clarifies the political attitudes of all parties, giving no chance for WM, although WM is a Pareto-superior solution for all parties in the economic sense.

The contributions of study are: (1) Introduction of an international WM among the different stakeholders, most of whom are not riparian counties; (2) Utilization of game theory and optimization; (3) Incorporation of political feasibility analyses; and finally (4) An approach applicable to other countries such as Turkey, Iraq, Syria, and other nonriparian countries such as Kuwait, Saudi Arabia, Jordan, Israel, and Lebanon, that would like to receive water from the Euphrates and Tigris.

3.2. Spatial Equilibrium Models

3.2.1. Spatial Price Equilibrium Model by Samuelson (1952)

P. A. Samuelson's (1952) paper, "Spatial Price Equilibrium and Linear Programming," is the first to fully formalize the spatial price equilibrium problem. This model has become the basis for most further developments in interregional trade models considering spatial distances and costs. It involves two theoretical concepts. The first one is the *maximization of the net social payoff (NSP)* by means of trade among different producer and consumer regions. The other one is the utilization of linear programming in order to ***minimize interregional transport costs (TC).*** **Samuelson combines these two concepts into one interregional trade model, optimizing *NSP* while simultaneously considering transport costs among the regions.**

The preconditions of an interregional trade **are: (a) existence of at least two regions, (b) regional demand and supply (D&S) functions for a normal good, and (c) interregional transport costs (*TC*) controlling the optimum trade (flow of goods). Any price difference creates an opportunity for arbitrage between regions. In other words, until regional price differences are less than or equal to transport costs, goods are transported from low price areas to high price areas. Both the selling region and the buying region get extra benefits from this trade, i.e., in both regions welfare levels increase due to the transfer of the excess supply to the excess demand area. In his two-region model, Samuelson maximizes *NSP* and minimizes *TC*, and finds an optimum good allocation considering both *TC* and *NSP* simultaneously. Because of transport costs, the equilibrium prices that are the solutions of this optimization problem are not the same for the buying and selling regions. Buyers also pay transport costs in addition to the equilibrium supply price in the supplier region. When transport costs equal zero, prices must be equal in both regions.**

Definition of the Social Payoff (SP): **To define *SP*, Samuelson uses the excess supply (*ES*) functions from the given D&S curves of both regions.[7] Figure (3.1) presents the two *ES* functions, where the excess quantities (which are of course traded between the two regions) appear on the horizontal axis and the price on the vertical axis. These two, functions, ES_1 and ES_2, enable us to measure the consumer and producer surplus resulting from the trade of quantity *M*, as represented by the polygon A_1JKA_2 in the same figure. This surplus will enable us to compute the net social payoff (*NSP*), the area represented by A_1FJ and A_2YK. At equilibrium, the area *YFJK* represents the transport cost. In Figure (3.2), the *NN* curve, which representing the area defined by A_1A_2KJ in Figure (3.1), is the social payoff (*SP*), a function of the quantity traded (E_{12}). The point represented by M in**

both Figures (3.1) and (3.2) is the optimum quantity traded. At M, the transport cost and the interregional price difference are equal, and the net social payoff takes its maximum value. In Figure (3.2), Samuelson defines the *TC* and *SP* functions as a function of the quantity imported or exported. Then he derives the *NSP* function by a vertical subtraction of *TC* from the *SP* function. The value *M* (quantity exported) making the first derivative of *NSP* equal to the zero is the optimum quantity exported (i.e. imported by the buyer region). The *TC* function is assumed a linear function having a constant unit cost for each unit of good transported from one region to the other.

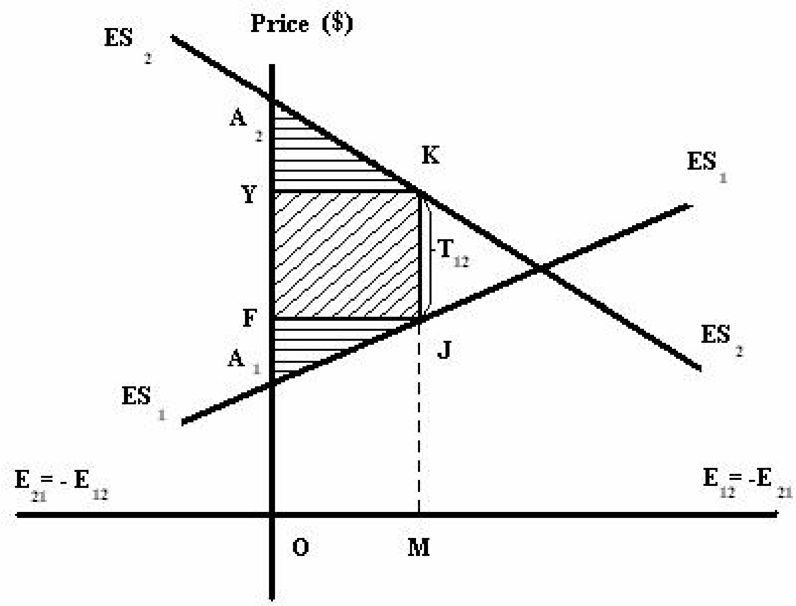


Figure 3.1: Excess Supply Functions and Spatial Equilibrium[8]

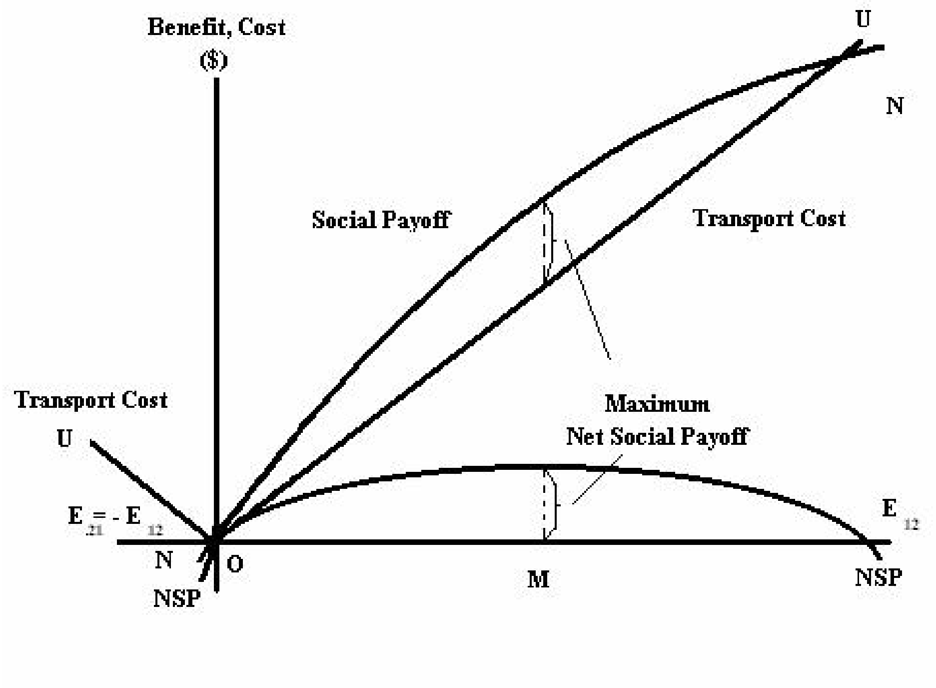


Figure 3.2: Maximizing Net Social Payoff[9]

In the following *mathematical formulation* (Equation 3.41) for a 2-region system, E_{12} is the equilibrium quantity exported and imported. The integrals represent the areas between the *ES* curves, from zero trade quantity to the equilibrium quantity traded, E_{12}. The first integral represents the area A_1OMJ (Figure 3.1), and the second represents A_2OMK (Figure 3.1). Their difference is equal to the total *SP*, including transport cost. Then, the transport cost, $t_{12}(E_{12})$, represented by the area *YKJF* in Figure (3.1), is subtracted and the *NSP* is derived, with:

$$\text{Maximize } NSP = -\int_0^{E_{12}} s_1(x)\,dx - \int_0^{-E_{12}} s_2(x)\,dx - t_{12}(E_{12}) \tag{3.41}$$

The maximum of *NSP* taken place when

$$dNSP / dE_{12} = 0, \tag{3.42}$$

which leads to

$$-T_{21} \le s_2(E_{21}) - s_1(E_{12}) \le T_{12} \quad \text{and} \tag{3.43}$$

$$E_{12} + E_{21} = 0 \tag{3.44}$$

where:

$S_i(E_i) = -\int_0^{E_i} s_i(x)\,dx$: the area under the excess demand curve; (3.45)

$s_i(x)$: inverse excess demand function, a function of the amount of goods transferred;

$t_{12}(E_{12})$: transport cost, t_{12}, paid for transporting the goods E_{12} from region 1 to 2;

$s_1(E_{12})$ or $s_2(E_{21})$: regional prices as function of transported goods, $E_{12}=- E_{21}$.

After obtaining the first derivative of the *NSP* function with respect to the quantity traded, we derive the conditions (Equations 3.43 and 3.44) defining the equilibrium prices ($s_i(x)=P_i$) leading to regional trade. After setting the first derivative of the *NSP* equal to zero, we can derive the prices maximizing the *NSP* in both regions. If the price difference exceeds transport cost, there is still a trade opportunity to further increase *NSP*. While maximizing *NSP*, all trade opportunities are utilized until the interregional price difference is equal to the interregional cost. Extending the model to n regions, we obtain:

$$NSP = \sum_{i=1}^{n} S_i(E_i) - \sum_{i<j}^{n} \sum_{j=1}^{n} t_{ij} E_{ij} \tag{3.46}$$

$$-t_{ij} \le s_i(E_i) - s_j(E_j) \le t_{ji} \quad \text{(for all } i,j\text{=1,…,}n\text{)} \tag{3.47}$$

The equilibrium prices in exporting and importing regions satisfy the condition in Equation (3.47) where *j* and *i* represent the origin and destination regions, respectively. In the *n* region case, $E_i = E_{i1} + ... + E_{in}$ is the sum of the imports of goods from all other regions to region *i*.

After solving for the price of the good in each region, we can easily derive *the quantity demanded and supplied* from the existing D&S functions. In order to find the quantities *exported and imported*, the following transportation model (LP) may be used. The idea is to satisfy the demand and supply constraints while minimizing *TC*:

Minimize $$\sum_{i=1}^{m} \sum_{j=m+1}^{n} t_{ij} E_{ij} \tag{3.48}$$

subject to:

$$\sum_{j=m+1}^{n} E_{ij} = E_i \quad (i = 1,...,m) \tag{3.49}$$

$$\sum_{i=1}^{m} E_{ij} = (-E_j) \quad (j = m+1,...n) \tag{3.50}$$

3.2.2. Spatial Equilibrium Model with Programming Formulations

T. Takayama & G. G. Judge (1964) article "Spatial Equilibrium and Quadratic Programming" elaborates on Samuelson (1952). Their contribution is the redefinition of models in practical forms applicable to real world cases. For each case, they give one programming example, with hypothetical transport costs and D&S curves.

> "Within the framework of interconnected competitive markets the purpose of this article is to show that by postulating appropriate *linear* dependencies between regional supply, demand and price it is possible to convert the Samuelson formulation into a quadratic programming problem. A computational algorithm is

then specified to obtain directly and efficiently the competitive optimum solution for regional prices and quantities and interregional flows: (1) linear demand functions and fixed regional supplies; (2) fixed regional demand and linear regional supply functions and (3) multiproduct linear regional demand and supply functions with linear substitution and/or complementary terms admitted" (Takayama & Judge 1964, p. 68).

The necessary inputs are a series of demand and supply functions and interregional transport costs, with *d, s, p, t,* and *x* representing demand, supply, the good's own price, transport cost, and the amount of goods transported, respectively. The subscripts *i* and *j* denote regions, (importing and exporting). We have:

$d_i = \alpha_i - \beta_i p_i \quad \alpha_i, \beta_i > 0$: Demand function for $i=1,2,\ldots,n$; (3.51)

$s_j = \theta_j + \gamma_j p^j \quad \theta_j >=< 0, \ \gamma_J > 0$: Supply function for $j=1,2,\ldots n$; (3.52)

t_{ij}: Transport unit cost between regions *i* and *j*;

x_{ij}: Nonnegative interregional flow (quantity of goods transported).

The following model (Equation 3.53) is similar to the model presented in Samuelson (1952). The first and the second components of *NSP* (first and second line) represent consumer and producer surpluses, derived from the excess supply and demand (ES= -ED) functions, and the remainder represents transport costs, which increase with the amount of good transported (*tx*). The pre-trade consumer and producer surpluses are represented by '∂_i' in region *i*. The model is then:

Maximize net social payoff:[10]

$$
\begin{aligned}
NSP(X) = & \sum_i \int_0^{\sum_j x_{ij}} (\lambda_i - \omega_i \sum_j x_{ij}) d(\sum_j x_{ij}) \\
& - \sum_j \int_0^{\sum_i x_{ij}} (\mu_j + \eta_j \sum_i x_{ij}) d(\sum_i x_{ij}) \\
& - \sum_i \partial_i - \sum_i \sum_j t_{ij} x_{ij}
\end{aligned}
\tag{3.53}
$$

where

$$\lambda_i = \alpha_i / \beta_i,\ \ \omega_i = 1/\beta_i,\ \ \mu_j = -\theta_j/\gamma_j,\ \ \eta_j = 1/\gamma_j \text{ for } j, i = 1,2,\ldots,n \tag{3.54}$$

$X = (x_{12} \ldots x_{nn})$ **: Vector of quantities used/transported (unknown);**

$\sum_j x_{ij}$ **: Total demand from region** ***i*****;**

$\sum_i x_{ij}$ **: Total supply to region** ***j*****.**

Equation (3.53) can be rewritten as:

Maximize

$$\begin{aligned} NSP(X) = {} & \sum_i \lambda_i \sum_j x_{ij} - \tfrac{1}{2}\sum_i \omega_i (\sum_j x_{ij})^2 - \sum_j \mu_j \sum_i x_{ij} \\ & - \tfrac{1}{2}\sum_j \eta_j (\sum_i x_{ij})^2 - \sum_i \partial_i - \sum_i \sum_j t_{ij} x_{ij} \end{aligned} \tag{3.55}$$

We can then derive the conditions justifying trade, which are the Kuhn-Tucker conditions stating the necessary conditions for a local maximum in a nonlinear optimization problem:

$$\partial NSP(X) / \partial x_{ij} = \lambda_i - \omega_i (\sum_j x_{ij}) - \mu_j - \eta_j (\sum_i x_{ij}) - t_{ij} \le 0 \tag{3.56}$$

$$(\partial NSP(X) / \partial x_{ij})\, x_{ij} = 0 \ \text{ for } \ x_{ij} \ge 0 \tag{3.57}$$

In the next section, the first and the second components of ***NSP*** **(first and second line of Equation 3.53), representing consumer and producer surpluses, will be the objective functions of the programming formulation, and the conditions derived from the first derivative of** ***NSP*** **with respect to** x_{ij} **will be its constraints.**
Using the demand and supply prices formulations

$$\lambda_i - \omega_i(\sum_j x_{ij}) = p_i, \tag{3.58}$$

$$\mu_j + \eta_j(\sum_i x_{ij}) = p^j, \tag{3.59}$$

Takayama and Judge restate the Kuhn-Tucker condition as follows:

$$\begin{aligned} p_i - p^j &\leq t_{ij} \\ (p_i - p^j - t_{ij})x_{ij} &= 0 \end{aligned} \tag{3.60}$$

The following presents Takayama & Judge's different programming formulations. There are three selected programming formulations: The *first* one finds the quantity traded; the *second* one solves for the prices maximizing the *NSP* and justifying interregional trade; and the *last* one incorporates multiple goods into the model.[11] The first two formulations are the reciprocal of each other, and are applicable to problems having (a) a constant demand (or supply) region with linear supply (or demand) functions or (b) both linear demand and supply functions. The last formulation is for the more complex linear demand and supply functions in which the various goods affect each other in terms of quantity produced and demanded.

I. Maximize NSP as a function of quantity: As can be seen from Equation (3.61), the *NSP* does not have a transport cost component; nonetheless, this component is redefined in the constraint part of the programming formulation, (Equation 3.62-3.63) In this way, the problem is redefined as a constrained optimization problem instead of an unconstrained one.

Maximize

$$\begin{aligned} NSP(X) = &\sum_i \lambda_i \sum_j x_{ij} - \tfrac{1}{2}\sum_i \omega_i(\sum_j x_{ij})^2 \\ &- \sum_j \mu_j \sum_i x_{ij} - \tfrac{1}{2}\sum_j \eta_j(\sum_i x_{ij})^2 \end{aligned} \tag{3.61}$$

subject to:

$$\lambda_i - \omega_i(\sum_j x_{ij}) - \mu_j - \eta_j(\sum_i x_{ij}) - t_{ij} \le 0 \qquad (3.62)$$

$$x_{ij} \ge 0 \qquad (3.63)$$

II. Maximize NSP as a function of price:

Maximize

$$\begin{aligned} NSP(P) &= \sum_i \int_0^{p_i} (d_i)\,dp_i - \sum_i \int_0^{\hat{p}_i} (d_i)\,dp_i - \sum_j \int_0^{p_j} (s_j)\,dp^j + \sum_j \int_0^{\hat{p}_j} (s_j)\,dp^j \\ &= \sum_i \alpha_i p_i - \tfrac{1}{2}\sum_i \beta_i (p_i)^2 - \sum_j \theta_j p^j - \tfrac{1}{2}\sum_j \gamma_j (p^j)^2 \end{aligned} \qquad (3.64)$$

subject to:

$$p_i - p^j \le t_{ij} \qquad (3.65)$$

$$p_i, p^j \ge 0 \qquad (3.66)$$

III. Multi-product case (maximizing the NSP as a function of price): **The following programming formulation applies to the multiregion-multiproduct case, where there are m products and n regions. It is assumed that demand and supply functions are well-behaved continuous linear functions. Indices *k* and *h* denote products in the demand and supply functions, with:**

$$D^k = (d_i^k) = \left(\alpha_i^k - \sum_{h=1}^{m} \beta_{hk}^i p_i^h \right) \qquad (3.67)$$

$$S^k = (s_j^k) = \left(\theta_j^k + \sum_{h=1}^{m} \gamma_{hk}^j p^{jh} \right) \qquad (3.68)$$

d_i^k**: demand of product *k* in region *i*.**

s_j^k**: supply of product *k* in region *j*.**

Maximize

$$
\begin{aligned}
NSP(P) &= \sum_{i} \sum_{k} \int_0^{p_i^k} (\alpha_i^k - \beta_{kk}^i p_i^k - \tfrac{1}{2} \sum_{h \neq k} \beta_{hk}^i p_i^h)\, dp_i^k \\
&\quad - \sum_{j} \sum_{k} \int_0^{p^{jk}} (\theta_j^k + \gamma_{kk}^j p^{jk} + \tfrac{1}{2} \sum_{h \neq k} \gamma_{hk}^j p^{jh})\, dp^{jk} \\
&= \sum_{i} \sum_{k} {}_i^k\alpha p_i^k - \tfrac{1}{2} \sum_{i} \sum_{k} \sum_{h} \beta_{hk}^i p_i^k p_i^h \\
&\quad - \sum_{j} \sum_{k} \theta_j^k p^{jk} - \tfrac{1}{2} \sum_{j} \sum_{k} \sum_{h} \gamma_{hk}^j p^{jk} p^{jh}
\end{aligned} \tag{3.69}
$$

subject to:

$$
p_i^k - p^{jk} \leq t_{ij}^k \tag{3.70}
$$

All three formulations are conceptually identical, the only differences being in solving the model for either price or quantity traded, and, thus, in the computation of the *NSP* (i.e. the necessary integration for computing the excess demand and supply traded). Takayama & Judge also elaborate objective functions and constraints to compute both prices and quantities together in one optimization setting. These more complex formulations are not reviewed here. The examples given in the article can also be solved in a two-step formulation. Initially, the relevant problem is solved for prices. Then using these prices, quantities demanded are computed. In the final stage, the quantities exported and imported are computed using the linear programming formulation for minimizing TC (transport costs).

3.2.3. Application of Spatial Equilibrium Models to Water Allocation Problems

Three empirical studies about the allocation of scarce water resources are reviewed: *Vaux & Howitt (1984), Flinn & Guise (1970)*, and *Booker & Young (1994).* The first deals with the allocation of regional water resources among regional demand nodes, the second deals with water allocation to different beneficiaries within and out of the river basin, and the third develops an interregional spatial equilibrium model for

water resources allocation considering the changing seasonal demands for water, the physical constraints of existing infrastructure, and a constant water supply.

3.2.3.1. 'Managing Water Scarcity: An Evaluation of Interregional Transfers' (Vaux and Howitt, 1984)

In their article, Vaux and Howitt (1984) study water resource allocation in California. In their literature review, Vaux and Howitt introduce Enke's (1952) model, which is often considered as a precursor to Samuelson's (1952) model. Vaux and Howitt then summarize Samuelson's (1952), Takayama and Judge's (1964), and Flinn & Guise's (1970) models, and state that the major difference between the former studies and Flinn & Guise's (1970) model is that the latter uses nonlinear demand functions, which may be more appropriate to find accurate equilibrium prices and quantities.

Vaux and Howitt's objective is to test market mechanisms, which may work much more efficiently than institutional approaches for solving scarcity problems, by extending water systems and /or by finding new water sources. Theoretically, the market is a mechanism for the efficient allocation of *exclusive* and *rivalry* goods. Since water is getting scarce, and thus is becoming a rivalry and exclusive good, the market may becomes an appropriate mechanism for its allocation. In the western U.S., California is a good case to test a water market as a substitute for central water institutions, i.e., for testing the economic potential of interregional trade, in contrast to large conveyance facilities (Vaux and Howitt, 1984, p. 785). The model requires as inputs the demand & supply functions and interregional transport costs. The water demand & supply functions are prepared for three time periods (1980, 1995, and 2020). The authors consider two scenarios: (1) one scenario retains the current pricing practices in each region, without any interregional market-based transaction, i.e., every region finds its equilibrium quantity and price unilaterally; and (2) the other scenario utilizes water trade among the regions to determine prices.

The current pricing practice, in which there is no interregional water transfer, is based on marginal cost pricing. Whenever the marginal cost exceeds the average cost, average cost pricing is no longer a valid approach, since it does not reflect the scarcity cost involved and encourages excessive water consumption. However, average cost pricing is applied when decreasing costs prevail in order to be able to cover costs, Furthermore, whenever economic demand justifies new supply augmentation, supply-increasing projects are implemented. In the *base case scenario*, the authors first utilize the existing prices in 1980, and then utilize the scarcity prices, which account for the growth of the urban, industrial, and agricultural sectors, as a base for the computations for the year 1995 and 2020. Because supplies are inelastic, the increasing prices do not significantly change the quantity supplied, which is approximately constant. In the *second scenarios*, due to interregional trade, supplies are augmented from the regions having relatively elastic supply to the high price regions having inelastic water supply.

Optimization Model:

The model is built upon the following demand and supply curves.

Demand relationships:

$$Q_i^D = a_i + b_i P_i^{h_i} \tag{3.71}$$

$$a_i > 0 \qquad b_i < 0 \qquad h_i = 1/2 \qquad i = 1,2$$

$$a_i > 0 \qquad b_i < 0 \qquad h_i = 1 \qquad i = 3,\ldots,5$$

where

Q_i^D: quantity demanded by the ith region;

P_i : demand price of water in the ith region;

a_i, b_i, h_i: parameters.

Supply relationships

$$Q_j^S = c_j + d_j P_j \tag{3.72}$$

$$c_j <>= 0 \quad d_j \geq 0 \qquad j = 1,\ldots,8$$

where

Q_j^S : quantity supplied by the jth region;

P_j : marginal cost of water in the jth region;

c_j, d_j : parameters.

The different h_i values, derived from existing data, imply both linear and nonlinear demand functions.

Objective function:

$$\begin{aligned} \textit{Maximize NSP} = & \sum_{i=1}^{5} \int_{0}^{Q_i^D} \left(\frac{-a_i}{b_i} + \frac{q}{b_i} \right)^{1/h_i} dq \\ & + \sum_{j=1}^{8} \int_{0}^{Q_j^s} \left(\frac{-c_j}{d_j} + \frac{q}{d_j} \right) dq \\ & - \sum_{i=1}^{5} S_i - \sum_{j=1}^{8} M_j - \sum_{i=1}^{5} \sum_{j=1}^{8} T_{ji} Q_{ji} \end{aligned} \tag{3.73}$$

subject to:

$$Q_i^D = \sum_{j=1}^{8} Q_{ji} \tag{3.74}$$

$$Q_j^s = \sum_{i=1}^{5} Q_{ji} \tag{3.75}$$

$$Q_{ji}^D \geq 0 \tag{3.76}$$

where

Q_i^D : total quantity consumed in demand region i;

Q_j^s : total quantity supplied by supply region j;

Q_{ji} : quantity transferred from supply region j to demand region i;

S_i : pretrade consumer surplus in the ith demand region;

M_j : pretrade producer surplus in the jth supply region;

T_{ji} : unit cost of transporting water from region j to region i;

The model yields two important results: water transfer by trade (1) reduces the need for large supply-augmenting conveyance facilities, which are required in the base case scenario, and (2) generates monetary benefits, i.e., provides welfare gains among the buyers and sellers by the transfer of excess supplies to the excess demand regions. The highest benefits are achieved in the urban areas facing significant growth, and therefore significant demand for water. While water is being transferred to urban areas, the supplying regions are getting the monetary benefits of water exported. In this way, without new supply augmentation projects, the water scarcity problems are resolved through the market mechanism.

3.2.3.2. 'An Application of Spatial Equilibrium Analysis to Water Resource Allocation' (Flinn & Guise, 1970)

In their article, Flinn & Guise (1970) study the allocation of limited water resources in a closed system. Their model also incorporates the physical constraints of water delivery systems and seasonal variations in water demands. Their goal is to demonstrate that the interregional equilibrium models, originally developed by Samuelson (1952) and elaborated by Takayama & Judge (1964), may be used to determine the efficient allocation and pricing of water in a river basin. It is assumed that there is a constant supply of water and a given physical infrastructure limiting the actual water delivery, with some system losses. This leads to different equilibrium prices in different regions in different seasons. The physical structure of the hypothetical river basin contains an industrial complex, an urban area, and three irrigation areas. Before distribution over the industrial complex and urban area through a pipeline, water is purified at a filtration plant, whereas irrigation water is distributed by irrigation canals after withdrawal from the river.

Model Development

In developing a quadratic programming formulation, Flinn & Guise (1970) formalize the trade model to find the maximum 'Net Social Payoff' (*NSP*) and the optimum quantity traded. Equation (3.77) shows demand functions for different time periods (*i*) and regions (*j*). The authors transform Equation (3.77) into the equivalent Equation (3.78), in order to be able to present the mathematical procedures in a compact matrix form:

$$x^i_j = \alpha^i_j - \beta^i_j p^i_j \qquad i=1,..,n \text{ and } j=1,\ldots m \qquad (3.77)$$

$$\alpha^i_j > 0 \text{ and } \beta^i_j > 0$$

where

i: discrete time period in which water is demanded (*1,..n*);

j: region in which water is demanded (*1,…,m*);

$X = [x^i_j]$: a column vector, the elements of which denote the quantity of water x^i_j consumed in region *j* during period *i*;

$T = [t^i_j]$: a column vector, the elements of which denote the specific marginal cost t^i_j associated with the transfer of a unit of water from the reservoir to demand region *j* in time period *i*;

$P_1 = [p^i_j]$: a column vector, the elements of which denote the demand price per unit of water in demand region *j* during time periods *i,* where $p^i_j \geq 0$;

$$P_1 = Q_1^{-1}(C_1 - G_1 X) \qquad (3.78)$$

where

$C_1 = [\alpha^I_J]$: a column vector, the elements of which denote the intercepts of the equations defined in Equation (3.77);

Q_1: a square matrix of dimension *mn* by *mn*, the elements of which are all zero except on the main diagonal, where they take the values of the slope coefficients defined in the set of equations (3.77);

G_1: an identity matrix of dimension *mn* by *mn*;

Next, the authors define the following constraints, which are related to supply, physical structure, and system losses, in matrix form:

$$\boldsymbol{G_2 X \leq C_2} \tag{3.79}$$

$$\boldsymbol{G_3 X \leq C_3} \tag{3.80}$$

where

C_2:	**a scalar quantity representing the total supply of water available for distribution over the planning period;**
$C_3 = [\theta_j^i]$:	**a column vector, the elements of which denote the maximum feasible quantity of water θ_j^i that can be provided in demand region *j* during time period *i* because of the capacity limits of the distribution system and, in general, $\sum_i \sum_j \theta_j^i \geq C_2$;**
$G_2 = [\gamma_j^i]$:	**a row vector, the elements of which denote the reciprocals of the delivery efficiencies of the water released from the dam to demand region *j* during time period *i*;**
$G_3 = G_1$:	**an identity matrix of dimension *mn* by *mn*.**

The allocation model is then:

$$\textit{Maximize } NSP(X) = \int_0^{G_1 X} P_1' d(G_1 \psi) - T' X \tag{3.81}$$

subject to:

Equations (3.79) and (3.80) and

$$X \geq 0 \tag{3.82}$$

Equation (3.81) is then reformulated as a quadratic function of the unknown vector X:

$$Maximize\ NSP(X) = C_1'Q_1^{-1}G_1X - \tfrac{1}{2}X'G_1'Q_1^{-1}G_1X - T'X \qquad (3.83)$$

Constraints Equations (3.79) and (3.80) are next incorporated into the objective function while using the Lagrangean multipliers P_2 and P_3:

$$\begin{aligned} Maximize\ \ \Phi(X, P_2, P_3) = {} & C_1'Q_1^{-1}G_1X - \tfrac{1}{2}X'G_1'Q_1^{-1}G_1X - T'X \\ & - P_2'(C_2 - G_2X) + P_3'(C_3 - G_3X) \end{aligned} \qquad (3.84)$$

P_2 can be interpreted as an imputed supply price for water, depending upon the total quantity of water available to meet demand, and P_3 as a supplementary supply price for water, arising from the specific capacity limits constraining water distribution. Flinn & Guise then present the dual formulation of the model (Equations 3.79-3.81), solving for equilibrium prices:

$$Maximize\ F(P_1, P_2, P_3) = C_1'P_1 - \tfrac{1}{2}P_1'Q_1P_1\ - C_2'P_2 - C_3'P_3 \qquad (3.85)$$

subject to:

$$G_1'P_1 - G_2'P_2 - G_3'P_3 \le T \qquad (3.86)$$

$$P_1 \ge 0 \quad P_2 \ge 0 \quad P_3 \ge 0 \qquad (3.87)$$

The authors transform the optimization formulation of Equations (3.85 and 3.87) into a Lagrangean maximization problem, which is a quadratic formulation involving both equilibrium prices and quantities at the same time:

$$\begin{aligned} Maximize\ \ L(P_1, P_2, P_3, X) = {} & C_1'P_1 - \tfrac{1}{2}P_1'Q_1P_1\ - C_2'P_2 - C_3'P_3 \\ & + X'(T - G_1'P_1 + G_2'P_2 + G_3'P_3) \end{aligned} \qquad (3.88)$$

$$P_1 \ge 0 \quad P_2 \ge 0 \quad P_3 \ge 0 \quad X \ge 0 \qquad (3.89)$$

The following equations represent the Kuhn-Tucker conditions for an optimum solution of the quadratic formulation:

$$\partial L/\partial P_1 = C_1 - Q_1 P_1 - G_1 X \leq 0 \text{ and } (\partial L/\partial P_1)' P_1 \equiv 0 \qquad (3.90)$$

$$\partial L/\partial P_2 = -C_2 + G_2 X \leq 0 \text{ and } (\partial L/\partial P_2)' P_2 \equiv 0 \qquad (3.91)$$

$$\partial L/\partial P_3 = -C_3 + G_3 X \leq 0 \text{ and } (\partial L/\partial P_3)' P_3 \equiv 0 \qquad (3.92)$$

$$\partial L/\partial X = T - G_1' P_1 + G_2' P_2 + G_3' P_3 \leq 0 \text{ and } (\partial L/\partial X_1)' X \equiv 0 \qquad (3.93)$$

Model Application

Flinn & Guise define hypothetical demand functions, which are consistent with the literature, and consider four seasons (spring, summer, autumn, and winter). There are nine demand functions for irrigation purposes, and four seasonal functions for the industrial complex and urban region, each. The constraints are (1) the active annual yield of the dam, (2) the filtration plant capacity, (3) the three channel capacities through the three irrigation regions, and (4) the five operational efficiencies for all regions (one for industry, one for the urban sector, and three for the three irrigation regions). The authors compute twenty equilibrium prices and the corresponding twenty quantities of water transferred. With the application of this model, Flinn & Guise show the potential of spatial equilibrium models for water resources allocation.

3.2.3.3. 'Modeling Intrastate and Interstate Markets for Colorado River Water Resources' (Booker & Young, 1994)

Booker & Young (1994), in their article, provide a brief summary of the legal history of interstate water commerce (p. 67). As a response to disputes rising from water scarcity problems due to growing urban water needs in Southwestern states, the U.S. Supreme Court took two decisions favoring interstate water commerce in the Sporhase case in 1982, and in the El Paso case in 1983.

> “For many years, states in the Colorado Basin and elsewhere in the West have operated under the assumption that their power to regulate groundwater was complete and that their compacts dividing surface waters with other states unquestionably governed the allocation of supplies.
> Several recent court cases have called both of these suppositions into question. The two leading ones are the *Sporhase* case decided by the Supreme Court on July 2, 1982, and the *El Passo* case decide by the Federal District Court of New Mexico on January 17, 1983. The *El Passo* case is being appealed and may also finally go to the Supreme Court. In both cases, the courts have for the first time unequivocably proclaimed that water is and article of interstate commerce” (Kneese & Bonem, 1986, p. 98).

Booker & Young identify the two phases of a regional water economy as: 1) the expansionary phase, in which the incremental cost of additional supply is not high, and 2) the mature phase, in which the incremental cost increases sharply due to limited (scarce) water resources.[12] In the second phase, scarcity defines the water economy with its scarcity prices; on the other hand, in the first phase, price is defined only by water supply costs (i.e. energy costs, distribution costs). Therefore, in the expansionary phase, the incremental cost is significantly lower than the cost in the mature phase.

The model tests the possible benefits of a water market, as an alternative to current institutional allocation practices leading to high-cost engineering solutions for increasing demand problems. Using water transfer options across different sectors, such as industry, agriculture, energy, and municipal governments, the model allocates water to the highest value use. Water quality issues are also incorporated into the model. The contributions of this study are categorized into two groups: (1) on the supply side, the incorporation of quality (salinity) as well as quantity (evaporation, water export and inflow) issues in each region (defined as a node), with the major tributary inflows, diversion points, reservoirs, and hydroelectric power plants explicitly presented as nodes; (2) on the demand side, both offstream (irrigation, municipal, thermal energy) and instream (hydropower and water quality) use of empirical marginal benefit functions, potentially leading to optimal allocations after shifting from institutional practice to interstate and intersectoral water trade. The model considers the Colorado River Basin as a closed system, without opportunities for supply augmentation, and the model does not account for the secondary impacts of potential reallocations, such as negatively impacted economic activities (multiplier effects) in the water exporting and importing regions.

Model:

This is a nonlinear optimization model, named the Colorado River Institutional Model (CRIM), and used to investigate alternative institutional scenarios, combining river flows, salinity concentrations and water demanding sectors across river locations. The objective function consists of benefit functions generated from the integration of different demand functions. On the other hand, because the water supply is constant, withdrawals, exports, evaporations, and returns flows are dealt through constraints, node by node. Similarly, salinity discharges and loads are defined node by node. The Colorado River System is a closed system whose supply of water is constant, with an average value of 13.0 million acre-feet at Lee's Ferry. There is a total of twenty nodes: fourteen nodes representing sectors with economic demand for consumptive or non consumptive water use, and six nodes representing significant sources or depletions of river water and salt loads, or important geographical or institutional features. The CRIM is designed as a single mainstream, with tributaries and diversions represented as demand and supply sectors (Booker & Young, 1994, p. 70).

Total flows and salinity concentrations are functions of withdrawals, exports, and salt discharges, which are decision variables (Booker & Young, 1994, p. 72). The model solves for optimal water withdrawals and salinity concentrations. The objective function consists of two parts: (1) the Upper Basin and (2) the Lower Basin. The Lower Basin nodes are indexed by *j*, while the Upper Basin nodes are indexed by *i*. The physical constraints are defined by Equations (3.95) and (3.96) and are illustrated in Figure (3.3). The mass balance equation (3.95) is related to the quantity of water, and the mass balance equation (3.96) (nonlinear functions) to salinity. Equations (3.97) and (3.98) represents constraints on diversion and export flows.

Objective function:

$$\textit{Mazimixe} \sum_i \pi_i(w_i, x_i, z_i) + \sum_j (\pi_j(w_j, x_j) - c_j(w_j, x_j, \sigma_j)) \tag{3.94}$$

subject to:

$$Q_i = Q_{i-1} - V_i - \eta_i w_i - x_i + Q_i^a + Q_i^f \tag{3.95}$$

$$s_i = s_{i-1} + s_i^n + z_i - s_{i-1}(x_i / Q_i) \tag{3.96}$$

$$w_i \leq \overline{w}_i, \tag{3.97}$$

$$x_i \leq \overline{x}_i. \tag{3.98}$$

***In the objective function, we have*:**

$\pi_i(w_i, x_i, z_i)$: **net benefit for Upper Basin node *i*;**

$\pi_j(w_j, x_j)$: **net benefit for Lower Basin node *j*;**[13]

$c_j(w_j, x_j, \sigma_j)$: **Lower Basin salinity damage;**

The endogenous variables are:

w_i: **water diversions at node *i*;**

x_i: **water export at node *i*;**

z_i: **salt discharges from economic activity at node *i*;**

The derived variables are:

s_i: **total salt load leaving node *i*;**

Q_i: **total flow leaving node *i*;**

σ_j : **salinity concentration at node *j* (*=S*$_j$*/Q*$_j$).**

The indices are:

i: **Upper Basin node index (*1,…,14*);**

j: **Lower Basin node index (*15,…,20*).**

***In the water balance constraints, we have (see also Figure 3.3, right-hand side)*:**

$V_i \geq 0$: **evaporation loss between nodes *i* and *i-1*;**

$Q_i^a <> 0$: **net flow adjustment for inflows and diversions between nodes *i* and *i-1*;**

$Q_i^f \geq 0$: **tributary flow into node *i*;**

η_i : **portion of diverted water used for consumption at node *i*.**

$(1-\eta_i)\, w_i$: **return flows from node *i*;**

$\eta_i\, w_i + x_i$: **total consumptive use at *i*;**

$w_i \equiv Q_i$: **water release from the nodes having dams for hydropower generation, i.e. the water leaving node *i* generates energy but is not consumptive.**

***In the salinity balance constraints, we have (see also Figure 3.3, left-hand side)*:**

$s_i^n <> 0$: **net salt addition from sources between nodes *i-1* and *i*;**

$s_{i-1}(x_i / Q_i) \geq 0$ **:salt exports arising from out of Basin diversion.**

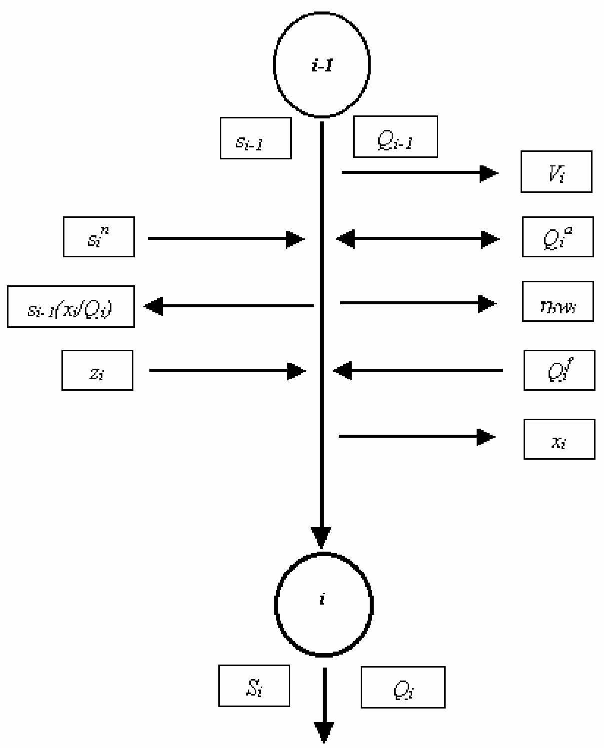


Figure 3.3: River Flow Water and Salinity Balance Diagram

Benefit functions:

There are different benefit functions for agricultural, municipal, hydropower and cooling uses.

Benefits from agricultural use: **There are two basic forms of benefit functions: one is only a function of water used, and the other is a function of both water used and salinity. The *first one* is the integral of the inverse water demand function (Equation 3.100), which is estimated by regression analyses (Equation 3.99), prepared for the Imperial Valley (California).**

$$p(w) = a(w - w_0)^b \tag{3.99}$$

$$\pi(w) = \pi_0 + \alpha(w - w_0)^\beta \tag{3.100}$$

where $\alpha = a/(b+1)$, $\beta = b+1$, and π_0 irrigation profit at $w = w_0$.

Land rent is included in the profit function [Equation (3.101)], which is a slightly modified version of Equation (3.100), as a linear function of water withdrawal (12.7 w). Salinity damages $c(w,\sigma)$ are defined as the differences in profits at salinity concentrations of 800 ($\pi_{800}(w)$) and 1100 ($\pi_{1100}(w)$) mg/liter, respectively. Agricultural salinity damages are assumed linear in salinity level ($\partial c/\partial\sigma = constant$), but decrease with water use ($\partial c/\partial w < 0$).[14] We have:

$$\pi_{800} = 94600 + 12.7w - 3.67 * 10^5 (w - w_0)^{-0.43} \tag{3.101}$$

$$\pi_{1100} = 63700 + 12.7w - 5.24 * 10^5 (w - w_0)^{-0.59} \tag{3.102}$$

The *second* form of benefit function, which is prepared for the Grand Valley (Colorado), incorporates salinity discharges into second-order polynomial benefit functions.[15] Grand Valley irrigation benefit is estimated through regression analysis using a quadratic functional form with

$$\pi(w, z) = -11{,}800 + 86.3w - 0.190w^2 + 0.799z - 0.0742z^2 + 0.1333zw \tag{3.103}$$

Benefits of hydropower: Two benefit functions are derived for the Lower and Upper Basins. They are simple regression models, where energy generation (E) is linearly dependent upon the quantity of water released, with:

$$E_U = 93 + 0.616Q_U \quad \text{and} \quad E_L = -14 + 0.724Q_L \tag{3.104}$$

Q is the total quantity of water released from the dams in the Lower (L) and Upper (U) Basins. These functions are then converted into the functional form used in the optimization model, depending on the amount of water ($\pi_U = 13w$ and $\pi_L = 31w$) released from the dams (which are not consumptive users of the water).[16]

Cooling water: Some part of the water is utilized by coal-fired electric plants for cooling purposes. The functional form, which is a nonlinear benefit function ($\pi = 2830w - 109w^2$), is drawn from another study.[17]

Urban use and municipal damages: The urban water use benefit function is derived from an econometric study. A survey was done, and economic demand functions were derived from a sample of California households. The municipal damages are defined as the costs of household damages, such as corrosion in piping and appliances within houses (Booker & Young, 1994, p. 75).

Scenarios and Conclusions:

Booker & Young define the existing institutional setting, including water release to Mexico, and introduce six scenarios for their optimization model. The first scenario "…approximates the allocation of Colorado River water under the existing interstate and intrastate priorities known as the 'Law of the River'." The second one "…allows unrestricted intrastate transfers based on water values in consumptive use." The third one "…considers unrestricted interstate (and intrastate) transfers based on consumptive use values alone." The remaining fourth, fifth, and sixth scenarios "…allow interstate water

transfers based on alternative consumptive and non consumptive use values." Specifically, scenario four and five include consumptive use values and economic values for hydropower production and salinity reduction, respectively." The last scenario is theoretically equivalent to a comprehensive water resources bank (with exclusion of free riders) accepting bids from hydropower beneficiaries and consumptive water users, including those damaged by salinity levels.

Regarding the scenarios, the model concludes that, although both interstate and intrastate water markets yield potential efficiency gains from trade, there is no significant superiority for an interstate water market over an intrastate water market, due to the negligible marginal value differences. Prominent benefits emerge only from non-consumptive uses (e.g. electricity generation) and salinity reductions due to water transfer from the Upper to the Lower Basins. Finally, Booker & Young state that, when considering the potential of future growth in Las Vegas and probable improvements in water transfers to California, interstate water transfers can be justified. They emphasize the importance of the emergence of the water market for efficiency improvements, together with its correct signals for both consumptive and nonconsumptive water uses.

NOTES

[1] In this way, taxation and subsidy issues enter into the problems.

[2] The authors add that most of the standard cost allotment cases satisfies the conditions stated by Equation (3.5) and (3.6); however, the Tennessee Valley Authority experts indicate that it is not possible to allocate the joint costs meaningfully, especially while considering the marginal costs and benefits. From J. P. Heaney & R. E. Dickinson, "Methods for Apportioning the Cost of a Water Resource Project," Water Resources Research 18.3 (1982): 477.

[3] Dinar and Wolf (1994) do not specify the $F^j(W^j, T^j)$ in their study.

[4] 2^n*-1* computes the total number of sets can be derived from the *n* number of players excluding the empty set.

[5] By the year 2020, considering the constraints of Equation (3.39):
100.10^6: Projected demand by GS and supplied from EG;
.006+.214=.220: Least value (lower bound) of water;

.006: Marginal productivity of water in EG;
.214: Average cost of water delivery to GS from EG;
.300: The maximum value (upper bound) of water.

[6] **By the year 2020, considering the constraints of Equation (3.40):**
$500 \cdot 10^6$: Projected demand from outside of EG;
$400 \cdot 10^6$: Projected demand in IL;
$100 \cdot 10^6$: Projected demand in GS;
$50 \cdot 10^6$: Projected demand in WB;
$006 + .198 + 21.4 \cdot 10^6 / 500 \cdot 10^6 = .204$: Least value (lover bound) of water in EG;
$21.4 \cdot 10^6$: Total technology improvement cost of EG;
$500 \cdot 10^6$: Total amount water transferred;
$21.4 \cdot 10^6 / 500 \cdot 10^6$: Technology cost per m^3 of water delivered;
.198: Average cost of delivering water to either IL (Negev) or GS;
.300: Maximum value (upper bound) of water in EG and IL;
.140: Least value (lover bound) of water in IL;
$68 \cdot 10^6 + 26.4 \cdot 10^6$: Benefits of IL from the technology improvements.

[7] **If there is excess demand, excess supply (ES) will have a negative sign.**

[8] **Original graph is in Samuelson (1952) page 288-290.**

[9] **Original graph is in Samuelson (1952) page 288-290.**

[10] **In this section analyses are done in real functional forms, which is an explicit presentation and clarification in Takayama and Judge (1964) different from Samuelson (1952), reviewed in Section 3.1.**

[12] **Alan Randall, "Property Entitlements and Pricing Policies for a Maturing Water Economy," The Australian Journal of Agricultural Economics, 25 (1981) 196.**

[13] **The authors use indices i and j in the objective function as a differentiation of Upper and Lower Basins; however, they do not pursue to use index j in the constraints.**

[14] **In Booker & Young's (1994) research the cost of salinity damages ($c(w, \sigma)$) are not explicitly presented in functional forms.**

[15] **For the full set of benefit functions, see Booker & Young (1994; p. 72).**

[16] **U.S. Bureau of Reclamation, Colorado River Alternative Operating Strategies for Distributing Surplus Water and Avoiding Spills, (Denver: Engineering and Research Center, 1986).**

[17] **D. Abbey, "Energy Production and Water Resources in the Colorado River Basin," Natural Resources Journal 19 (1979): 275-314.**

CHAPTER 4

THE EUPHRATES AND TIGRIS RIVER BASIN MODEL (ETRBM)

This chapter presents the basic water allocation model for the Euphrates and Tigris basin, named ETRBM. Its spatial and mathematical structure is first described. Next, the data used to estimate its parameters are discussed. Finally, the solution for a benchmark case is presented. It is, however, important to underline that the primary focus of this modeling effort is methodological. While the goal of the research is to develop a tool capable of answering various policy questions, and to illustrate such analyses while using data as realistic as possible, there is no claim that the results obtained in this and the next two chapters could be directly used by policy makers. For that purpose, a much more intensive data-gathering effort would be necessary. Therefore, the research presented in this dissertation is best viewed as a “proof-of-concept” approach, rather than an operational one.

4.1. Structure of the ETRBM

The ETRBM is an optimization model for the analysis and planning of international and interbasin cooperation over two separate but interlinked rivers, the Euphrates and the Tigris. The literature on the Euphrates and the Tigris focuses on water politics, legal analyses, and water balances, but does not provide a model for the overall optimal utilization of the basin resources. The ETRBM comprehensively reflects the structure of the two rivers, incorporating supply reservoirs and centers of water demand throughout the basin, while accounting for evaporation, return flows, and water balances throughout the river system. The ETRBM is the core model, which is modified/adjusted to carry further analyses, such as the cooperative games presented in Chapter 6. The structure of the ETRBM is explained in the following two subsections. In the first one, its spatial structure is presented, while in the second one its mathematical form is depicted.

There are several major assumptions in the current version of the ETRBM:

1) Agricultural productivity is assumed to be the same throughout the region; therefore, in the benchmark case, all countries are treated equally. In Chapter 6, this assumption is relaxed.
2) Water unit values in urban and agricultural areas do not vary throughout the basin. Thus, all cities and agricultural districts are treated in the same way, ignoring the potential differences regarding development, technology, and socio-cultural life.
3) Environmental issues, such as salinization and drainage problems, and low Biochemical Oxygen Demand (BOD) levels, are ignored.
4) Energy prices are assumed to be the same throughout the region. Hence, demand differences for energy among the riparian countries are ignored. In Chapter 5, different energy values are considered for the overall basin, to assess the sensitivity of the ETRBM. It is expected that the upstream countries (first Turkey then Syria) would value energy more due to having less alternative energy resources. The country-based relaxation of this assumption is left for further research.
5) In Iraq, Syria, and the Southeast Anatolia Region (in Turkey), only cities exceeding 100,000 people are incorporated into the model.
6) Groundwater resources are not considered in the analyses, due to lack of geographical information.
7) The optimization model maximizes the total net benefits, rather than the benefits of any country or of any sub-portion(s) of the basin. Later, in Chapter 6, country benefits

are separately maximized to estimate the core and the relative powers of the riparian countries.

8) Water transportation unit costs (per kilometer-volume) do not vary throughout the region due to lack of geographical information about the agricultural districts. Economies of scale in water delivery systems are considered at two scales only: urban and agriculture.
9) Agricultural district sizes are not homogenously determined. If an agricultural area can be feasibly irrigated, it is assumed that its total area is irrigated.
10) Supply-to-supply intermodal link unit costs are assumed to be similar to the agricultural transport unit costs between supply and demand nodes.
11) Water withdrawals per acre and per person are constrained by upper limits, to prevent excessive withdrawals.
12) The ETRBM considers all built and planned dam projects, thus approximating the final state of complete river basin development. However, both agricultural and urban demands are consistent with the conditions in the year 2000.

In the literature, only a few studies focus on the optimum allocation of resources and benefits among the parties at the national and international levels. Among these studies, four are comparable to the ETRBM in some respects: Booker & Young (1994), Dinar & Wolf (1994), and Rogers (1969 and 1993). They are extensively reviewed in Chapter 3.

With regard to the way the river basin system is structured, the ETRBM is similar to the model developed by Booker and Young (1994) for the Colorado River, the CRIM (Colorado River Institutional Model). Booker and Young (1994) use a nonlinear framework and incorporate salinity issues into the CRIM. Their goal is to allocate scarce water resources among states by focusing on the creation of a water market. In contrast, the ETRBM is designed as a linear program where water is allocated to agricultural and urban demand nodes in the three countries, subject to nodal water balances and upper and lower limits to nodal water allocations, so as to maximize total net benefits, taken as linear functions of the end-use water allocations minus linear functions of related transportation costs. The model provides the option of building inter-basin water transfer links.

Working on the Ganges, Rogers (1969 and 1994) studies cooperation in an international setting and presents game theory and Pareto frontier analyses. In his first model, Rogers (1969) uses a linear programming framework to compute the optimum benefits of different form of coalitions, and then evaluates the results in a nonzero-sum game framework between two countries (East Pakistan and India). Incorporating Nepal in the system in his second study on the Ganges, Roger (1994) simply outlines the applicability of game theory and Pareto frontier analyses to water resources allocation problems (among Nepal, India, and Bangladesh).[1] The ETRBM, on the other hand, involves extensive applications of game theory analyses to the ETRB.

Dinar & Wolf (1994) aim at illustrating the potential of water trading among Middle East countries (mainly Egypt and Israel), accounting for political constraints among riparian countries. They provide some of the regional parameters that are used in this study, such as the values of water for urban and agricultural uses. Their study considers coalition alternatives but does not search for core solutions, as prescribed by cooperative game theory.

4.1.1. Spatial Structure of the ETRBM

The ETRBM includes 63 demand (*i*) and 45 supply (*j*) nodes (Figures 4.1 and 4.3). The supply nodes provide water for both urban and agricultural uses, and each demand node is served by only one supply node, taken as the most accessible node.[2] Distances to demand nodes are presented in Table 4.2, and the locations of supply nodes are indicated in Figure 4.1.

Out of the 45 ETRBM *supply* nodes, 17 are in the Euphrates basin, and the remaining 28 in the Tigris basin. Turkey has 15 of the supply nodes in its territory: 5 in the Euphrates and 10 in the Tigris basins. Syria has only 7 supply nodes, all in

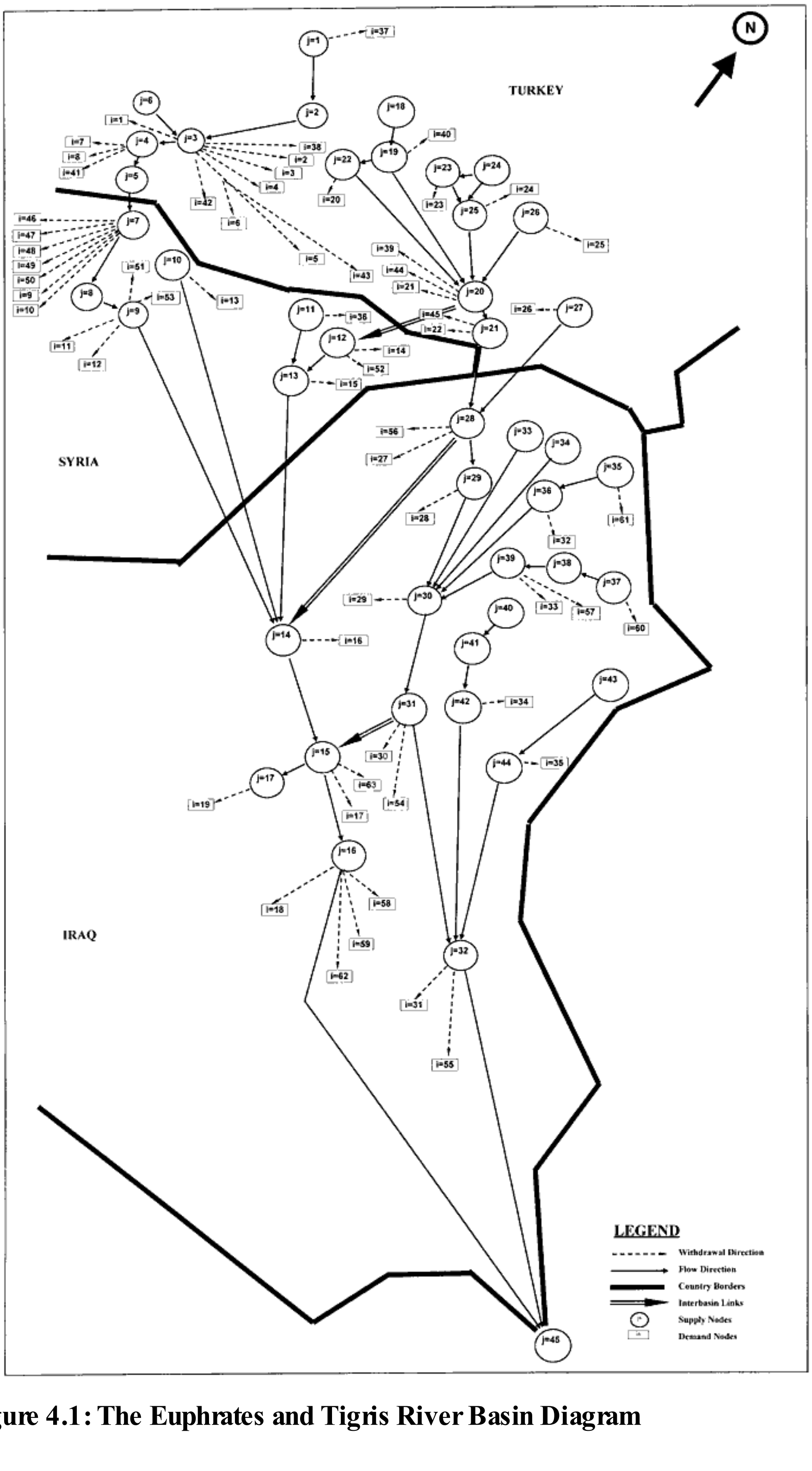


Figure 4.1: The Euphrates and Tigris River Basin Diagram

the Euphrates basin. Iraq has 22 supply nodes, 4 in the Euphrates basin and 18 in the Tigris basin. Node 45 represents the Gulf, which is assigned to Iraq, and represents the end point of all flows downstream.

There are three interbasin links that reflect proposals mentioned in the literature, all of which link the Tigris to the Euphrates, with one already built (from *j=31* to *j=16,* the Tharthar Canal).[3] While one of the links is designed to connect Turkey to Syria (from *j=21* on the Tigris to *j=12* on the Euphrates), the other two links are located within the borders of Iraq (from node *j=28* to *j=14* and from *j=31* to *j=16*).

Of the 63 *demand* nodes, 37 are in the Euphrates basin: 16 for urban uses and 21 for agricultural uses. Of the 26 *demand* nodes in the Tigris basin, 10 are for urban uses and 16 for agriculture uses. Syria has 16 demand nodes, all of which are in the Euphrates basin, whereas Turkey and Iraq have 13 and 8 demand nodes in the Euphrates basin, and 11 and 15 demand nodes in the Tigris basin, respectively (Table 4.2).

4.1.2. Mathematical Structure of the ETRBM

We first present the model equations, followed by the definitions of all indices, variables, and parameters, and by a discussion of the objective function and the constraints. The basic model (Equations 4.1 – 4.10) is as follows:

Maximize

$$\begin{aligned} NEB = & \sum\nolimits_{agr} VALAG \cdot WT_i - \sum\nolimits_{j,agr} W_{j,i} \cdot DSD_{j,i} \cdot AGRTC \\ & + \sum\nolimits_{urb} VALUR \cdot WT_i - \sum\nolimits_{j,urb} W_{j,i} \cdot DSD_{j,i} \cdot URBTC \\ & + \sum\nolimits_{j,l} EPR \cdot EG_j \cdot PQ_{j,l} \\ & - \left[(PQ_{28,14} \cdot CTSS \cdot DSS_{28,14}) + (PQ_{31,16} \cdot CTSS \cdot DSS_{31,16}) + (PQ_{21,12} \cdot CTSS \cdot DSS_{21,12}) \right] \end{aligned} \tag{4.1}$$

Subject to:

$$WT_i = \sum\nolimits_j W_{j,i} \qquad i=1,\dots,63 \tag{4.2}$$

$$\sum_i W_{i,j} + Q_j + REL_j = \sum_i RFR_{i,j} \cdot WT_i + TF_j + \sum_l PQ_{l,j} \quad j=1,\ldots,45 \qquad (4.3)$$

$$WT_i \geq SIZE_i \cdot MINAGR \qquad \forall\ i \in agr \qquad (4.4)$$

$$WT_i \leq SIZE_i \cdot MAXAGR \qquad \forall\ i \in agr \qquad (4.5)$$

$$WT_i \geq SIZE_i \cdot MINURB \qquad \forall\ i \in urb \qquad (4.6)$$

$$WT_i \leq SIZE_i \cdot MAXURB \qquad \forall\ i \in urb \qquad (4.7)$$

$$\sum_l PQ_{j,l} = Q_j \qquad \forall\ j \in inc \qquad (4.8)$$

$$PQ_{j,l} \leq M \cdot FTRNSS_{j,l} \qquad \forall\ j \text{ and } l \qquad (4.9)$$

$$W_{j,i} \leq M \cdot FTRNSD_{j,i} \qquad \forall\ j \text{ and } i \qquad (4.10)$$

Indices

***i*:**	**demand nodes (1 to 63)**
***j & l*:**	**supply nodes (1 to 45)**
agr:	**set of agricultural demand nodes**
urb:	**set of urban demand nodes**
inc:	**all supply nodes, except the Gulf**

Variables

NEB:	**total benefit net of transportation costs**	**($)**
$PQ_{j,l}$:	**internodal flow (node j to node l)**	**(Mm^3)**
$PQ_{21,12}$:	**total water transfer from Turkey to Syria through the link project 21 to 12**	**(Mm^3)**
$PQ_{28,14}$:	**total water transfer from Turkey to Iraq through the link project 28 to 14**	**(Mm^3)**
$PQ_{31,16}$:	**total water transfer from Turkey to Iraq through the link project 31 to 16**	**(Mm^3)**
Q_j:	**total water flowing out of node j towards downstream nodes**	**(Mm^3)**
$W_{j,i}$:	**water transferred from supply node j to demand node i**	**(Mm^3)**
WT_i:	**total water consumption at node i**	**(Mm^3)**

Parameters

AGRTC:	agricultural water transport unit cost	(\$ per Mm^3-km)
URBTC:	urban water transport unit cost	(\$ per Mm^3-km)
VALAG:	agriculture water unit value	(\$ per Mm^3)
VALUR:	urban water unit value	(\$ per Mm^3)
CTSS:	internodal water transport unit cost	(\$ per Mm^3-km)
$DSD_{j,i}$:	distance from supply node j to demand node i	(km)
$DSS_{j,l}$:	distance from supply node j to supply node l	(km)
EPR:	energy price for electricity	(\$ per MWh)
EG_j:	electric generation capacities for the dam at supply node j	(MWh per Mm^3)
MINAGR:	minimum agricultural consumption rate	(Mm^3 per ha)
MAXAGR:	maximum agricultural consumption rate	(Mm^3 per ha)
MINURB:	minimum urban consumption rate	(Mm^3 per inhabitant)
MAXURB:	maximum urban consumption rate	(Mm^3 per inhabitant)
REL_j:	reservoir evaporation loss at supply node j	(Mm^3)
$RFR_{i,j}$:	return flow rates from demand node i to supply node j	
$SIZE_i$:	size of demand node i (hectare for agricultural nodes, inhabitants for urban nodes)	
TF_j:	tributary and groundwater inflows at node j	(Mm^3)
$FTRNSS_{j,l}$:	feasibility of the link from node j to l (if feasible 1, otherwise 0)	
$FTRNSD_{j,i}$:	feasibility of the link from node j to i (if feasible 1, otherwise 0)	
M:	very large number	

The ETRBM is a linear programming model designed to maximize the total net benefits of the three riparian countries – Turkey, Syria, and Iraq – subject to resources, conservation, and policy constraints. The calculations of various output-based variables are described in detail in Appendix A. The objective function, which is to be maximized, represents the net economic benefits of the basin. The gross benefits are derived from agricultural, urban, and energy uses of the water in the basin at the various demand nodes, and the net benefits are the gross benefits minus the water transportation costs from supply to demand nodes, as well as over interbasin links.

Let *VALAG* be the unit value of water to agriculture, and let WT_i be the water consumption at agricultural node i. Then the total value of the water at i is $VALAG \cdot WT_i$, and the total value of the water to all agricultural nodes is $\sum_{i \in agr} VALAG \cdot WT_i$. If W_{ji} is the amount of water transferred from node j to node i, DSD_{ji} the distance between the nodes,

and $AGRTC$ the transportation unit cost per unit distance (assumed to be spatially invariant), then the total water transport cost of getting water to node i is $\Sigma_j W_{ji} \cdot DSD_{ji} \cdot AGRTC$, and the total water transportation cost to all agricultural nodes is $\Sigma_{i\in agr}\Sigma_j W_{ji} \cdot DSD_{ji} \cdot AGRTC$. Hence the net benefits of water usage to agriculture is

$$\sum_{agr} VALAG \cdot WT_i - \sum_{j,agr} W_{j,i} \cdot DSD_{j,i} \cdot AGRTC \qquad \textbf{(4.11)}$$

Similarly to water used in agriculture, let $VALUR$ be the unit value of water to urban uses, and let WT_i be the water consumption at urban node i. Then the total value of the water at i is $VALUR \cdot WT_i$, and the total value of the water to all urban nodes is $\Sigma_{i\in urb} VALAG \cdot WT_i$. If W_{ji} is the amount of water transferred from node j to node i, DSD_{ji} the distance between the nodes, and $URBTC$ the transportation unit cost per unit distance (assumed to be spatially invariant), then the total water transport cost of getting water to node i is $\Sigma_j W_{ji} \cdot DSD_{ji} \cdot AGRTC$, and the total water transportation cost to all urban nodes is $\Sigma_{i\in urb}\Sigma_j W_{ji} \cdot DSD_{ji} \cdot AGRTC$. Hence the net benefits of water usage to urban centers is

$$\sum_{urb} VALUR \cdot WT_i - \sum_{j,urb} W_{j,i} \cdot DSD_{j,i} \cdot URBTC \qquad \textbf{(4.12)}$$

Energy benefits are measured by the market value of the energy generated by the downstream flow of water. Let EPR be the unit market price of water-generated energy, EG_j the quantity of energy generated at node j, and PQ_{jl} the flow of water into downstream node l from node j. Then the value of the energy generated at j, while releasing water to downstream node l, is $EPR \cdot EG_j \cdot PQ_{jl}$. The total value of energy generated in the basin is then

$$\sum_{j,l} EPR \cdot EG_j \cdot PQ_{j,l} \qquad \textbf{(4.13)}$$

In the cases of interbasin water transfer links, let PQ_{jl} be the flow of water from need j into downstream node l, DSS_{jl} the distance between the supply nodes, and $CTSS$ the transportation unit cost per unit distance (assumed to be spatially invariant) between the two river basins for those links. Because there are only three links, they are explicitly represented by the corresponding indices. These costs are born by the country receiving the water, as further explained in Chapter 6. Let $PQ_{21,12}$ be the water flowing from the Tigris, in Turkey, to the Euphrates, in Syria, over the link from nodes $j=21$ to $j=12$, and $PQ_{28,14}$ and $PQ_{31,16}$ the water flows over the links from nodes $j=28$ to $j=14$ and from nodes $j=31$ to $j=16$, both from the Tigris to the Euphrates within Iraq. The transportation cost for link j-l is then $PQ_{jl} \cdot CTSS \cdot DSS_{jl}$. The total interbasin link costs are then calculated as follows:

$$(PQ_{28,14} \cdot CTSS \cdot DSS_{28,14}) + (PQ_{31,16} \cdot CTSS \cdot DSS_{31,16}) + (PQ_{21,12} \cdot CTSS \cdot DSS_{21,12}) \quad (4.14)$$

Combining the benefits and costs in Equations (4.11) – (4.14) results in the objective function represented by Equation (4.1).

Equation (4.2) computes the total water delivery to demand node i, WT_i, as the sum of the deliveries W_{ji} from all *supply* nodes j to node i. As can be seen in Figure 4.2, the water inputs to supply node j are the tributary inflows TF_j, the return flows from the upstream withdrawals to supply node j ($TRFN_j$), taken as the sum of the products of return flow rates and withdrawals at node i, $\sum_i RFR_{ij} \cdot WT_i$, and water from upstream nodes l to j, $\sum_l PQ_{lj}$. The total input at node j is then

$$\sum_i RFR_{i,j} \cdot WT_i + TF_j + \sum_l PQ_{l,j} \quad (4.15)$$

On the other hand, water leaving node j is allocated to reservoir evaporation REL_j, water withdrawal for agricultural and urban uses $W_{j,i}$, and water release to downstream nodes Q_j. Then the total amount of water leaving node j is

$$\sum_i W_{i,j} + Q_j + REL_j \qquad (4.16)$$

Combining Equations (4.15) and (4.16) leads to the water balance constraint at each supply node j, as represented by Equation (4.3).

The parameter $SIZE_i$ is a measure of the size of demand node i (either urban or agriculture), and $MINAGR$, $MINURB$, $MAXAGR$, $MAXURB$ represent minimum usage rates – to sustain agricultural and urban activities – and maximum usage rates – to prevent excessive withdrawals. The total water consumption at node i, $\sum_j W_{ji}$, is noted WT_i, and is constrained by Equations (4.4) – (4.7).

In Equation (4.8), Q_j is expressed as the sum of all water flows released from node j to downstream nodes l, equal to $\sum_l PQ_{jl}$. Equation (4.9) eliminates infeasible supply-to-supply node linkages by using the product of the parameter $FTRNSS_{jl}$, set equal to if the link from node j to node l is feasible, and equal to zero otherwise, with M taken as a very large number. In the same way, Equation (4.10) eliminates infeasible supply-to-demand linkages using parameter $FTRNSD_{jl}$.

Several quantities and parameters are computed based on the optimal values of the basic variables. Parametric calculations in Equations A.1 – A.124 in Appendix A can be classified into two groups: 1) Parametric calculations to test the model [Equation (A.1) – (A.10)]; 2) Parametric calculations to analyze the model results [Equation (A.11) – (A.124)], and pertaining to benefits, costs, and water resources allocations. These equations contain variables and parameters that are used throughout this and the next three chapters for different analyses. These equations contain acronyms describing different countries, basins, and uses, where the lower cases at the end of the acronyms, a, u, and e, refer to the agriculture, urban, and electricity generation sectors, respectively and the lower cases t, s, i refer to Turkey, Syria, and Iraq, respectively (e.g. TECBWta, TECBWiu, TECBes).

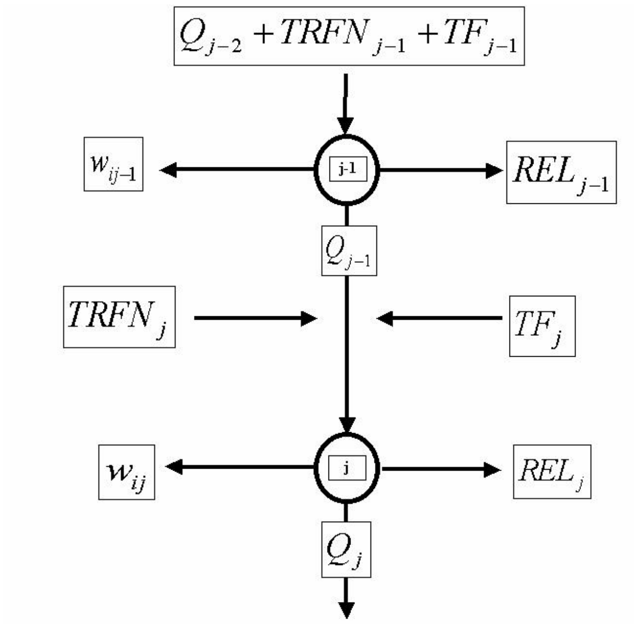


Figure 4.2: Flow Balances in the ETRBM

4.2. Data Sources and Parameter Estimates

This section describes data sources, assumptions, and derivations of the model parameters (including conversions to the metric system, and computations of current prices). In view of the shortage of data regarding the Euphrates and the Tigris basin, some of the parameters used in the ETRBM are derived from related studies in similar geographical areas. For instance, Dinar and Wolf (1994), in their study on the Nile basin, provide valuable information about the value of water in agriculture and domestic uses in the Middle East: while Israel is characterized by an efficient and intensive use of water in agriculture and domestic activities, Egypt features traditional uses of the Nile water, and therefore the values in the case of Egypt can be applied in the ETRBM. Hence, as indicated in this Chapter's introduction, the results must not be viewed as exact policy recommendations, but rather as illustrating the possible policy outcomes as well as directions for further research to improve the data. Also, it is important to note that the dams used as reservoirs (i.e., supply nodes) are either existing in 2000 or planned to be constructed in future years. Therefore, the future supply situation is applied to the demand for the year 2000, as computed with population and agricultural development figures for 2000.

4.2.1. Supply Data

The hydrological characteristics of the Euphrates and the Tigris make up the core of the supply data. Groundwater resources are ignored. There are 45 supply nodes, where the water may be withdrawn. Each node is assumed to be either a dam or a confluence of tributaries. The structure of the whole river system and its supply nodes are presented diagrammatically in Figure 4.1.

4.2.1.1. Tributary Flows

The literature (Kolars, 1986, 1991, 1992, 1994; Kliot, 1994; Bagis, 1989) provides data on the water contributions of each riparian country. However, these data do not include detailed tributary inflows at each confluence. Therefore, total country contributions must be apportioned among all tributaries. Nevertheless, the major tributary inflows for the Greater and Lesser Zab, Diyala, and Adhaim rivers, are available. The remainder is then assigned 1) by calculations, using the annual planned total energy generation figures and dam heights in the GAP/Turkey, and 2) by assumptions for the Iraqi, Syrian, and some Turkish tributaries. The sums of these inflows are consistent with total country water contributions. The energy generation per acre-foot and per foot of head is taken as 0.87 KWh, which is equivalent to 2.314 MWh energy for 1 Mm^3 water and per 1-meter head, after conversion. Tributary inflows are estimated in Turkey using dam heights and planned annual energy generation. The tributary inflows by supply nodes are available in Table 4.1.

4.2.1.2. Return Flows

Return flow data are available in the literature at the country level (Tables 2.15 and 2.16). There are also return flow figures for the major tributaries of the Tigris, in Iraq (Kolars, 1991, 1992, 1994). The other data found in the literature are the expected return flows in conjunction with withdrawals for planned irrigation areas, specifically for the Euphrates in Turkey and Syria. Using these figures, the necessary return-flow rates are

Table 4.1: Supply Node Parameters

j	Basin	Country	TF(j)	REL(j)	EG (j)	Dam Height (m)
1	Euphrates	Turkey	19,015.00	900.00	377.2	163.0
2			2,454.00	400.00	365.6	158.0
3			3,067.00	1,600.00	361.8	156.4
4			920.00	109.67	123.8	53.5
5			613.01	54.84	49.1	21.2
6		Syria	4,601.01	58.76	-	-
7			35.01	168.01	44.0	19.0
8			25.01	1,500.01	138.8	60.0
9			10.01	6.49	27.8	12.0
10			200.00	48.00	46.3	20.0
11			712.00	48.00	46.3	20.0
12			890.00	48.00	46.3	20.0
13			178.00	120.00	46.3	20.0
14		Iraq	0.00	1,500.00	-	-
15			0.00	112.50	23.1	10.0
16			0.00	2,062.50	23.1	10.0
17			0.00	1,500.00	-	-
18	Tigris	Turkey	2,775.00	77.85	261.5	113.0
19			555.00	32.21	173.6	75.0
20			2,775.00	577.72	167.0	72.2
21			0.00	37.21	51.8	22.4
22			1,850.00	40.27	75.9	32.8
23			6,475.00	242.95	231.7	100.1
24			925.00	29.53	97.3	42.0
25			925.00	72.48	165.5	71.5
26			1,850.00	25.50	170.3	73.6
27			370.00	0.00	-	-
28		Iraq	1,680.00	240.00	-	-
29			1,260.00	480.00	46.3	20.0
30			840.00	1,125.00	46.3	20.0
31			420.00	1,500.00	46.3	20.0
32			0.00	1,875.00	46.3	20.0
33			3,275.00	39.17	81.0	35.0
34			3,275.00	39.17	81.0	35.0
35			5,240.00	39.17	81.0	35.0
36			1,310.00	97.92	81.0	35.0
37			6,840.00	39.17	-	-
38			360.00	97.92	81.0	35.0
39			0.00	146.88	81.0	35.0
40			680.00	54.55	81.0	35.0
41			80.00	136.36	81.0	35.0
42			40.00	204.55	81.0	35.0
43			4,320.00	75.00	81.0	35.0
44			1,080.00	187.50	81.0	35.0
45			0.00	0.00	-	-

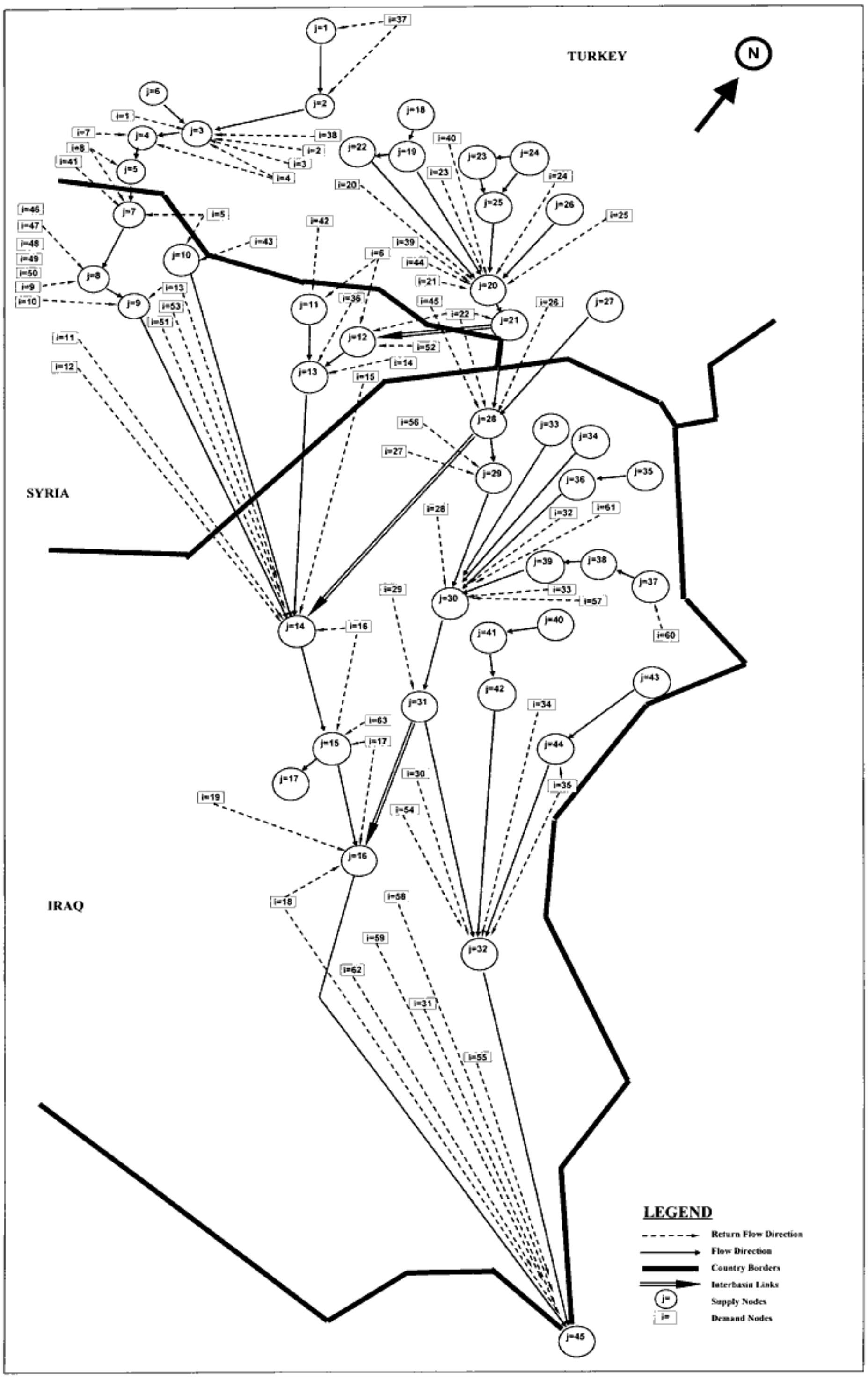


Figure 4.3: Return Flows Linkages Diagram

computed by dividing return flows by the quantities of water withdrawn. Since the estimated rates do not present significant spatial variations among agricultural districts, the same rates are applied to the other irrigation districts. One weakness of this assumption is that the return flows are linearly related to the amounts of water withdrawn, whereas, in reality, this relation cannot be reduced to a simple linear relation, because of varying evaporation rates, geology, system losses, and irrigation technologies. For modeling purposes, return flows destinations (supply nodes) are inferred from maps and catchment area data for the basin. While the average agricultural return flow is around 53%, the average urban return flow is around 80 % of the water used.[4] The return flow linkages (from demand to supply nodes) are presented in Figure 4.3.

4.2.1.3. Evaporation

The larger the surface of a reservoir the higher the evaporation loss. The other factor affecting water loss via evaporation is the increase in temperature, when the rivers are getting closer to the Gulf. Based on annual evaporation quantities and reservoir surface areas for the major reservoirs in the Euphrates basin (Figure 2.1 from Altinbilek, 1997), evaporation rates (per-km^2) are computed for the three riparian countries. The computed rates are used for the other reservoirs falling into the same climatic regions in Figure 2.2 (Kliot, 1994), as it is assumed that the same rates are applicable within the same climatic region. Using these rates, the annual average evaporation figures are estimated as follows.

The unknown reservoir surfaces are estimated based on their geographical locations and construction purposes. The higher the head of a dam the larger the agricultural land covered. In flat areas, such as in Iraq, dams are assumed to be built for irrigation purposes (with acceptable lower head), and not for electric generation (requiring higher head). In the case of Iraq, the availability of cheap alternative energy sources, such as large petroleum reserves, reduces its dependency on hydroelectric energy. Towards the lowlands, reservoir areas widen and evaporation increases. The unknown reserve surface areas are determined based on the following rules: 1) For the main branches of the Tigris in Iraq, from upstream to downstream nodes, reserve surface areas are taken equal to 100, 200, 300, 400, and 500 km^2; these surface areas are smaller than the major dams, such as the Ataturk and Keban Dams in Turkey (Figure 2.1); and 2) For the tributaries, the reserve surface areas are taken sequentially, from upstream to downstream, equal to 20, 50 and 75 km^2. These surface areas, together with annual evaporation rates, are used for the estimation of annual evaporation losses in the river basins by nodes. The evaporation figures by supply nodes are available on Table 4.1.

4.2.2. Demand Data

The demand side includes 63 spatially identified demand nodes: 37 agricultural regions and 26 major cities. Each demand node is assigned to the most accessible supply node. (A multiple assignment could, of course, be easily accommodated by the ETRBM). Due to the unavailability of regional data, values for the benefits obtained from agriculture and urban uses are derived from the literature, which indicates that 1) the total amounts of agricultural land for irrigation are 1,770,956 ha, 1,065,000 ha, and 3,290,000 ha for Turkey, Syria, and Iraq, respectively (Altinbilek, 1997; Bagis, 1989; Kolars & Mitchell, 1991; Kolars, 1994, 1992, 1986; Kliot, 1994; FAO, 1993), and 2) the total city populations are 4,904,132 for Turkey, 5,498,218 for Syria, and 7,392,800 for Iraq. Further details are provided in the coming sections, and the population and agricultural size parameters are presented in Table 4.2.

4.2.2.1. Agriculture & Urban Use

Productivity of agricultural land and water demand per hectare vary, due to climatic differences along the river basin. Located in the northern part of the system, Turkey is expected to have a relatively lower water demand per hectare than Iraq and Syria, due to more rainfall and less evaporation. As Sharif Elmusa stated in an interview[5], Turkey's

Table 4.2: Demand Node Parameters

i	Basin	Use	Country	Size(i)*	Distance to Demand Node (i) **
1	Euphrates	Agriculture	Turkey	77,400	4.69
2				160,100	85.94
3				69,700	17.19
4				146,500	20.31
5				141,500	43.75
6				334,900	101.56
7				71,600	43.75
8				23,000	20.31
9			Syria	155,000	36.84
10				25,000	28.95
11				165,000	7.89
12				40,000	21.05
13				185,000	34.21
14				210,000	10.53
15				75,000	39.47
16			Iraq	150,000	3.73
17				400,000	9.33
18				450,000	22.40
19				290,000	22.40
20	Tigris		Turkey	52,033	7.81
21				74,047	15.63
22				89,000	28.13
23				213,000	35.94
24				37,700	18.75
25				60,000	10.94
26				32,000	20.31
27			Iraq	50,000	9.33
28				50,000	9.33
29				200,000	9.33
30				500,000	9.33
31				600,000	9.33
32				50,000	9.33
33				50,000	9.33
34				250,000	9.33
35				250,000	9.33
36	Euphrates		Syria	210,000	13.16
37			Turkey	188,476	14.06
38		Urban		422,668	10.60
39	Tigris			335,713	12.37
40				936,737	0.71
41	Euphrates			1,303,779	49.47
42				367,594	165.63
43				1,009,640	42.40
44	Tigris			161,748	7.07
45				366,252	28.27
46	Euphrates		Syria	1,687,325	312.74
47				1,915,567	79.15
48				653,636	152.51
49				377,302	208.49
50				319,898	152.51
51				199,909	1.93
52				174,606	27.03
53				169,975	1.93
54	Tigris		Iraq	4,649,000	3.28
55				616,700	3.28
56				570,900	3.28
57				207,800	36.07
58	Euphrates			243,600	9.84
59				215,300	13.11
60	Tigris			279,400	45.90
61				333,900	29.51
62	Euphrates			138,800	3.28
63				137,400	3.28

* For agricultural use, size = number of hectares
For urban use, size = population
** From the most accessible supply node

agricultural land in this region has a higher productivity rate per unit of land than the other riparian countries. This can be explained by the fact that agricultural land in Turkey has not been exposed to salination and over-utilization.

There is a total of 37 agricultural nodes in the two river basins: 21 in the Euphrates basin and 16 in the Tigris basin. Total planned irrigable land areas for each riparian country are available in the literature (Kolars, 1992; Kliot, 1994). In addition, in the case of Turkey, data on each irrigation district and associated supply nodes are available (Altinbilek, 1997). However, irrigable agricultural area data are available for Syria and Iraq only at the country and/or regional level. To delineate irrigation districts (demand nodes) and assign them to supply nodes, a series of assumptions were made using existing irrigation maps. Due to lack of spatial information, agricultural productivity is assumed to be constant: the value of agricultural water (VALAG) is assumed the same throughout the region. Thus, crop diversity and double cropping options are ignored.

In the river basin, there are 26 urban demand nodes, and each of them is connected to a supply node. Eight are in Turkey (South Eastern Anatolia Region), eight in Syria, and the remaining ten in Iraq. These nodes are constituted by cities having 100,000 or more inhabitants. Population figures for Iraqi and Syrian cities are estimated for the year 2000, using the most recent figures available at the city level (in base years 1985 and 1994, respectively) and population growth rates provided by the CIA.[6] On the other hand, Turkey's South Eastern Anatolia has population characteristics different from the western part of the country, and the national population growth rate does not provide reliable regional population growth rates. Thus, the regional population growth rate for each city is estimated using two base year population figures (1985-1990), and then projecting the population to the year 2000.

While urban water consumption includes both industrial and commercial consumption, such distinctions and their implications are ignored. The literature on water demand points to significant variations among these sectors. For instance, industrial water demand is highly elastic. Industries have a large number of alternatives, from recycling to adopting different technologies requiring less water in the production process. The model also does not account for variations in demand resulting from cultural, socio-economic, and geographical factors (e.g., domestic demand is likely to be higher in dryer regions in the southern nodes toward the Gulf), and urban requirements are assumed to be the same at the household level. Therefore, as in the agriculture case, the value of the urban use of water (VALUR) is considered constant throughout the region. Table 4.2 provides both agricultural and urban size parameters.

Dinar and Wolf (1994) [7] use a value of water for agricultural and urban use in Israel of \$300,000 per-Mm^3 of water.[8] Assuming that the value of water in Israel is determined via the market as an outcome of efficient use, both the domestic and agricultural sectors are expected to purchase water at the same price: therefore, the marginal value reflects the urban use. On the other hand, in Egypt the marginal value of water is \$6,000 per-Mm^3, and represents low-technology economic returns from intensive water-consuming agriculture.[9] Therefore, based on Dinar and Wolf (1994), we would select: *VALUR* = \$300,000 per-Mm^3, and *VALAG* = \$6,000 per-Mm^3. Another approach might be to use the water prices from the study of Howitt, Mann, and Vaux (1982) on California (Table 4.3). Because the climate in Southern California is comparable to the climate in the Middle East, Southern California Agriculture and Urban (municipal and industrial) water prices may be considered as potential data for the ETRBM. Therefore, based on estimates for the year 2000, we would select: *VALUR* = \$292,638 per-Mm^3 and *VALAG* = \$51,611 per-Mm^3. We finally select *VALUR*=\$150,000 /Mm^3 and *VALAG*=\$25,000 /Mm^3. The reasons for selecting *VALUR*=\$150,000 /Mm^3 is that the value of urban use is significantly lower in Turkey, Syria, and Iraq, due to the relatively low industrial capacities of these countries, than in both Israel and the USA. These values are approximately at the mid-range of the intervals delineated above (\$0 - \$300,000/Mm^3 for urban use, and \$6,000 - \$52,000/Mm^3 for agricultural uses). Doing so, we neither underestimate *VALAG* by selecting very low values (Egypt) nor overestimate it by selecting the highest values (California).

Table 4.3: Value of Water in the Urban and Agricultural Sectors (Howitt, Mann, and Vaux, 1982)

Region and Sector	Price (Year 1980) (\$/Acre-Foot)	Price (Year 2000) (\$/Mm^3)
Northern agriculture	20.95	35497.5
Southern agriculture	30.46	51611.1
Imperial Valley	6.45	10928.8
Northern Municipal and industrial	139.47	236316.6
Southern Municipal and industrial	172.71	292638.2

There are two approaches for determining minimum and maximum agricultural consumptions, one of which applies to Middle Eastern countries, Egypt and Israel, (Dinar and Wolf, 1994), and the other to Tulare/California/USA (Howe and Easter, 1971). Using Dinar and Wolf (1994), the minimum agricultural water demand to sustain agriculture (*MINAGR*) corresponds to the water necessary for sprinkler irrigation systems (0.015 Mm^3 per ha), which requires significantly less water as compared to surface irrigation. On the other hand, the maximum amount necessary for agriculture (*MAXAGR*) is assumed to correspond to surface irrigation, which requires 25% more water (0.020 Mm^3 per ha) as compared to the sprinkler system. Thus, we would select: *MINAGR* = 0.015 Mm^3 /ha, and *MAXAGR* = 0.020 Mm^3/ha. Alternatively, Howe and Easter (1971) provide the marginal value of water for incremental changes in the quantity of water applied. The smallest amount of water (0.00107 Mm^3/ha) provides the minimum incremental benefit for agriculture. The total amount of water providing \$1 incremental benefit per one acre-foot water is considered the maximum water withdrawal (after conversion to the metric system, 0.01337 Mm^3 per-ha). Table 4.4 provides this conversion. Thus we would select: *MINAGR* = 0.00107 Mm^3 /ha and *MAXAGR* = 0.01337 Mm^3 /ha. Based on the above values, we finally select *MINAGR* = 0.0 and *MAXAGR* = 0.020 Mm^3.

Table 4.4: Conversion from Acre-Foot Water for 80-Acre Study Area to Mm^3 Water Demand Per Hectare

Minimum	28	Acre-feet/80 acres	34537.50	m^3/80 acres	0.034537	Mm^3/32.375 ha	0.0010668	Mm^3/ha
Maximum	351	Acre-feet/80 acres	432952.18	m^3/80 acres	0.432952	Mm^3/32.375 ha	0.0133731	Mm^3/ha

Source: For Tulare, California, USA, Howe and Easter (1971: p. 39; Table 4).

Dinar and Wolf (1994) provide water budgets for Egypt (EG), Israel (IL), the West Bank (WB), and the Gaza Strip (GS) (Table 4.5). The minimum amount of per-capita water consumed by the domestic and industrial sectors is considered the minimum water necessary for nonagricultural use. The minimum is obtained from the GS consumption (32.3 m^3/per-capita i.e. 0.0000325 Mm^3/per-capita), and the highest is obtained from the Egyptian and Israeli levels, (126 and 105.7 m^3/per-capita, i.e. 0.000126 and 0.000106 Mm^3/per-capita, respectively). We would thus select: *MINURB* = 0.0000325 Mm^3/per-capita, and *MAXURB* = 0.000105 Mm^3/per-capita. We finally select *MINURB* = 0.0 and *MAXURB* = 0001057 Mm^3.

Table 4.5: Per-Capita Water Consumption Estimation

	Population	Total Water	Agriculture		Domestic & Industrial*		Per Capita Water Consumption	
	Million (M)	(Mm^3)	(%)	(Mm^3)	%	(Mm^3)	(m^3/per-capita)	(Mm^3/per-capita)
EG	54.1	56800	88	49984	12	6816	126.0	0.00012599
IL	4.6	1800	73	1314	27	486	105.7	0.00010565
WB	0.9	110	82	90.2	18	19.8	22.0	0.00002200
GS	0.6	130	85	110.5	15	19.5	32.5	0.00003250

Derived from Dinar & Wolf (1994: p.50, 51; Table 1, 2).
*GS and WB do not have industrial activities.

Both parameters *MINURB* and *MINAGR* provide constraints for the smallest amounts of water required to be withdrawn in the ETRBM by the urban and agricultural sectors. However, forcing these minimum amounts to be strictly positive may lead to inefficiencies, with transport cost exceeding the benefits obtained from the use of water, depending, of course, on the values of the benefit and cost parameters. To illustrate, cities far away from the ETRB, such as Damascus, may receive water from the ETRB, even at a loss. To avoid such situations, the minimal values are reduced to zero.

4.2.3. Water Conveyance Cost and Energy Price Data

4.2.3.1. Transportation Costs

After identifying the spatial location of the supply and demand nodes, inter-nodal distances are measured through map analysis as strait line distances. Each demand node is assigned to one supply node only, the most accessible one. In the case of agricultural nodes, the distances from the supply node to closest and most remote points in the irrigation district are first measured and then averaged out to obtain the final distance. If a demand region constitutes a strip running parallel to the river, distance measures the separation between the river link (not the dam location) and the strip.

Transportation cost data provided by Hirshleifer (1969: p.179) are transformed into cost per unit of water (Mm^3) and per unit distance (km), as illustrated in Table 4.6.

Table 4.6: Water Conveyance Cost After Conversion to Metric System & Year 2000 $

Capacity (Mm3 per year)		0.0276	0.2763	1.3815	2.763	138.15
Dollars per Mm^3 per km, with pumping	(Yr. 2000)	30,691.79	13,882.13	6,846.63	4,957.90	849.93
Dollars per Mm^3 per km, gravity flow	(Yr. 2000)	24,553.43	8,263.17	3,069.18	2,242.86	………

Source: In eds. of Hirshleifer, De Haven And Milliman (1969, p.179)

In view of the lack of information about the detailed geography of the region and conveyance projects (planned or built), whether they are based on pumping or on gravity flows, the last two cost parameters from the pumping category (the most expensive, and thus upper-bound estimates) in Table 4.6 are selected for the ETRBM. Thus *URBTC*= \$4,958 per Mm^3-km, and *AGRTC*= \$850 per Mm^3-km.

The transport unit cost for prospective inter-river basin supply-to-supply links is assumed to be the same as the one for the largest-scale water delivery project for irrigation (least capacity 138.15 Mm^3). The assigned conveyance unit cost is then: *CTSS* \$850 per Mm^3-km.

4.2.3.2. Energy

The electricity generation capacities of the dams and the expected total annual energy generations are available for every dam in the Turkish portions of the Euphrates and the Tigris; however, these figures are not available for Syria (with minor exceptions) and Iraq. The average electric generation rate is 0.87 kWh per foot-head and acre-feet of water (Gibbons, 1986: p. 89).[10] The annual energy generation capacities of the dams must be converted into electricity generation per Mm^3 of water released from the head of dams. In order to estimate these figures, dam heights are needed. Turkey has a geographical advantage for the generation of energy from high-head dams. Syrian and Iraqi dams, when compared to the capacities of the Ataturk, Karakaya, and Keban dams, are relatively limited in size and potential. The literature provides dams head heights from the riverbed on the main branch of the Euphrates River (Bilen, 1994: p. 100; http://www.dsi.gov.tr/ bolge/bolgeler.htm). The remaining figures for the other dams are estimated as moderate head flow heights (between 20-35 m), considering the change in elevation through the river basins in both Syria and Iraq. For instance, the Euphrates in Iraq has a 200 m elevation change from the Syrian border to the Gulf. The unknown head heights are assigned under the following assumptions:

- All dams have electric generation capacities (even the ones that are assumed to be built for irrigation only), unless otherwise stated in the literature.
- If a dam is in Turkey and in mountainous terrain, 35 meters is the assumed height;
- If a dam is in Syria, 20 meters is the assumed height; and
- If a dam is in Iraq, 35 meters is the assumed height for mountainous tributary, and 20 meters for mainstream dams.

However when the annual expected power generation is available (e.g., for the Turkish portion of the Tigris), dam height is computed using the following formula:

$$\textit{Dam Height (m)} = \frac{\textit{Annual Expected Energy Generation (MWh)}}{\textit{(Energy Generation Constant) x (Tributary Inflow)}} \quad (4.11)$$

The tributary inflow is measured in Mm^3/year, and the energy generation constants per unit height and unit flow is measured in MWh/meter head and Mm^3 of water. The energy generation capacities by supply nodes (EG_j) are available in Table 4.1.

4.3. Benchmark Model Application

Table 4.7 presents an overall summary of the results. We observe the following:

- Energy benefits constitute nearly 50% of overall returns;
- Return flows make up almost 50% of the water input from tributaries, and are available for reuse;
- Total water withdrawal is very close to the total tributary flow input, whereas water released to the Gulf makes up to 35% of the total tributary inflow.

Table 4.7: General Summary of the Benchmark Solution ($ and Mm^3)

Solution		
Net system benefits (NEB),	$	2,407,731,200
Water use benefits (TECBW)	$	2,091,003,000
Energy generation benefits (TECBE)	$	1,175,087,800
Transportation costs for urban uses (TTCURB)	$	32,145,138
Transportation costs for agricultural uses (TTCAGR)	$	826,214,547
Interbasin transfer costs (TTRSS)	$	0
Water release to the Gulf (GULF)		28,225
Total water withdrawal (TWT)		78,528
Total return flow (FRET)		42,582
Total in-out balance (TOTBAL)		0
Total agricultural water withdrawal (TWAGR)		77,505
Total urban water withdrawal (TWURB)		1,022
System Parameters		
Total tributary flows (TFT)		81,920
Total reserve evaporation (RELT)		17,750
Minimum total withdrawal for agriculture (TWAGRMIN)		0
Maximum total withdrawal for agriculture (TWAGRMAX)		122,519
Minimum total withdrawal for urban use (TWURBMIN)		0
Maximum total withdrawal for urban use (TWURBMAX).		1,881

4.3.1. Benefit Allocation

Table 4.8 presents the benefit for the overall system and each country (Turkey, Syria, and Iraq). The table includes total economic benefits (TECB), total transportation costs (TTC), net economic benefits (NBEN), the ratios of economic benefits to transportation costs (R), the percentage of economic benefits by category (PTECBW, PTECBE, PTECBWU, and PTECBWA),[11] and the percentages of transportation costs by use (PTTCURB, PTTCAGR, and PTTRSS). The following is observed:

- Although the net benefits of Turkey and Iraq are almost the same, Turkey obtains most of her benefits from energy generation, whereas Iraq obtains hers from agriculture. The overall system optimization involves, first, the utilization of the energy generation potential at the upstream nodes, and then the utilization of the agricultural potential at the downstream nodes. The opportunity cost of withdrawing water at the upper river basin nodes is higher than the opportunity cost of withdrawing water at the downstream nodes. The ratios of benefits to costs show that Turkey has the lowest transport cost related to water withdrawal, and Iraq the highest. These results are analyzed in more depth in the parametric analyses of Chapter 5.
- Turkey and Iraq are the countries having the largest agricultural potential. However, Turkey's benefits are mostly obtained form energy generation (75% of total benefits),[12] in contrast to agricultural water withdrawals for Iraq (90% of total benefits). In Syria, the benefits are almost equally shared (56% for water withdrawals and 44% for energy generation).
- Total urban transportation costs constitute an insignificant share of the total transportation costs in the whole system and in each county. This can be attributed to the relative magnitude of urban demand based on population size.

Table 4.8: Summary of the Components of the Country Benefits

Summary	Total	Turkey	Syria	Iraq
Economic Benefits	$ 3,266,090,800	$ 1,161,095,600	$ 294,048,029	$ 1,810,947,300
Transport Costs	$ 858,359,685	$ 144,065,122	$ 60,237,792	$ 654,056,771
Net Economic Benefits	$ 2,407,731,200	$ 1,017,030,400	$ 233,810,237	$ 1,156,890,500
Economic Benefits / Transport Costs	3.81	8.06	4.88	2.77
Percent Distribution				
Economic Benefits				
Withdrawal	64.0%	24.6%	56.3%	90.5%
Energy	36.0%	75.4%	43.7%	9.5%
Urban Withdrawal	4.7%	3.0%	2.9%	6.1%
Agricultural Withdrawal	59.3%	21.6%	53.3%	84.5%
Transport Costs				
Urban Withdrawal	3.7%	7.6%	4.7%	2.8%
Agricultural Withdrawal	96.3%	92.4%	95.3%	97.2%
Link Transshipment	0.0%	0.0%	0.0%	0.0%

4.3.2. Resources Allocation

Politically, more water has been associated with more benefits. Turkey, Syria, and Iraq have been competing for a higher share of water, rather than maximizing the overall return and allocating economic benefits. They believe that more water is better for their future needs and wealth. Table 4.9 presents the optimum water allocations by subsets of countries, basins, and uses. The major conclusions from these tables are as follows:

- Iraq obtains its major benefits from agriculture water withdrawal. The highest withdrawal (61,934 Mm^3) clearly shows the intensity of agriculture in Iraq. Turkey, with the second largest agricultural land (nearly two thirds of Iraqi land), withdraws only one sixth of Iraqi withdrawal (10,263 Mm^3) (Table 4.9).
- Urban withdrawals (1,022 Mm^3) are significantly lower than agricultural withdrawal (77,505 Mm^3).

4.3.3. Discussions

Given the assumptions and data limitations, the ETRBM is developed and applied as a proof-of-concept model rather than for providing exact policy applications. However, it provides a basic tool that can be easily updated once better data are obtained.

Table 4.9: Water Resources Allocation by Country, Basin, and Use (Mm^3)

Summary	Total		Turkey		Syria		Iraq	
Euphrates Urban	180	0.2%	45	0.1%	58	0.1%	78	0.1%
Tigris Urban	843	1.1%	190	0.2%	-	-	652	0.8%
Euphrates Agriculture	35,475	45.2%	3,402	4.3%	6,273	8.0%	25,800	32.9%
Tigris Agriculture	42,030	53.5%	6,626	8.4%	-	-	35,405	45.1%
Basin								
Euphrates Total	35,655	45.4%	3,447	4.4%	6,331	8.1%	25,878	33.0%
Tigris Total	42,873	54.6%	6,816	8.7%	-	-	36,057	45.9%
Use								
Urban Total	1,022	1.3%	235	0.3%	58	0.1%	730	0.9%
Agriculture Total	77,505	98.7%	10,028	12.8%	6,273	8.0%	61,205	77.9%
Overall								
Total Withdrawals	78,528	100.0%	10,263	13.1%	6,331	8.1%	61,934	78.9%

In view of the geographic position of the countries (the upstream and high elevations for Turkey and downstream flat lands for both Syria and Iraq), optimizing the overall the ETRB resources leads to using water for energy generation upstream, and then for agriculture downstream. Water withdrawals are more costly upstream than downstream, due to the opportunity cost associated with withdrawals. While water withdrawn can no longer be used for energy generation, water that is not withdrawn can be used several times for this purpose, until it finally reaches the flat agricultural lands and then the Gulf. In other words, the higher one moves upstream, the greater the opportunity cost.

The water released to the Gulf, which represents 35% of total tributary inflows, can be explained by 1) the upper limits (*MAXAGR* and *MAXURB*) of water withdrawals, and 2) the domination of energy generation at the upstream nodes, leading to more water released than can be absorbed by agricultural and urban use in the downstream countries.

This release to the Gulf provides room for 1) potential withdrawals to satisfy future increases in demands, because of population growth and economic development, and because of demands coming from other Gulf states, and 2) dilution of harmful substances coming from upstream agriculture (as return flows) and urban uses (waste water).

Table 4.10: Water Flows by Nodes and Energy Generation Capacities

j	Basin	Country	TF(j)	REL(j)	Q.l(j)	Z(j)	TWDN(j)	TRFN(j)	BAL(j)
1	Euphrates	Turkey	19,015.00	900.00	18,115.00	0.00	0.00	0.00	0
2			2,454.00	400.00	20,169.00	18,115.00	0.00	0.00	0
3			3,067.00	1,600.00	24,811.41	24,711.25	2,986.68	1,619.84	0
4			920.00	109.67	25,161.74	24,811.41	460.00	0.00	0
5			613.01	54.84	25,818.82	25,161.75	0.01	98.91	0
6		Syria	4,601.01	58.76	4,542.26	0.01	0.01	0.01	0
7			35.01	168.01	25,834.16	25,818.82	0.01	148.35	0
8			25.01	1,500.01	24,359.16	25,834.16	0.01	0.01	0
9			10.01	6.49	20,223.59	24,359.16	4,139.11	0.01	0
10			200.00	48.00	152.00	0.00	0.00	0.00	0
11			712.00	48.00	0.00	0.00	664.00	0.00	0
12			890.00	48.00	0.00	0.00	1,527.69	685.69	0
13			178.00	120.00	1,227.86	0.00	0.00	1,169.86	0
14		Iraq	0.00	1,500.00	19,666.62	21,603.43	3,000.00	2,563.19	0
15			0.00	112.50	13,707.44	19,666.62	8,014.52	2,167.84	0
16			0.00	2,062.50	2,828.54	6,407.44	9,063.18	7,546.78	0
17			0.00	1,500.00	0.00	7,300.00	5,800.00	0.00	0
18	Tigris	Turkey	2,775.00	77.85	2,697.15	0.00	0.00	0.00	0
19			555.00	32.21	3,120.93	2,697.15	99.01	0.00	0
20			2,775.00	577.72	14,935.51	11,740.54	1,533.52	2,531.21	0
21			0.00	37.21	13,271.28	14,935.51	1,818.71	191.69	0
22			1,850.00	40.27	769.07	0.00	1,040.66	0.00	0
23			6,475.00	242.95	7,127.52	895.47	0.00	0.00	0
24			925.00	29.53	895.47	0.00	0.00	0.00	0
25			925.00	72.48	7,226.04	7,127.52	754.00	0.00	0
26			1,850.00	25.50	624.50	0.00	1,200.00	0.00	0
27			370.00	0.00	0.00	0.00	370.00	0.00	0
28		Iraq	1,680.00	240.00	13,976.98	13,271.28	1,060.34	326.05	0
29			1,260.00	480.00	14,343.72	13,976.98	1,000.00	586.74	0
30			840.00	1,125.00	29,467.64	32,109.03	4,000.00	1,643.62	0
31			420.00	1,500.00	20,052.47	29,467.64	10,491.40	2,156.22	0
32			0.00	1,875.00	14,943.59	21,536.12	12,065.19	7,347.66	0
33			3,275.00	39.17	3,235.83	0.00	0.00	0.00	0
34			3,275.00	39.17	3,235.83	0.00	0.00	0.00	0
35			5,240.00	39.17	5,200.83	0.00	0.00	0.00	0
36			1,310.00	97.92	5,377.62	5,200.83	1,035.29	0.00	0
37			6,840.00	39.17	6,800.83	0.00	0.00	0.00	0
38			360.00	97.92	7,062.91	6,800.83	0.00	0.00	0
39			0.00	146.88	5,916.03	7,062.91	1,000.00	0.00	0
40			680.00	54.55	625.45	0.00	0.00	0.00	0
41			80.00	136.36	569.09	625.45	0.00	0.00	0
42			40.00	204.55	0.00	569.09	404.54	0.00	0
43			4,320.00	75.00	4,245.00	0.00	0.00	0.00	0
44			1,080.00	187.50	1,483.65	4,245.00	5,000.00	1,346.15	0
45			0.00	0.00	28,224.69	17,772.13	0.00	10,452.56	0

Table 4.11: Water Withdrawals by Demand Nodes

i	Basin	Use	Country	WT(i)	City Name
1	Euphrates	Agriculture	Turkey	1,548	
2				0	
3				1,394	
4				0	
5				0	
6				0	
7				0	
8				460	
9			Syria	0	
10				0	
11				3,300	
12				800	
13				0	
14				1,509	
15				0	
16			Iraq	3,000	
17				8,000	
18				9,000	
19				5,800	
20	Tigris		Turkey	1,041	
21				1,481	
22				1,780	
23				0	
24				754	
25				1,200	
26				370	
27			Iraq	1,000	
28				1,000	
29				4,000	
30				10,000	
31				12,000	
32				1,000	
33				1,000	
34				405	
35				5,000	
36	Euphrates		Syria	664	
37			Turkey	0	
38		Urban		45	Adiyaman
39	Tigris			35	Batman
40				99	Diyarbakir
41	Euphrates			0	Gaziantep
42				0	Mardin
43				0	Sanliurfa
44	Tigris			17	Siirt
45				39	Sirnak
46	Euphrates		Syria	0	*Damascus*
47				0	*Aleppo*
48				0	*Homs*
49				0	*Latakia*
50				0	*Hama*
51				21	*Rakka*
52				18	*Al-Qamishli*
53				18	*Deir ez-Zor*
54	Tigris		Iraq	491	Baghdad
55				65	Al-Basrah
56				60	Al-Mawsil
57				0	Kirkuk
58	Euphrates			26	An-Najaf
59				23	Al-Hillah
60	Tigris			0	As Sulaimaniya
61				35	Irbil
62	Euphrates			15	An-Nasiriyah
63				15	Ar Ramadi

NOTES

[1] Pareto frontier analyses are based on the study of Robert Dorfman, Henry D. Jacoby and Harold A. Thomas Jr. named Models for Managing Water Quality, Harvard University Press, Cambridge, 1972.

[2] Each demand node can be served by more than one node via changing the parameters in (a) the distance matrix, $DSD_{j,i}$, and (b) the matrix for the feasibility of the link from node j to i (if feasible 1, otherwise 0), $FTRNSD_{j,i}$.

[3] Ozden Bilen, Prospect for Technical Cooperation in the Euphrates – Tigris Basin in eds., A. K. Biswas, International Waters of the Middle East: From Euphrates-Tigris to Nile (Bombay: Oxford University Press, 1994) pp. 103-107.

[4] These figures are derived from and interview with Prof. Burkhard von Rabenau (November, 2000).

[5] During a seminar at the Ohio State University in 1998.

[6] CIA, (1998): http://www.odci.gov/cia/publications/factbook/country-frame.html

[7] Dinar and Wolf (1994) does not clearly provide the base year of the marginal vales; therefore, there is need to modify the values to 2000 prices. One alternative is assuming the prices are current prices in the one year before the publication. The values can be easily converted into the current prices or any year using the following web address: http://woodrow.mpls.frb.fed.us/economy/calc/cpihome.html

[8] Marginal value of 1 m^3 is \$0.3 and equivalently 1 Mm^3 is \$300,000 in Israel.

[9] Marginal value of 1 m^3 is \$0.006 and equivalently 1 Mm^3 is \$6,000 in Egypt. Besides, the agriculture usually subsidized sector and difficult to measure; therefore marginal value for actual agricultural use is much lower than this average marginal value figure.

[10] The energy generation per acre-foot and per foot of head is taken as 0.87 KWh, which is equivalent to 2.314 MWh energy for 1 Mm^3 water and per 1-meter head, after conversion.

[11] Figures are not net of transportation costs.

[12] Withdrawal benefits are not net of transport costs; therefore, the percent of energy benefits are expected to be higher if computed for net benefits.

CHAPTER 5

SENSITIVITY ANALYSES OF THE ETRBM

This chapter presents sensitivity analyses of the ETRBM (the Euphrates and Tigris River Basin Model) presented in Chapter 4. It selects six parameters, solves the model over ranges of values of these parameters, and assesses how water allocations and benefits allocations vary with change in these parameters.

5.1. Parameters

We have selected six critical parameters in order to analyze the sensitivity of the model:

EPR:	energy price for electricity	($ per MWh)
AGRTC:	agricultural water transport unit cost	($ per Mm^3-km)
URBTC:	urban water transport unit cost	($ per Mm^3-km)
CTSS:	internodal water transport unit cost	($ per Mm^3-km)
VALAG:	agriculture water unit value	($ per Mm^3)
VALUR:	urban water unit value	($ per Mm^3)

First, the six parameters are considered separately, and the model is solved for 35 values of each parameter, or a total of 210 values for all six parameters. Next, the six parameters are analyzed simultaneously over a grid. Finally, the four most important parameters are further analyzed over a grid. The tools used for these analyses include descriptive statistics, single and multiple regression analyses, elasticity analyses, and graphical representations. The list of the variables and parameters that are used throughout the chapter is presented at the end of the chapter.

5.2. Single Parameter Analyses

The objectives of the single parameter analyses are 1) to analyze the model mechanics and responsiveness (rather than reaching policy conclusions), and 2) to select reasonable parameter ranges to be used later in the simultaneous six and four parameter analyses. In many instances (from Figures 5.1 to 5.48), changes in the values of the parameters (on the horizontal axis) result in linear increases or decreases in benefit values and constant water withdrawals. This linearity occurs because the model variables do not change beyond a certain value of the parameter, as the model constraints provide no longer any slack for variations in the solution. Therefore, the only changing element is the parameter itself, hence the linearity of the objective function or a portion of it. When a demand node becomes feasible in the ETRBM (i.e., its benefits exceed the corresponding transport costs and it has the highest marginal contribution to the objective function), withdrawal takes place until the saturation level (*MAXAGR* and *MAXURB*) is reached or resource constraints are binding. Then the next node (with lesser marginal value) contributing to the objective function is considered for resource allocation and so on, until there are no more nodes remaining or no more resources are available for further allocation. Then, further incremental changes in the parameter are directly reflected in the value of the objective function by changing the benefits (or costs). Conversely, the resources allocation no longer changes, hence a flat graph. Such flat graphs may be modified when the feasibility of a node changes (becoming feasible or infeasible).

The wide ranges of parameters reduce the visual clarity of the linearity and the non-linearity of the plots; therefore, minor differences from a linear trend cannot be easily observed given the extent of the vertical axis of the graphs. These deviations can be easily uncovered after reviewing the resources allocation components of the benefits in the preceding graphs for the same parameter.

5.2.1. Energy Price (EPR)

EPR varies between 0 and 1,525 $/MWh. Figures 5.1, 5.2, and 5.3 present scatter plots of water withdrawn as function of EPR. Turkey stops withdrawing water when EPR approximates to $100 per MWh. The same trend is observed for Syria and Iraq when

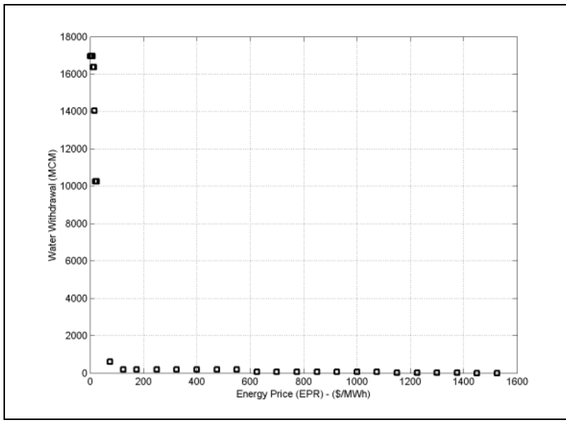


Figure 5.1: Water Withdrawal by Turkey as a Function of Energy Price

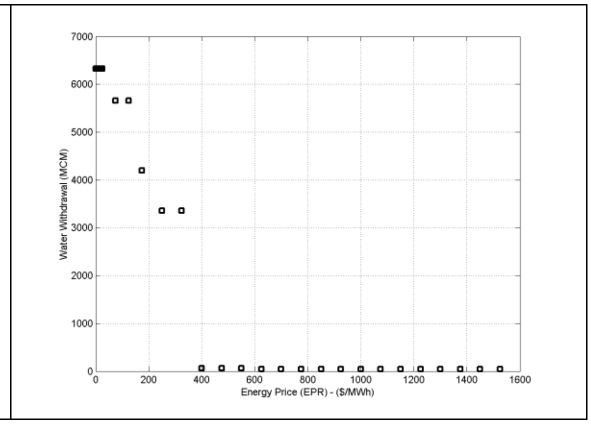


Figure 5.2: Water Withdrawal by Syria as a Function of Energy Price

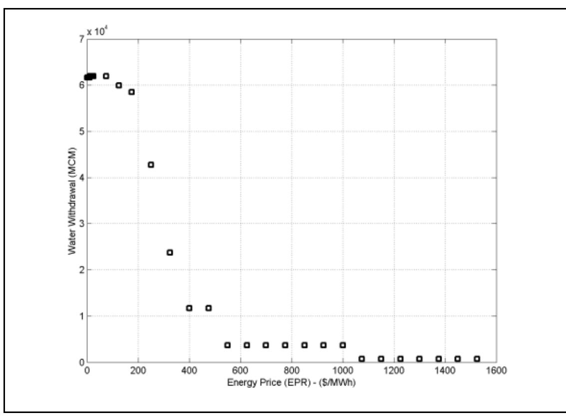


Figure 5.3: Water Withdrawal by Iraq as a Function of Energy Price

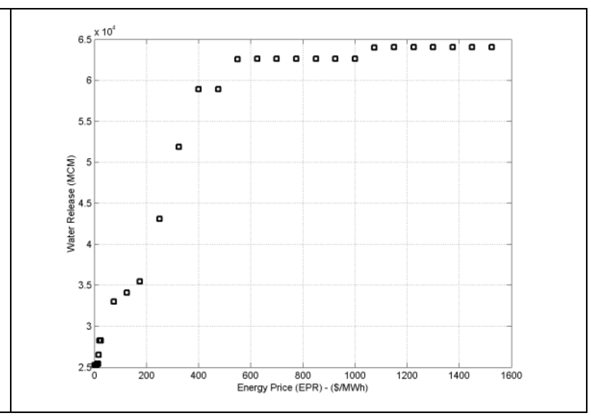


Figure 5.4: Water Released to the Gulf as a Function of Energy Price

EPR reaches $400 and $550 per MWh, respectively. Table B1 in Appendix B provides additional descriptive statistics. The following can be observed:

- After $450 MWh, the change in water withdrawal becomes less intense. Complementarily, the water released to the Gulf flattens at $550 MWh and reaches its maximum at nearly $1100 (Figure 5.4).
- Benefit functions are close to linear and do not display much variations in their slopes, for each country and the overall system (Figures 5.5 – 5.8). After reaching the point of no withdrawal, any benefit increase is totally linearly linked to changes in EPR.
- The increase in the value of EPR leads to a decline in agricultural water use, which eliminates the need to use internodal links, where the water is transferred from the Tigris to the Euphrates (Table B1 in Appendix B).
- The higher EPR, the higher the opportunity cost of water withdrawal. In other words, the opportunity cost of withdrawing water in Turkey is equal to the energy benefits plus the agricultural benefits at downstream nodes. Turkey's withdrawal means loss of water from the river basin and loss of energy generation.

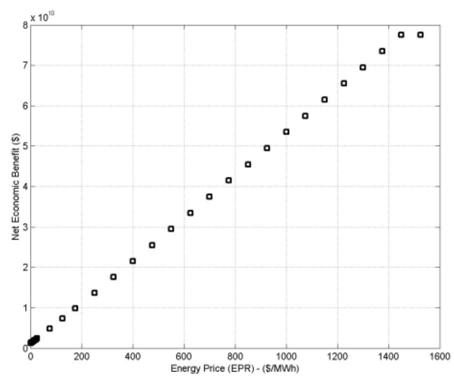


Figure 5.5: Net Economic Benefit as a Function of Energy Price

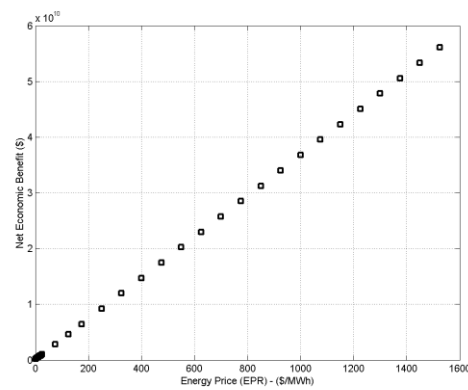


Figure 5.6: Net Turkish Economic Benefit as a Function of Energy Price

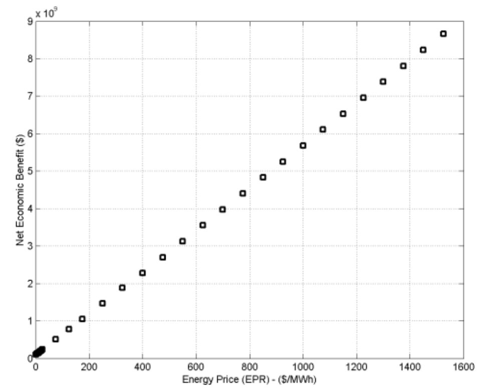


Figure 5.7: Net Syrian Economic Benefit as a Function of Energy Price

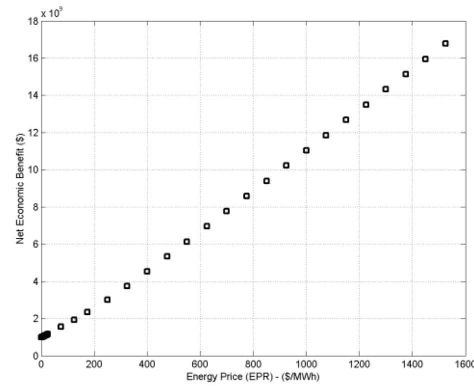


Figure 5.8: Net Iraqi Economic Benefit as Function of Energy Price

5.2.2. Value of Water in Agriculture (VALAG)

VALAG varies between 0 and 10^6 \$/Mm^3. In contrast to EPR, an increase in VALAG encourages water withdrawals. The decrease in the opportunity cost of early water withdrawal, due to the decreased importance of EPR, makes early withdrawals more feasible. The following can be observed:

- Iraq is the first country reaching its maximum withdrawal level, just before VALAG equals \$50,000 per Mm^3 (Figure 5.11).

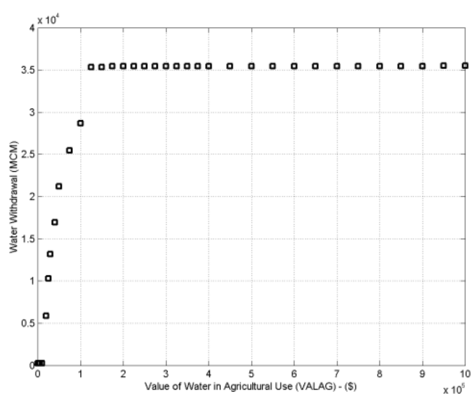


Figure 5.9: Water Withdrawal by Turkey as a Function of Water Use Value in Agriculture

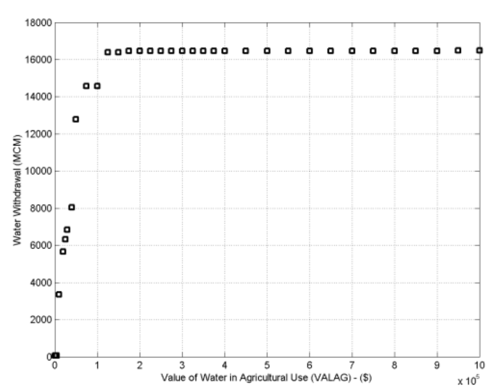


Figure 5.10: Water Withdrawal by Syria as a Function of Water Use Value in Agriculture

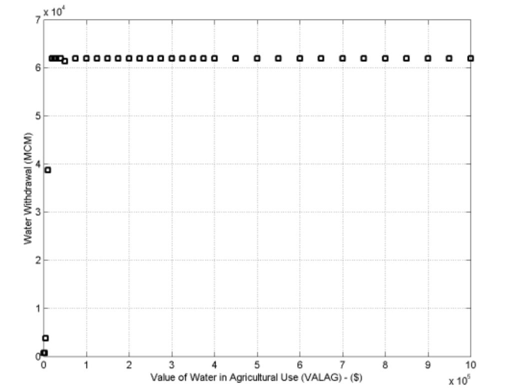


Figure 5.11: Water Withdrawal by Iraq as a Function of Water Use Value in Agriculture

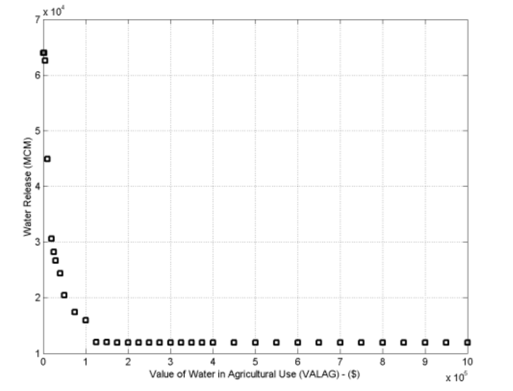


Figure 5.12: Water released to the Gulf as a Function of Water Use Value in Agriculture

- When VALAG exceeds \$150,000 per Mm^3, both Turkey and Syria reach their maximum withdrawal values (Figures 5.9 and 5.10), and water released to the Gulf reaches its minimum level (Figure 5.12). This supports the claim that there is a withdrawal tradeoff between energy and agriculture for Turkey and Syria.
- For Iraq, increases in both EPR and VALAG lead to higher withdrawals. The reason may be that water resources are not binding for agricultural use in Iraq, and EPR, even at its value at \$25 MWh, is still large enough to favor energy benefits over agricultural use in the upstream nodes. This is in contradiction to the assumption that, because of its geographical position, Iraq is vulnerable to unilateral water withdrawal by the upstream countries.
- Changes in VALAG lead to linear increases in benefits. The little tilt in the benefit graphs can be attributed to the impact of the changing allocation of water to withdrawal versus energy generation. After this change, the linear increase in benefits is fully explained by the increase in VALAG (Figures 5.13, 5.14, 5.15, and 5.16).

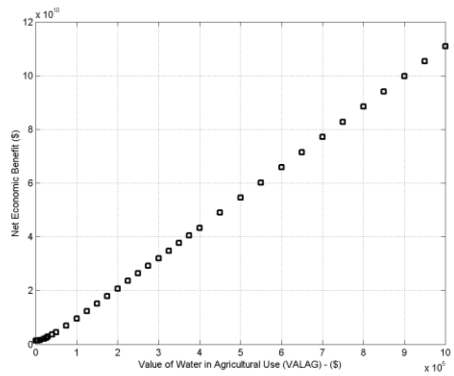


Figure 5.13: Net Economic Benefit as a Function of Water Use Value in Agriculture

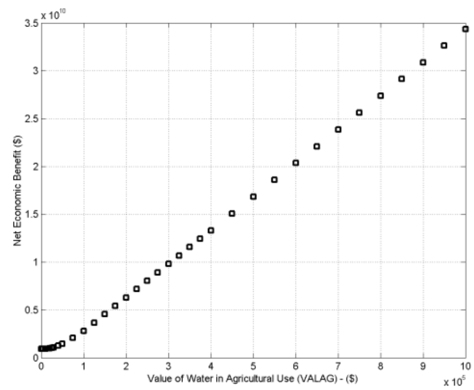


Figure 5.14: Net Turkish Economic Benefit as a Function of Water Use Value in Agriculture

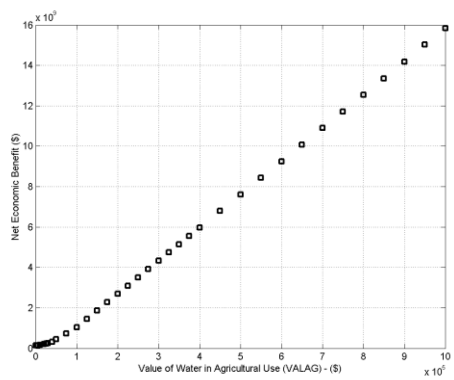


Figure 5.15: Net Syrian Economic Benefit as a Function of Water Use Value in Agriculture

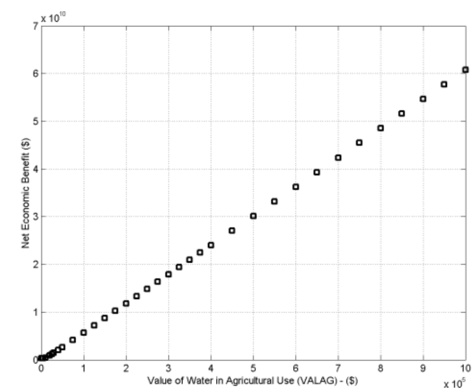


Figure 5.16: Net Iraqi Economic Benefit as a Function of Water Use Value in Agriculture

5.2.3. Value of Water in Urban Uses (VALUR)

It is expected that changes in the value of water in urban uses (VALUR) will result in impacts similar to those of VALAG. Figures 5.17, 5.18, and 5.19 illustrate the changes in withdrawals in response to changes in VALUR, varying between 0 and 10^6 \$/Mm^3. The following can be observed:

- The staircase-type changes in withdrawals for both Turkey and Syria illustrate the incremental impact of additional cities selected by the model to be served by supply nodes. In other words, whenever VALUR exceeds the unit cost of transportation plus the opportunity cost of other uses (irrigation and electric generation), serving farther cities, even Damascus, becomes feasible. All Syrian and Iraqi cities exceeding 100,000 inhabitants are listed as demand nodes, and their transport unit costs are linear function of their distance to supply nodes. Both graphs show the declining deterrence of distances when the value of water increases. Iraq reaches its maximum withdrawal when VALUR is around \$250,000 per Mm^3, and Syria and Turkey do so at \$900,000 per Mm^3. Figure 5.20 shows the amount of water left to the Gulf, which represents, of course, the complete reversal of the water withdrawals.

- Because Iraqi settlements are very close to the rivers, the deterrence effect of transportation costs is easily overcome by the increasing value of urban water consumption (VALUR). Therefore, there is an early and relatively small tilt in the benefit curve of Iraq (NEBi), but later and bigger tilts for the benefit curves of both Turkey and Syria (Figures 5.22, 5.23, and 5.24).

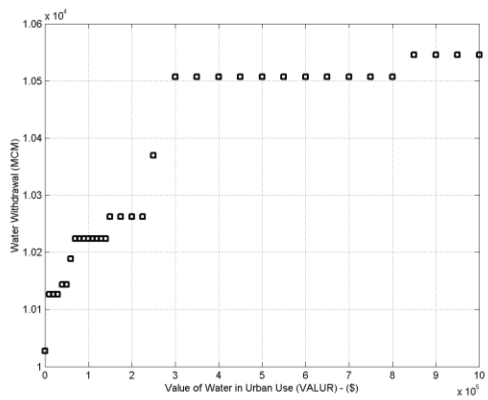


Figure 5.17: Water Withdrawal by Turkey as a Function of Water Value in Urban Use

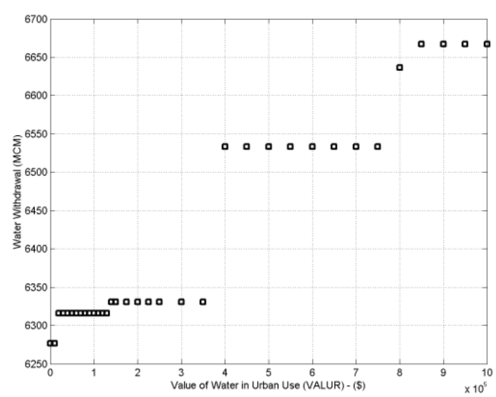


Figure 5.18: Water Withdrawal by Syria as a Function of Water Value in Urban Use

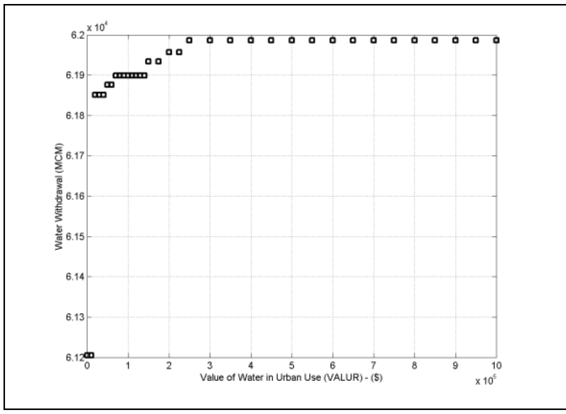


Figure 5.19: Water Withdrawal by Iraq as a Function of Water Value in Urban Use

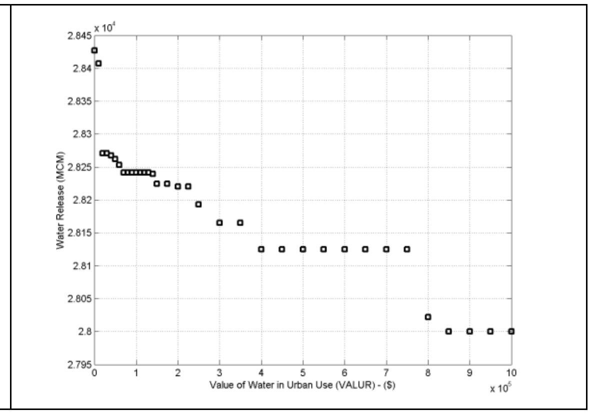


Figure 5.20: Water released to the Gulf as a Function of Water Value in Urban Use

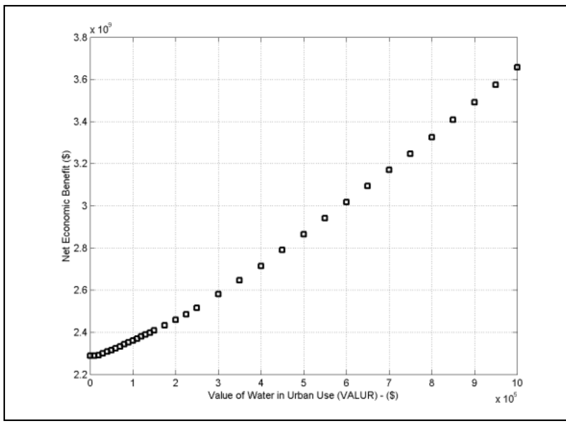


Figure 5.21: Net Economic Benefit as a Function of Water Value in Urban Use

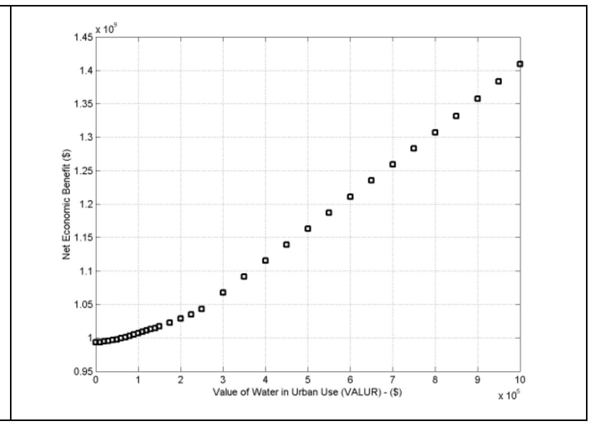


Figure 5.22: Net Turkish Economic Benefit as a Function of Water Value in Urban Use

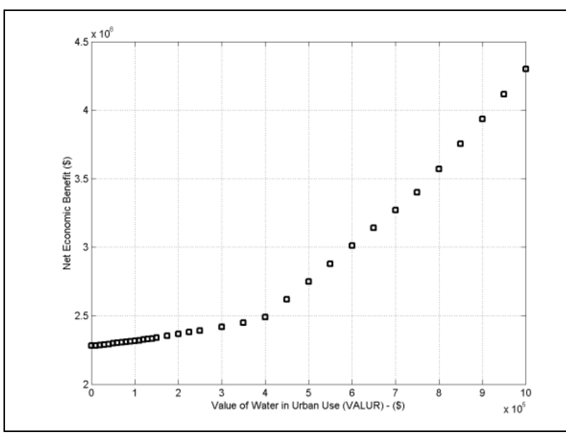


Figure 5.23: Net Syrian Economic Benefit as a Function of Water Value in Urban Use

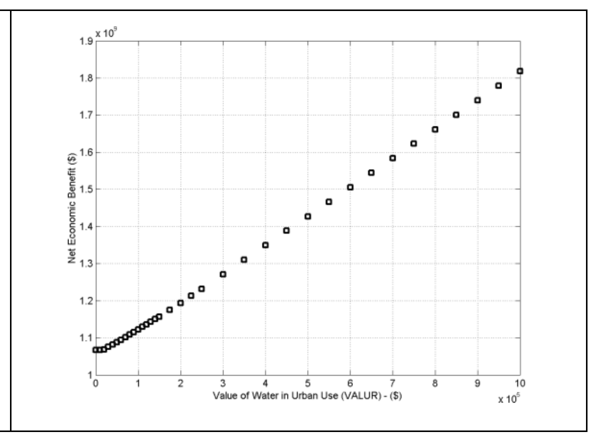


Figure 5.24: Net Iraqi Economic Benefit as a Function of Water Value in Urban Use

5.2.4. Agricultural Water Transport Cost (AGRTC)

In contrast to the effect of VALAG, an increase in the unit cost of transportation to agricultural demand nodes (AGRTC) has a negative impact on water withdrawal both in Turkey and Syria, but not in Iraq (Figures 5.25, 5.26, and 5.27). This can be attributed to the increase in the relative importance of EPR with respect to VALAG after transport cost, and the relative proximity of agricultural lands to the rivers in Iraq, as compared to Turkey and Syria. Due to the downstream position of Iraq and the existence of energy generation options, especially at upstream nodes, Iraqi withdrawal reaches its maximum with a low AGRTC, nearly \$50 per Mm^3-km. On the other hand, both Syria and Turkey decrease their withdrawals with increasing AGRTC. If EPR is kept at zero, only AGRTC and the associated distance between supply and demand nodes play a significant role on withdrawals; thus, more upstream water withdrawals take place due to 1) lesser distance to the demand nodes and 2) the option of reutilization of return flows downstream. The following can be observed:

- Figure 5.28 shows the release to the Gulf, i.e., whatever is not withdrawn is left to the Gulf.
- Iraq reaches its maximum level of withdrawal at a very low agricultural transportation cost, and then its benefit decreases linearly as a function of AGRTC (Figure 5.32). The linearity is due to the fact that most of the withdrawal nodes are close to the river basin and supply nodes (Table 4.9), and changes in AGRTC are the only source of effect on the Iraqi benefits. On the other hand, both Turkey and Syria display a relatively more irregular and nonlinear downward decline in their benefits (Figures 5.30 and 5.31), due to varying distances from supply nodes (Table 4.9).
- The first drop in water consumption in Iraq (Figure 5.27) can be explained as follows. The water delivery costs through the interbasin links are designed to be paid by the country with the destination nodes; therefore, the cost of the water delivered through the link ($PQ_{21,12}$) and used by Iraq, is being paid by Syria. On Figure 5.32, the decline

in the Iraqi benefit is associated with decreasing water transfer from the Tigris to the Euphrates, while Syria is getting the benefit of not paying the cost of the water transferred. In other words (Figure 5.31), if Iraq does not withdraw water in the Euphrates basin, Syria does not pay the price of water transfer. The decrease, then increase in the Iraqi benefit can be explained in two steps. First the decrease is associated with declining water transfer through link ($PQ_{21,12}$=2691 to 560 Mm^3). Once the water is delivered, Iraq obtains benefits from withdrawals (both directly or indirectly from return flows from Syria). Therefore, the decrease in water transfer for Iraqi use yields benefits for Syria (not paying the cost of water deliveries over the link). Second, the increase in Iraqi benefit is associated with the decrease in Turkish withdrawals upstream ($W_{3,3}$ declines from 3,202 to 30 Mm^3). This leads to more water available for Iraqi use downstream and more benefits.

- The second drop in water consumption in Iraq (Figure 5.27) can be explained as follows. In Figure 5.27, the decline in withdrawal in Iraq with an increasing AGRTC is the expected outcome; however, this decrease (around AGRTC=$150 to $175) is followed by an increase (around AGRTC=$225 to $250), illustrating a slight alteration in the allocation among countries. What appears to be a drop and then an increase in Iraqi withdrawals in Figure 5.27 is only 148 Mm^3 and is associated with the disappearance of water transferred over the link $PQ_{21,12}$ (458 Mm^3) for Syrian use. Because the return flow from Syria goes directly to Iraq as an additional resource, the reduction in Syrian withdrawal of the water, which is transferred from the Tigris basin through the link, indirectly hampers Iraqi withdrawals. Nevertheless, the later rise of Iraqi withdrawal is clearly compensated by the decline in water withdrawal in Turkey. The increase in water consumption is a recovery from the initial decline in Figure 5.27 and less than the amount unused by Turkey due to high AGRTC.
- The rise in withdrawal in Turkey (Figure 5.25) results from less water withdrawal in Syria. This can be attributed to the distance from supply nodes to demand nodes. An increase in AGRTC affects the nodes farther away; therefore, the node (i=15) in Syria, farthest away from the supply node (39.47km), is affected more than the closer

node (i=4) in Turkey (20.31km). Thus, the demand node in Turkey has a more positive contribution to the overall system than the Syrian demand node. Consequently, Turkish withdrawal increases and then decreases with increasing AGRTC ($550 to 575 and $600 to 625 respectively).

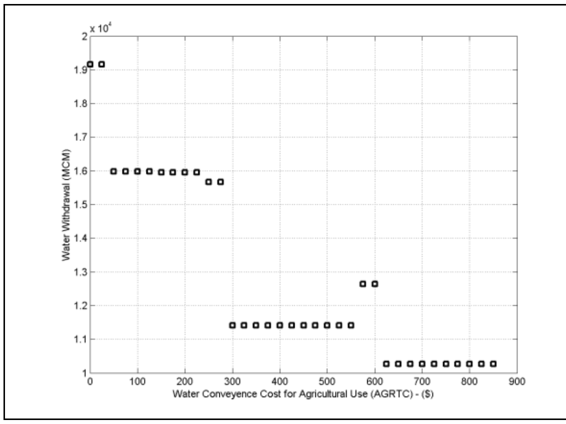


Figure 5.25: Water Withdrawal by Turkey as a Function of Agricultural Water Conveyance Cost

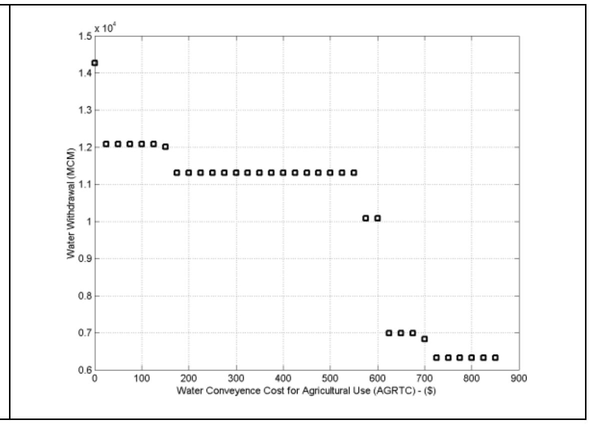


Figure 5.26: Water Withdrawal by Syria as a Function of Agricultural Water Conveyance Cost

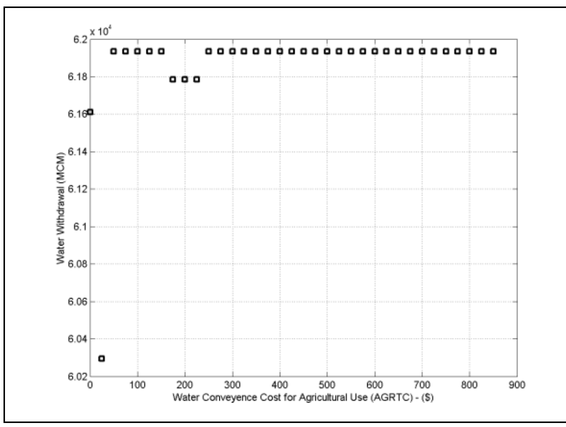


Figure 5.27: Water Withdrawal by Iraq as a Function of Agricultural Water Conveyance Cost

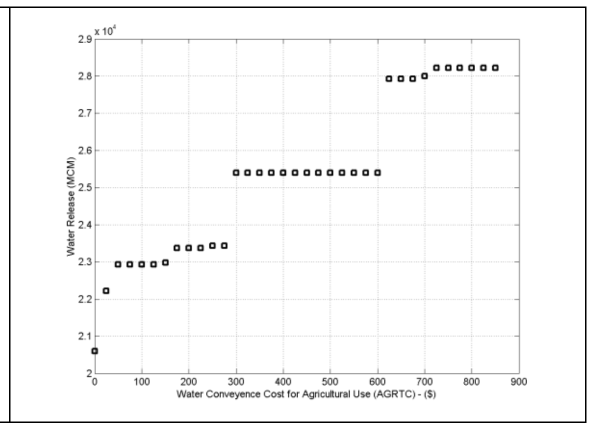


Figure 5.28: Water released to the Gulf as a Function of Agricultural Water Conveyance Cost

- In summary, overall water withdrawals and releases display the general expected relations. Increasing AGRTC deters water withdrawal and increases water release to the Gulf (Figure 5.28).

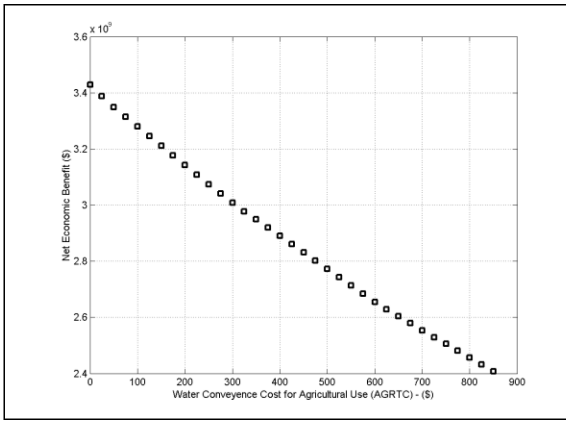


Figure 5.29: Net Economic Benefit as a Function of Agricultural Water Conveyance Cost

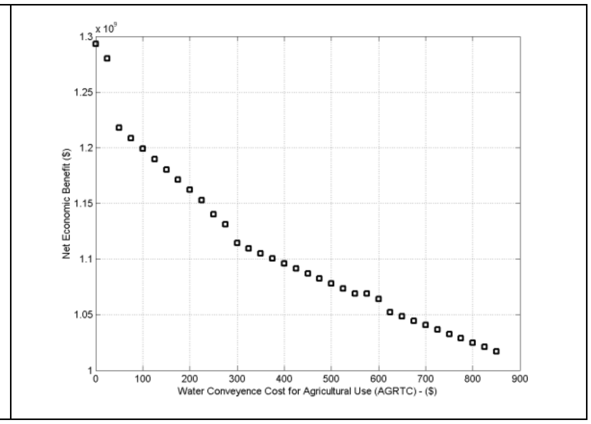


Figure 5.30: Net Turkish Economic Benefit as a Function of Agricultural Water Conveyance Cost

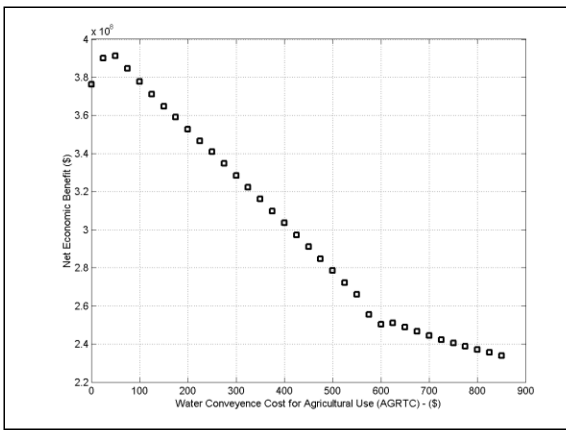


Figure 5.31: Net Syrian Economic Benefit as a Function of Agricultural Water Conveyance Cost

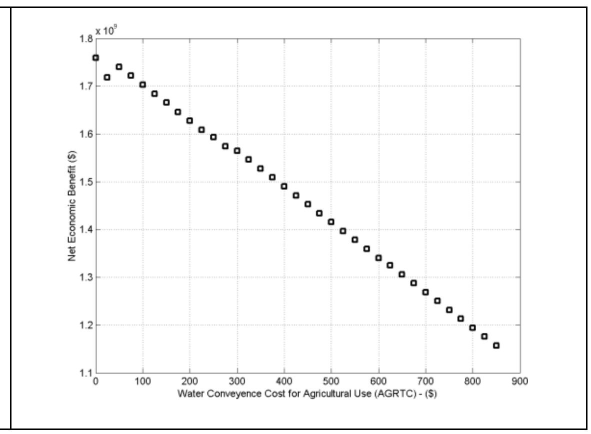


Figure 5.32: Net Iraqi Economic Benefit as a Function of Agricultural Water Conveyance Cost

5.2.5. Urban Use Water Transport Cost (URBTC)

Unlike the case of AGRTC, an increase in URBTC has the same directional impact on all countries' withdrawals (Figures 5.33, 5.34, 5.35). Iraq, again, is the country showing the least changes. The stair shape of the plots underscores the discrete impact of transport costs to large urban areas. The following can be observed:

* Figure 5.36 shows the increasing relation of URBTC with water release to the Gulf, as expected.

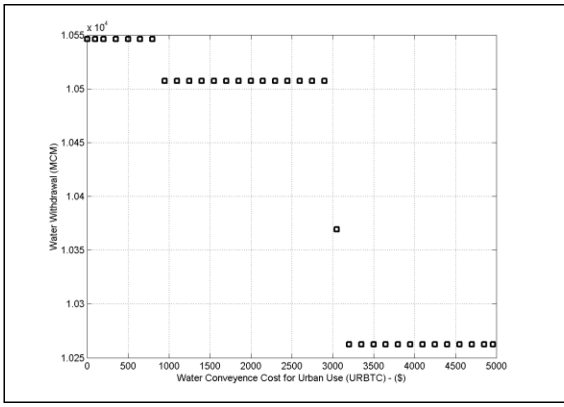


Figure 5.33: Water Withdrawal by Turkey as a Function of Urban Water Conveyance Cost

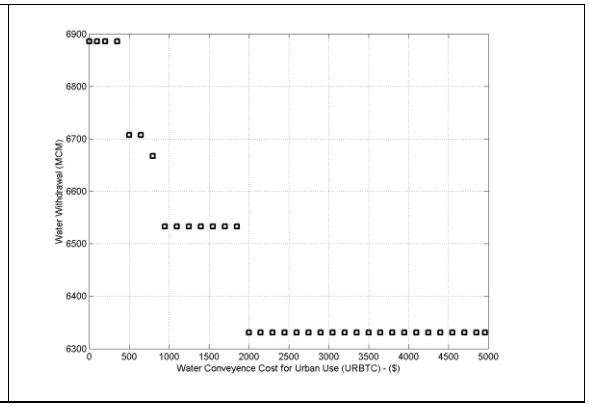


Figure 5.34: Water Withdrawal by Syria as a Function of Urban Water Conveyance Cost

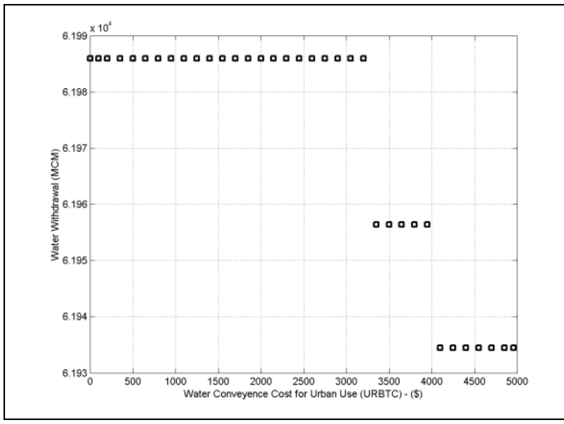


Figure 5.35: Water Withdrawal by Iraq as a Function of Urban Water Conveyance Cost

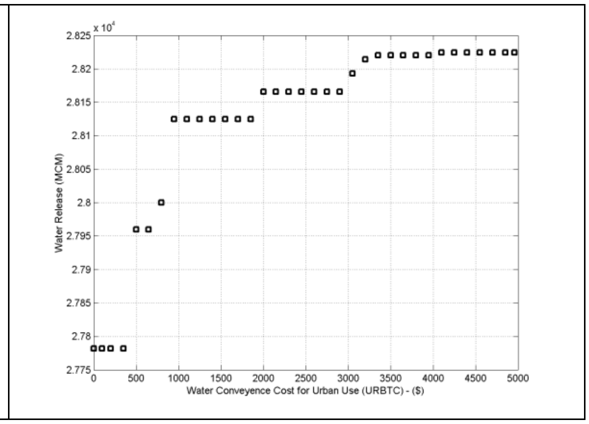


Figure 5.36: Water released to the Gulf as a Function of Urban Water Conveyance Cost

* The benefit curves are, to some degree, similar to those for AGRTC (Figures 5.37 – 5.40). The plot of Syrian benefits displays a nonlinear curve, which is the main source of the nonlinearity in the overall benefits curve. Because urban demand nodes in Syria are scattered throughout the country and have varying distances, the changes in

unit cost of delivery (URBTC) have larger incremental impacts on Syrian benefits (Figure 5.39). Turkey has a partially nonlinear curve, whereas the Iraqi benefit curve is almost linear. While the nonlinearity is related to the varying distances of urban demand nodes and the amounts of water to be delivered, the linearity reflects the pecuniary effects of URBTC on rising cost, but not any change in the amount of withdrawal.

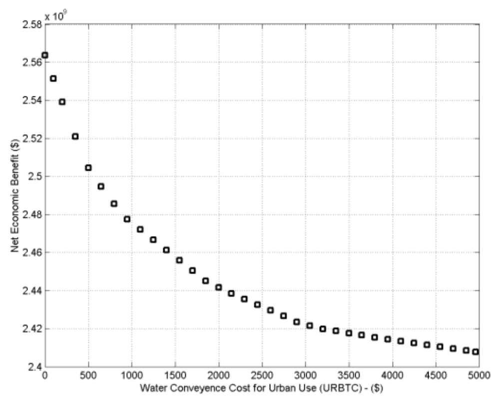


Figure 5.37: Net Economic Benefit as a Function of Urban Water Conveyance Cost

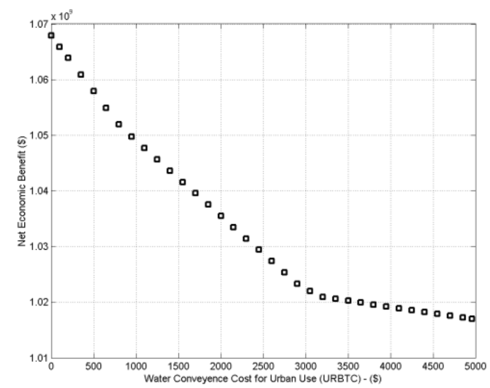


Figure 5.38: Net Turkish Economic Benefit as a Function of Urban Water Conveyance Cost

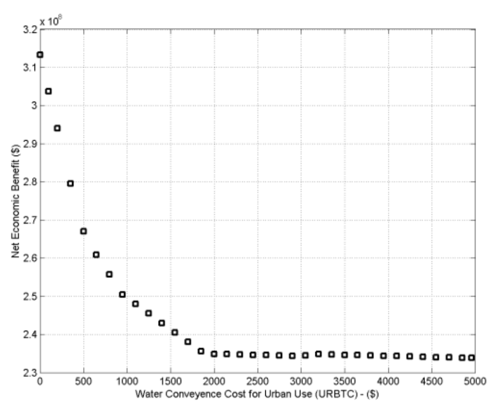


Figure 5.39: Net Syrian Economic Benefit as a Function of Urban Water Conveyance Cost

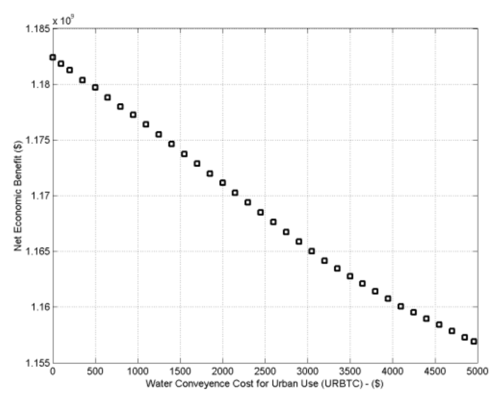


Figure 5.40: Net Iraqi Economic Benefit as a Function of Urban Water Conveyance Cost

5.2.6. Inter-Supply Nodes Water Transport Cost (CTSS)

CTSS is an important variable characterizing the links between the two river basins (supply to supply). As mentioned in section 5.2.4, CTSS is paid by the destination country. Thus the discussion in this section is primarily on the inter supply link $PQ_{21,12}$, which originates in Turkey and ends in Syria (Syria pays for the cost of transportation, but Turkey does not). The two other inter-supply links remain within the borders of Iraq, and thus do not affect the allocation among the three countries.[1]

- The increasing benefits of Turkey with higher CTSS indicate that there is a tradeoff between Turkish benefits and overall benefits (Figures 5.45 and 5.46). When CTSS increases, the overall benefit decreases; however the increase in Turkey's benefit is the outcome of both increasing water withdrawal at node i=22, and energy generation at node 21. In the meantime, Syria starts utilizing the water coming as return flow (37%) from node i=22 as a substitute for the decline in water transferred through the link $PQ_{21,12}$.
- An increase in CTSS from $100 to $125 leads to an increase in withdrawal in Turkey for node i=22 (which has a 37% return flow rate to node j=12). This explains why the benefit of using water for node i=22 and obtaining free return flow to node j=12 exceeds the benefit of utilizing water transferred after paying for the link transfer cost. In other words, this means that, rather than using the link with higher cost, utilizing the return flow after agricultural use in Turkey is more beneficial and provides a stronger marginal contribution to the objective function (overall optimization). Because Turkey withdraws more water and the others countries do not change their water withdrawal regimes, the release to the Gulf naturally decreases (Figure 5.44). In the meantime, Iraqi benefit from energy generation but not from water withdrawal declines due to increasing water use in Turkey (Figure 5.48).
- When CTSS=$275, the water delivered through the link $PQ_{21,12}$ decreases to zero. Withdrawal in Syria is then negatively affected, but not Iraqi withdrawal (Figures 5.42 and 5.43). However the Iraqi benefit increases due to more water available and higher energy generation capacities in the Tigris basin than in the Euphrates basin. In

other words, when the water delivered through the link declines to zero, an additional source (the non-transferred water) is provided for release to downstream nodes for energy generation in the Tigris basin.

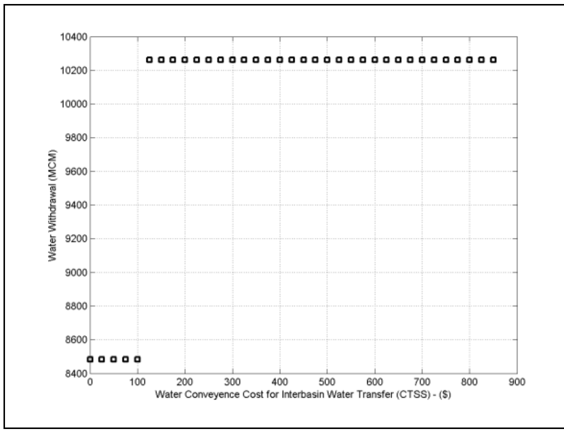


Figure 5.41: Water Withdrawal by Turkey as a Function of Interbasin Water Conveyance Cost

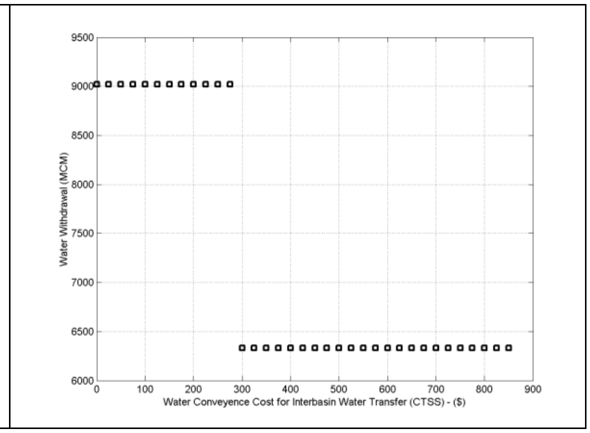


Figure 5.42: Water Withdrawal by Syria as a Function of Interbasin Water Conveyance Cost

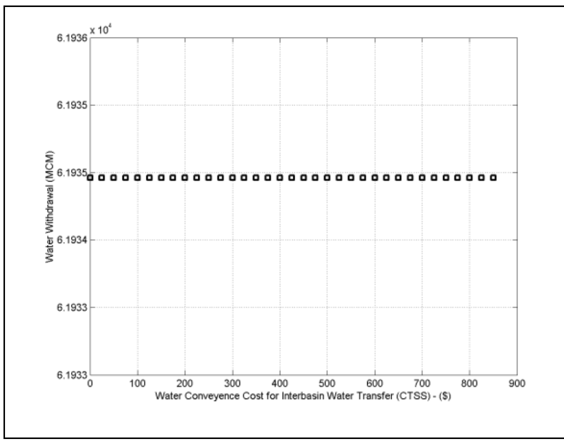


Figure 5.43: Water Withdrawal by Iraq as a Function of Interbasin Water Conveyance Cost

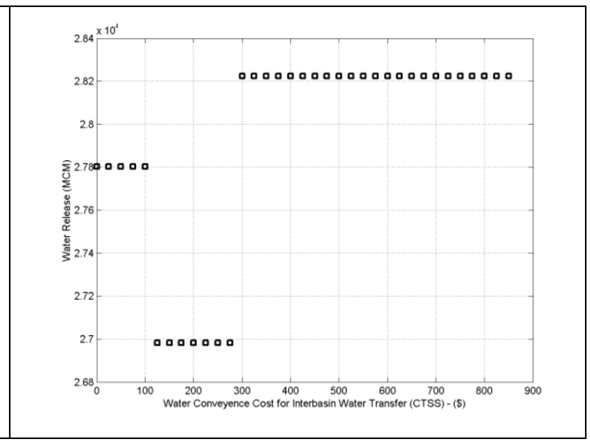


Figure 5.44: Water released to the Gulf as a Function of Interbasin Water Conveyance Cost

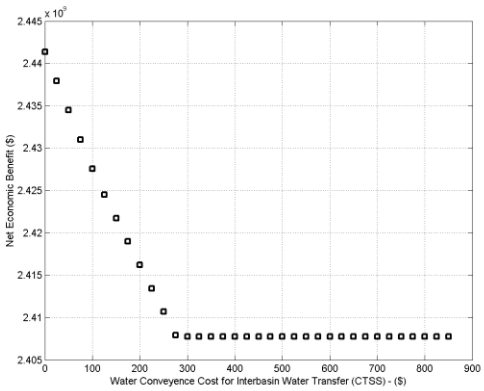


Figure 5.45: Net Economic Benefit as a Function of Interbasin Water Conveyance Cost

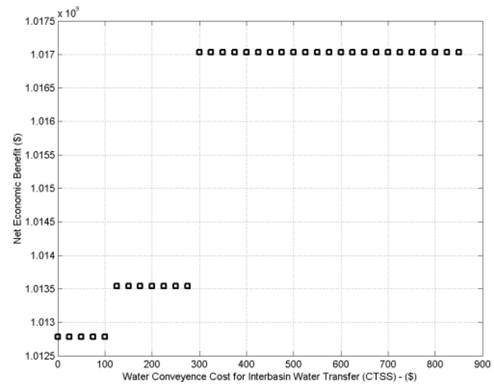


Figure 5.46: Net Turkish Economic Benefit as a Function of Interbasin Water Conveyance Cost

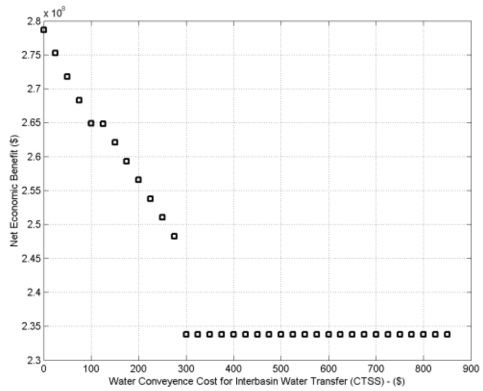


Figure 5.47: Net Syrian Economic Benefit as a Function of Interbasin Water Conveyance Cost

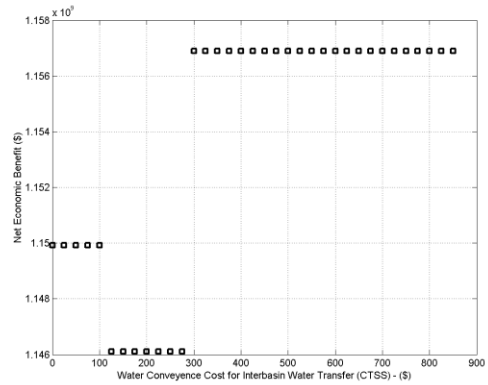


Figure 5.48: Net Iraqi Economic Benefit as a Function of Interbasin Water Conveyance Cost

5.2.7. Single Parameter Elasticities

The total and country benefits have been regressed on the individual parameters (EPR, VALAG, VALUR, AGRTC, URBTC, CTSS). These regressions represent approximation of the curves presented in the previous sections. Because both dependent and independent variables are in logarithmic form, the coefficient of the explanatory variable represents the constant elasticity of the benefits with regard to the parameter.

Table 5.1: Single-Parameter Regression Results

Dependent variable	R^2	Adjusted R^2	Prob - F		Coefficients & t - statistics						
					Constant	LNEPR	LNVALAG	LNVALUR	LNAGRTC	LNURBTC	LNCTSS
LNNEB	0.954	0.952	0.0000	**Coefficient**	19.78	0.69					
				t - value	139.45	25.72					
LNNEBT	0.983	0.982	0.0000	**Coefficient**	18.22	0.87					
				t - value	169.57	42.86					
LNNEBS	0.963	0.962	0.0000	**Coefficient**	17.28	0.73					
				t - value	128.57	28.74					
LNNEBI	0.896	0.893	0.0000	**Coefficient**	19.70	0.47					
				t - value	132.36	16.62					
LNNEB	0.958	0.957	0.0000	**Coefficient**	13.12		0.88				
				t - value	33.28		27.12				
LNNEBT	0.909	0.906	0.0000	**Coefficient**	13.49		0.76				
				t - value	26.14		17.87				
LNNEBS	0.951	0.949	0.0000	**Coefficient**	9.97		0.97				
				t - value	21.04		24.81				
LNNEBI	0.985	0.984	0.0000	**Coefficient**	11.16		0.99				
				t - value	42.37		45.60				
LNNEB	0.772	0.765	0.0000	**Coefficient**	20.35			0.11			
				t - value	156.54			10.41			
LNNEBT	0.734	0.726	0.0000	**Coefficient**	19.82			0.08			
				t - value	185.74			9.39			
LNNEBS	0.624	0.612	0.0000	**Coefficient**	17.82			0.13			
				t - value	81.74			7.28			
LNNEBI	0.822	0.816	0.0000	**Coefficient**	19.39			0.13			
				t - value	146.99			12.15			
LNNEB	0.851	0.846	0.0000	**Coefficient**	22.41				-0.11		
				t - value	464.92				-13.50		
LNNEBT	0.959	0.957	0.0000	**Coefficient**	21.21				-0.07		
				t - value	1463.22				-27.28		
LNNEBS	0.846	0.841	0.0000	**Coefficient**	20.60				-0.19		
				t - value	247.26				-13.26		
LNNEBI	0.785	0.778	0.0000	**Coefficient**	21.84				-0.13		
				t - value	313.69				-10.81		
LNNEB	0.989	0.989	0.0000	**Coefficient**	21.74					-0.02	
				t - value	9209.23					-53.68	
LNNEBT	0.924	0.922	0.0000	**Coefficient**	20.87					-0.02	
				t - value	3553.67					-19.71	
LNNEBS	0.915	0.912	0.0000	**Coefficient**	19.82					-0.07	
				t - value	707.42					-18.51	
LNNEBI	0.836	0.831	0.0000	**Coefficient**	20.93					-0.01	
				t - value	5412.80					-12.78	
LNNEB	0.872	0.868	0.0000	**Coefficient**	21.63						-0.0039
				t - value	13792.78						-14.74
LNNEBT	0.755	0.747	0.0000	**Coefficient**	20.73						0.0018
				t - value	19531.22						9.92
LNNEBS	0.863	0.858	0.0000	**Coefficient**	19.66						-0.0603
				t - value	785.34						-14.17
LNNEBI	0.506	0.491	0.0000	**Coefficient**	20.85						0.0033
				t - value	6165.40						5.73

A comparison of the coefficients clarifies the relative importance of the parameters. Table 5.1 presents the results of theses estimations. The following can be observed:

- All coefficients are statistically significant, and all signs are consistent with expectations. The overall system benefit (NEB) is most sensitive to VALAG, due to the size of the agricultural areas in the basin. Turkey (NEBt) is the country taking advantage of high elevations and, therefore, is more sensitive to EPR (0.87). On the other hand, Syria (NEBs) and Iraq (NEBi) are more sensitive to VALAG (0.97 and 0.99).

- In terms of cost parameters, the overall system benefit (NEB) is most responsive to AGRTC (-0.11), and Turkey (NEBt), Syria (NEBs), and Iraq (NEBi) are all more responsive to AGRTC (-0.07, -0.19, and -0.13, respectively) than to URBTC and CTSS.

From this single parameter analysis, it is clear that Turkey derives the highest benefits from increases in EPR, whereas, for both Syria and Iraq, VALAG is more important, due to plain land and lower elevation (less energy generation).

5.3. Six-Parameter Analyses

Complementing the previous single-parameter analyses, this section presents the results of solving the ETRBM using all the six parameters simultaneously while varying them over a six-dimensional grid, leading to 729 different scenarios. The analyses provide: 1) the relative allocation of benefits and 2) the statistical robustness of the parameters.

5.3.1. Range of Shares and Associated Tradeoffs

Table 5.2 presents descriptive statistics for the benefits, parameters, and benefits shares. The ranges of benefits shares for Turkey and Iraq are similar, from 30% to 60%, while Syria is characterized by a narrow range, from 9% to 12%. This implies that the major tradeoffs occur between Turkey and Iraq. This may be explained by the scale and geography of the countries, with both Turkey and Iraq having more agricultural lands and energy generation potential.

Table 5.2: Descriptive Statistics for Six-Parameter Analyses

	N	Range	Minimum	Maximum	Mean	Std. Deviation
NEB	729	9,324,078,800	2,407,731,200	11,731,810,000	7,157,853,131	2,553,615,939
NEBT	729	4,159,802,900	1,017,030,400	5,176,833,300	3,194,250,960	1,362,929,357
NEBS	729	1,195,936,363	233,810,237	1,429,746,600	799,432,460	327,525,801
NEBI	729	3,968,340,600	1,156,890,500	5,125,231,100	3,164,169,684	1,245,158,302
EPR	729	100	25	125	75	41
VALAG	729	50,000	25,000	75,000	50,000	20,426
VALUR	729	50,000	150,000	200,000	175,000	20,426
AGRTC	729	340	510	850	680	139
URBTC	729	1,958	3,000	4,958	3,986	800
CTSS	729	340	510	850	680	139
SHARET	729	0.335	0.294	0.630	0.442	0.100
SHARES	729	0.032	0.094	0.126	0.109	0.008
SHAREI	729	0.334	0.264	0.598	0.448	0.099

5.3.2. Net Benefit Allocation vs. Share of Benefits

NEB, NEBt, NEBs, NEBi, SHAREt, SHAREs, and SHAREi are regressed on the six parameters (Tables 5.3 and 5.4). All variables are in logarithmic forms. The regressions equations are all statistically significant and have very high R^2 values, the lowest of which is .84. The most salient features of these results are as follows:

- In all equations, EPR and VALAG are highly significant, and VALUR, and URBTC are mostly insignificant.
- For the overall system benefit (NEB), VALAG has the highest elasticity (0.62), followed by EPR (0.44). This is consistent with the single-parameter analyses (Section 5.1). For country benefits, variations in the value of the elasticities across countries provide important insights. While EPR is important for the benefit of Turkey (elasticity of 0.70), VALAG is important for Iraqi and Syrian benefits (elasticities of 0.93 and 0.74). It can be concluded that, while energy is the most important benefit-generating component for Turkey, agriculture is the most important factor for Iraq. The elasticities also point to the relative substitutability of energy and agriculture in each country. For instance, energy is not really a substitute for agriculture in Iraq. On the other hand, energy is an important substitute for agriculture in Turkey and Syria.

Table 5.3: Benefit Regressions - Six Independent Variables

Dependent variable	LNNEB		LNNEBT		LNNEBS		LNNEBI	
	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
Constant	14.730	28.5	15.973	28.0	11.894	23.0	11.672	41.0
LNEPR	0.435	68.5	0.699	99.9	0.485	76.3	0.168	48.0
LNVALAG	0.622	66.2	0.316	30.4	0.744	79.1	0.934	180.4
LNVALUR	0.032	0.9	0.021	0.5	0.016	0.4	0.050	2.5
LNAGRTC	-0.132	-6.5	-0.099	-4.4	-0.169	-8.3	-0.179	-16.0
LNURBTC	-0.006	-0.3	-0.008	-0.3	-0.004	-0.2	-0.007	-0.6
LNCTSS	-0.008	-0.4	-0.002	-0.1	-0.083	-4.1	0.004	0.3
R^2	0.9266		0.9380		0.9440		0.9798	
Adj - R^2	0.9260		0.9375		0.9436		0.9797	
Prob - F	0.0000		0.0000		0.0000		0.0000	

Table 5.4: Benefit Shares Regressions - Six Independent Variables

Dependent variable	LNSHRT		LNSHRS		LNSHRI	
	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
Constant	1.243	9.4	-2.837	-21.1	-3.059	-11.7
LNEPR	0.265	162.7	0.051	30.6	-0.267	-82.9
LNVALAG	-0.307	-127.4	0.122	50.1	0.312	65.5
LNVALUR	-0.011	-1.2	-0.017	-1.8	0.018	1.0
LNAGRTC	0.033	6.3	-0.037	-7.0	-0.047	-4.5
LNURBTC	-0.001	-0.2	0.003	0.5	-0.001	-0.1
LNCTSS	0.006	1.1	-0.074	-14.0	0.012	1.2
R^2	0.9834		0.8365		0.9394	
Adj - R^2	0.9833		0.8351		0.9389	
Prob - F	0.0000		0.0000		0.0000	

- CTSS is barely significant in the overall system benefit. For Syria CTSS is highly significant, because of the water intake from the Tigris to the Euphrates.
- VALUR and URBTC have low t-values. This can be attributed to the upper withdrawal ceiling, and the relatively small scale of urban populations. Because the highest value of water use – as well as the largest return flow rate to the system – characterize the urban sector, reaching the upper ceiling is expected to occur much earlier at urban demand nodes than at agricultural demand nodes.
- The signs are consistent with the expectations that benefit parameters have positive signs, and cost parameters negative signs. However, in the SHAREi (Iraq) equation, EPR has a negative and statistically significant sign. On the other hand, the positive

coefficient of EPR in the NEBi equation points to the positive contribution of EPR on the overall benefit of Iraq. At the same time, the negative effect of EPR on the share of Iraqi benefits implies that relatively more benefits are obtained by Turkey than by Iraq. In contrast, the Turkish share (SHAREt) is negatively affected by an increase in VALAG.

5.4. Four-Parameter Analyses

The parameters VALUR and URBTC have been shown to have little impact on the model results, and are therefore, in the remainder of this chapter, held fixed at their base values. This section focuses on the four remaining parameters, and provides more detailed benefit analyses. There are subcomponents of NEB, such as TECBWa, TECBWu, (agricultural and urban economic benefits) and TECBe (energy economic benefits) by country. Additionally, resource utilization figures, like water withdrawals by countries (WTt, WTs, and WTi), water transferred over the links (PQs and PQi), and water released to the Gulf (GULF) are also analyzed. In order to obtain better fits, the number of observations for multiple regression analyses is increased to 1296, keeping the same ranges as in the six-parameter-analyses. These regressions equations are estimated with the four parameters: EPR, VALAG, AGRTC, and CTSS.

The statistical outputs are presented as follows: 1) Descriptive statistics; 2) Multiple linear regressions with all variables in logarithmic form; 3) Multiple regression with 2^{nd} – order terms, using the translog (quadratic) formulation, in order to uncover interaction effects.

5.4.1. Descriptive Statistics

Because the ranges of the parameters are the same, increasing the number of observations from 729 to 1294 does not affect the benefits interpretations made in the six-parameter descriptive statistical analyses (Section 5.3). However, in this section, new dependent variables (subcomponents of NEB and water resources used by countries) provide some more insights. The following can be observed:

- Turkish agricultural benefits can decrease down to zero, which implies that Turkish water withdrawal can decrease down to zero. This can only happen if energy prices are very high, and agricultural withdrawal in Turkey has a very high opportunity cost due to the foregone benefits of energy (Table 5.5).
- Urban water use in Syria is constant. This affects the regression analyses, because a lack of variations prevents estimating a multiple regression model (Table 5.5).
- The resource use variables (TWT, WTt, WTs, and WTi) indicate that Iraqi withdrawal does not display significant variations. Its range is the smallest among the three countries. Turkey is the country most significantly affected by parameter variations. This also supports the conclusion of the single parameter analyses, that overall optimization favors Iraqi water withdrawal (Section 5.2).
- PQs and PQi are important component of inter-basin water transfer. The link in Syria carries a significant amount of water, representing nearly 13% of all tributary inflows. The water transferred by the link in Iraq is very low (142 Mm^3), close to negligible.
- The water released from dams to the Gulf and the water indirectly returned to the Gulf from agriculture and urban uses sum up to nearly 15% of all the tributary inflows in the ETRB.

While benefit allocations to Turkey and Iraq are similar in terms of shares and ranges, water resources allocations differ significantly. In Turkey, the loss from less water withdrawal is compensated by an alternative benefit, energy generation, which is 4.6 and 5.6 times larger than that of Syria and Iraq.

5.4.2. Multiple Regressions Analyses

Two functional forms are used in the regression analyses:

- ***Using the linear logarithmic*** form provides basic information about the statistical significances of the coefficients of the dependent variables and their signs. The coefficients represent constant elasticity figures.
- ***Using the translog (quadratic logarithmic)*** form provides potentially better fits for the models, due to the incorporation of quadratic and interaction terms; however, the results are more difficult to interpret. The derivatives of the translog function provide point elasticity functions for each dependent variable.

Table 5.5: Descriptive Statistics for Four-Parameter Analyses

	N	Range	Minimum	Maximum	Mean	Std. Deviation
NEB	1296	9,252,028,800	2,407,731,200	11,659,760,000	7,074,808,743	2,138,474,381
EPR	1296	100	25	125	75	34
VALAG	1296	50,000	25,000	75,000	50,000	17,085
VALUR	1296	-	150,000	150,000	150,000	-
AGRTC	1296	340	510	850	680	116
URBTC	1296	-	4,958	4,958	4,958	-
CTSS	1296	340	510	850	680	116
NEBT	1296	4,142,057,100	1,017,030,400	5,159,087,500	3,148,011,851	1,145,726,322
NEBS	1296	1,188,198,663	233,810,237	1,422,008,900	791,029,872	275,183,014
NEBI	1296	3,921,770,200	1,156,890,500	5,078,660,700	3,135,767,024	1,040,692,947
TECBWA	1296	6,830,642,600	1,620,171,200	8,450,813,800	4,406,245,792	1,858,023,061
TECBWTA	1296	2,636,184,000	-	2,636,184,000	710,477,188	547,843,140
TECBWSA	1296	1,084,231,579	140,057,721	1,224,289,300	636,321,374	323,908,671
TECBWIA	1296	3,110,227,000	1,480,113,500	4,590,340,500	3,059,447,232	1,046,461,972
TECBWU	1296	11,100,910	142,267,803	153,368,713	147,989,238	3,208,074
TECBWTU	1296	5,806,925	29,440,610	35,247,536	34,279,715	2,164,949
TECBWSU	1296	-	8,632,889	8,632,889	8,632,889	-
TECBWIU	1296	5,293,985	104,194,304	109,488,288	105,076,634	1,973,713
TECBE	1296	5,512,507,342	750,547,958	6,263,055,300	3,437,642,906	1,708,306,207
TECBET	1296	4,024,076,827	569,862,973	4,593,939,800	2,583,730,819	1,281,757,012
TECBES	1296	608,998,189	74,444,305	683,442,494	360,271,456	179,865,500
TECBEI	1296	880,699,076	106,240,679	986,939,756	493,640,636	248,442,169
TWT	1296	47,945	65,755	113,700	86,397	10,014
WTT	1296	35,188	196	35,384	12,643	7,295
WTS	1296	10,722	5,660	16,381	11,874	3,215
WTI	1296	2,138	59,796	61,934	61,879	218
SHARET	1296	0.335	0.295	0.630	0.442	0.086
SHARES	1296	0.037	0.089	0.125	0.110	0.007
SHAREI	1296	0.333	0.264	0.597	0.448	0.084
PQS	1296	11,305	-	11,305	2,005	2,080
PQI	1296	142	-	142	0	8
PQ_21_12	1296	11,305	-	11,305	2,005	2,080
PQ_28_14	1296	-	-	-	-	-
PQ_31_16	1296	142	-	142	0	8
GULF	1296	22,118	11,983	34,101	24,581	4,622

The results indicate that the translog models have better fits (higher R^2) than the linear (logarithmic) models. Although the contribution of the translog models to the linear ones seems marginal when looking at the R^2 values, F-test results (see Table C1 in Appendix C) show that the contributions of the quadratic terms to the linear (restricted) models are statistically significant, except in one case (*LTECBWU*). Regarding the t-values, EPR and VALAG are the main sources of variations in the benefits. In addition to the regression results presented in table form, three-dimensional graphs are also presented with both EPR and VALAG as independent variables. The following analyses are presented below: 1) Analysis of the overall benefit and its relative allocations among countries; 2) Analysis of benefits by sectors and countries, including agricultural, urban, and energy benefits; 3) Analysis of water resource uses by countries; and 4) Inter-basin link utilization.

5.4.2.1. Analysis of the Overall Benefit and Its Allocation to Countries

The dependent variables are NEB, NEBt, NEBs, NEBi, SHAREt, SHAREs, and SHAREi. Tables 5.6 – 5.9 provide the regression equations, and Figures 5.49 – 5.63 display the best-fit models. The following are the most interesting results:

- The linear benefit regression equations in Table 5.6 have very high R^2 (exceeding 0.94), and are statistically significant. The coefficients are also highly statistically significant, except for LNCTSS in the regression of NEB, NEBt, and NEBi. The destination node for the link to Syria ($PQ_{21,12}$) provides statistically significant economic benefit to Syria. LNEPR and LNVALAG have positive signs, and LNAGRTC a negative sign, as expected.
- The *share equations* in Table 5.7 depict the changes in the relative allocation of benefits. All the coefficients are statistically significant, except the coefficients of LNCTSS for the Turkish and Iraqi shares (SHAREt and SHAREi). LNVALAG has a negative coefficient for the Turkish share (SHAREt). For Iraq, the negative sign is

associated with LNEPR. The Turkish share decreases with an increase in LNVALAG (Figure 5.61), and the Iraqi share declines with an increase in EPR (Figure 5.63).

Table 5.6: Total and Country Benefits Regressions with Four Independent Variables – Log Linear Form

Dependent variable	LNNEB		LNNEBT		LNNEBS		LNNEBI	
	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	15.099	107.0	16.315	105.1	12.150	83.6	12.099	158.6
LNEPR	0.436	102.0	0.715	152.0	0.483	109.8	0.163	70.3
LNVALAG	0.612	98.2	0.286	41.7	0.744	115.8	0.939	278.7
LNAGRTC	-0.128	-9.6	-0.086	-5.9	-0.198	-14.4	-0.169	-23.4
LNCTSS	-0.008	-0.6	-0.005	-0.3	-0.071	-5.2	0.004	0.6
R^2	0.9398		0.9507		0.9522		0.9847	
Adj R^2	0.9396		0.9505		0.9520		0.9847	
Prob - F	0		0		0		0	

Table 5.7: Country Benefit Shares Regressions with Four Independent Variables – Log Linear Form

Dependent variable	LNSHARET		LNSHARES		LNSHAREI	
	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	1.215	31.0	-2.950	-59.5	-3.001	-40.6
LNEPR	0.279	235.1	0.047	31.4	-0.274	-122.2
LNVALAG	-0.326	-188.5	0.132	60.1	0.327	100.1
LNAGRTC	0.042	11.3	-0.071	-15.1	-0.041	-5.9
LNCTSS	0.003	0.7	-0.063	-13.5	0.012	1.7
R^2	0.9860		0.7951		0.9509	
Adj R^2	0.9860		0.7945		0.9507	
Prob - F	0		0		0	

- *The constant elasticity* figures provided by the coefficients of the independent variables in Table 5.6 indicate the percentage changes in benefits resulting from one percent change in the independent variables (parameters). Table 5.6 shows that the Turkish benefit is sensitive to EPR (0.71), but less so to VALAG (0.29). For Iraqi benefits, the relation is reversed: the highest elasticity is associated with VALAG (0.94), while EPR has a much lower elasticity (0.16). For Syria, though VALAG has the highest elasticity (0.74), EPR has a non-negligible impact on Syrian benefits (0.48).

- Tables 5.8 and 5.9 provide interaction and quadratic effects, through the translog regression equations. Because the R^2 of the linear model is often quite close to 1.00, the translog equations do not have much to contribute in additional explanation. In all regression equations, there are strong interaction effects between LNEPR and LNVALAG, between LNEPR and LNAGRTC and between LNVALAG and LNAGRTC. Also, the variables ($LNEPR^2$) and ($LNVALAG^2$) have highly significant coefficients. These effects suggest that the various benefits are characterized by non-constant elasticities. This is clearly apparent on Figures 5.53 – 5.60.

Table 5.8: Total and Country Benefits Regressions with Four Independent Variables – Translog Form

Dependent	LNNEB		LNNEBT		LNNEBS		LNNEBI	
Independent	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	22.320	59.0	21.775	12.3	21.920	9.2	17.743	19.7
LNEPR	2.609	195.5	2.835	45.4	2.514	30.0	1.367	42.9
LNVALAG	-1.730	-65.5	-1.944	-15.7	-2.659	-16.1	-0.177	-2.8
LNAGRTC	-0.048	-0.7	0.401	1.3	0.333	0.8	-0.838	-5.3
LNCTSS	0.077	1.2	0.046	0.1	0.617	1.5	-0.021	-0.1
LEPRLEPR	0.132	295.3	0.140	67.1	0.090	32.0	0.070	65.8
LVAGLVAG	0.176	183.0	0.209	46.5	0.241	40.1	0.038	16.4
LATCLATC	-0.057	-12.8	-0.007	-0.3	-0.122	-4.4	-0.098	-9.2
LCTSLCTS	-0.001	-0.2	-0.003	-0.1	0.012	0.4	-0.003	-0.3
LEPRLVAG	-0.358	-624.9	-0.380	-142.1	-0.353	-98.3	-0.188	-137.5
LEPRLATC	0.083	67.8	0.118	20.6	0.107	13.9	0.035	11.8
LEPRLCTS	0.010	8.5	0.010	1.8	0.054	7.0	0.004	1.2
LVAGLATC	0.026	14.8	-0.088	-10.5	0.057	5.1	0.166	38.8
LVAGLCTS	-0.013	-7.5	-0.010	-1.2	-0.099	-8.9	0.003	0.8
LATCLCTS	0.004	1.2	0.008	0.5	-0.001	0.0	0.002	0.2
R^2	0.9999		0.9978		0.9956		0.9993	
Adjusted R^2	0.9998		0.9978		0.9956		0.9993	
Prob - F	0.0000		0.0000		0.0000		0.0000	

- *The three-dimensional graphs* (Figures 5.49 – 5.52) depict the net economic benefit surfaces created by varying EPR and VALAG. Comparisons can be made over the different country graphs, since the ranges for EPR and VALAG are the same. The Turkish benefit has the strongest rate of increase with EPR. In contrast, the Iraqi benefit (NEBt) has the strongest rate of increase with VALAG, followed by Syria and Turkey. This result confirms that upstream countries are more responsive to changes in EPR, whereas downstream countries are more responsive to changes in VALAG.

Table 5.9: Country Benefit Shares Regressions with Four Independent Variables – Translog Form

Dependent	LNSHARET		LNSHARES		LNSHAREI	
Independent	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	-0.545	-0.3	-0.400	-0.2	-4.578	-5.4
LNEPR	0.226	3.4	-0.095	-1.2	-1.242	-41.3
LNVALAG	-0.213	-1.6	-0.929	-5.9	1.553	26.1
LNAGRTC	0.449	1.4	0.381	1.0	-0.789	-5.3
LNCTSS	-0.031	-0.1	0.540	1.4	-0.098	-0.7
LEPRLEPR	0.008	3.7	-0.042	-15.9	-0.062	-61.3
LVAGLVAG	0.033	6.9	0.066	11.4	-0.138	-63.9
LATCLATC	0.050	2.2	-0.065	-2.4	-0.041	-4.0
LCTSLCTS	-0.002	-0.1	0.013	0.5	-0.002	-0.2
LEPRLVAG	-0.022	-7.9	0.005	1.3	0.170	131.7
LEPRLATC	0.035	5.7	0.024	3.2	-0.048	-17.6
LEPRLCTS	0.000	0.0	0.043	5.9	-0.007	-2.5
LVAGLATC	-0.114	-12.8	0.031	2.9	0.139	34.6
LVAGLCTS	0.003	0.3	-0.086	-8.1	0.017	4.2
LATCLCTS	0.004	0.2	-0.005	-0.2	-0.003	-0.3
R^2	0.9888		0.8534		0.9978	
Adjusted R^2	0.9887		0.8518		0.9977	
Prob - F	0.0000		0.0000		0.0000	

- *Point elasticity figures for EPR and VALAG using the translog regression models:* Tables 5.10 & 5.11 show point elasticities of the benefits & benefit shares with respect to EPR and VALAG and Figures 5.53 – 5.60 depict the variations of these elasticities. The following can be observed:
    - Turkey (NEBt) has the highest-elasticity benefit with respect to EPR (1.22), and Iraq (NEBi) the lowest (-0.03). On the other hand, Syria and Iraq (NEBs and NEBi) have the highest-elasticity benefits with respect to VALAG (1.3 and 1.2, respectively), while Turkey has the lowest (-0.22). As a result, EPR is more likely to affect the upper river basins (Turkish benefit) and VALAG is more likely to affect downstream plain lands (Iraqi benefit). This relation between VALAG and EPR represents the tradeoff between agricultural and energy use. Furthermore, the lower VALAG and the higher EPR, the higher the elasticity of the net benefits for the system and the countries in the system.
    - Turkey has the highest-elasticity share benefit with respect to EPR (0.32), while Iraq has the lowest (-0.49). This implies that a change in EPR is more likely to affect the benefits of Turkey through energy benefits. On the other hand, Iraq has the highest elasticity share of benefits with respect to VALAG (0.63), and Turkey

has the lowest (-0.41). This shows that VALAG tilts the relative allocation of benefits towards Iraq.

- SHAREi is negatively affected by changes in EPR. Correspondingly, SHAREt is negatively affected by changes in VALAG.
- In conclusion, the opposite impacts of VALAG and EPR on the benefits of the two countries at the opposite ends of the basin (Turkey and Iraq) underscores the importance of geographical locations and associated potentials held by the countries.

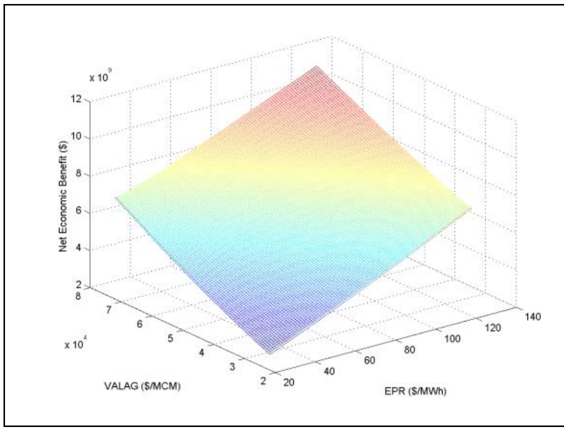


Figure 5.49: NEB with Respect to EPR & VALAG – Translog Function

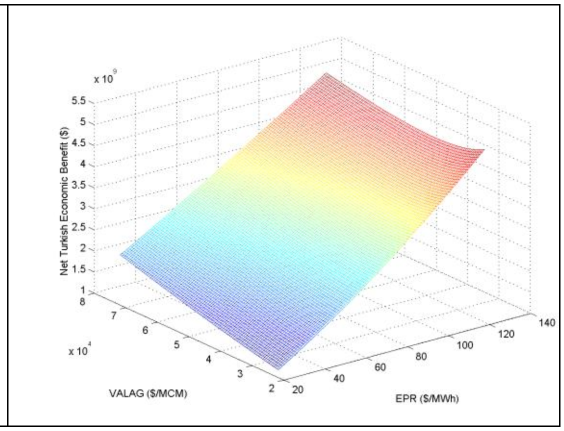


Figure 5.50: NEBt with Respect to EPR & VALAG – Translog Function

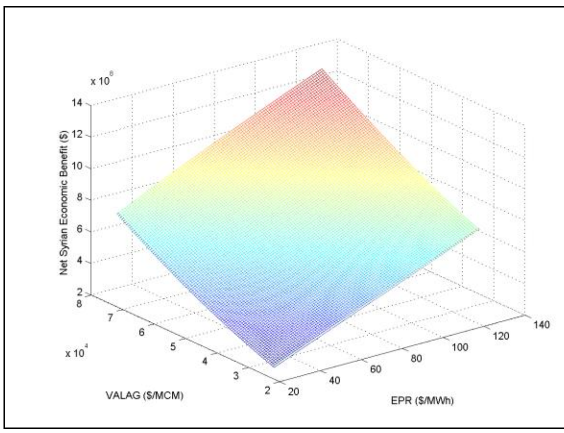


Figure 5.51: NEBs with Respect to EPR & VALAG – Translog Function

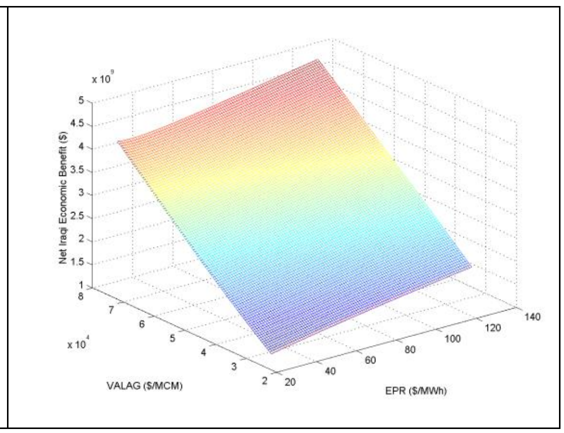


Figure 5.52: NEBi with Respect to EPR & VALAG – Translog Function

Table 5.10: Point Elasticity of Benefits with Respect to EPR and VALAG – Translog Function

				With respect to					With respect to		
				EPR	EPR				VALAG	VALAG	R^2
Elasticity of				MIN	MAX				MIN	MAX	
				25	*125*				*25000*	*75000*	
NEB	VALAG	MIN	*25000*	0.48	0.9	EPR	MIN	*25*	0.76	1.18	0.9999
	VALAG	MAX	*75000*	0.08	0.5	EPR	MAX	*125*	0.19	0.57	
NEBT	VALAG	MIN	*25000*	0.76	1.22	EPR	MIN	*25*	0.4	0.88	0.9978
	VALAG	MAX	*75000*	0.35	0.79	EPR	MAX	*125*	-0.22	0.25	
NEBS	VALAG	MIN	*25000*	0.6	0.88	EPR	MIN	*25*	0.8	1.34	0.9956
	VALAG	MAX	*75000*	0.2	0.5	EPR	MAX	*125*	0.24	0.76	
NEBI	VALAG	MIN	*25000*	0.158	0.4	EPR	MIN	*25*	1.125	1.204	0.9993
	VALAG	MAX	*75000*	-0.03	0.2	EPR	MAX	*125*	0.824	0.9	

Table 5.11: Point Elasticity of Benefit Shares with Respect to Ranges of EPR and VALAG – Translog Function

				With respect to					With respect to		
				EPR	EPR				VALAG	VALAG	R^2
Elasticity of				MIN	MAX				MIN	MAX	
				25	*125*				*25000*	*75000*	
SHARET	VALAG	MIN	*25000*	0.288	0.315	EPR	MIN	*25*	-0.368	-0.294	0.9888
	VALAG	MAX	*75000*	0.264	0.29	EPR	MAX	*125*	-0.405	-0.33	
SHARES	VALAG	MIN	*25000*	0.124	-0.025	EPR	MIN	*25*	0.042	0.187	0.8534
	VALAG	MAX	*75000*	0.126	-0.029	EPR	MAX	*125*	0.048	0.193	
SHAREI	VALAG	MIN	*25000*	-0.31	-0.49	EPR	MIN	*25*	0.35	0.05	0.9978
	VALAG	MAX	*75000*	-0.11	-0.31	EPR	MAX	*125*	0.63	0.33	

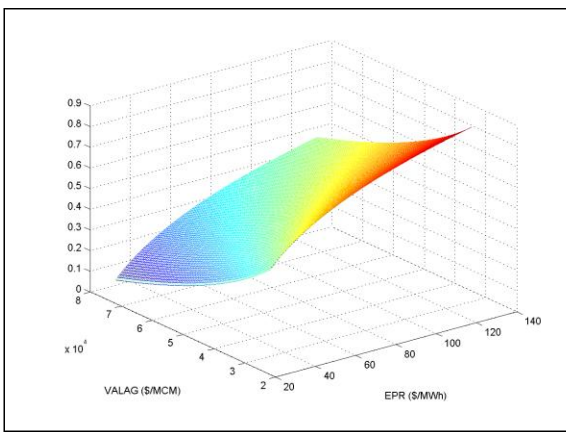


Figure 5.53: Elasticity of NEB with Respect to EPR – Translog Function

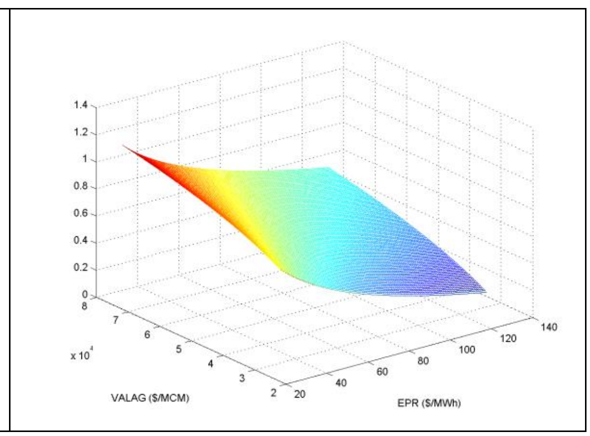


Figure 5.54: Elasticity of NEB with Respect to VALAG – Translog Function

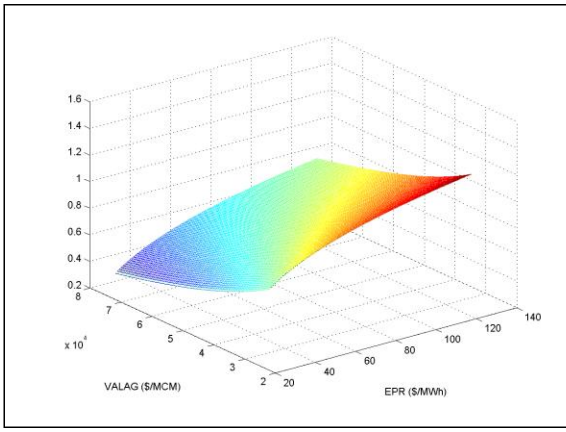


Figure 5.55: Elasticity of NEBt with Respect to EPR – Translog Function

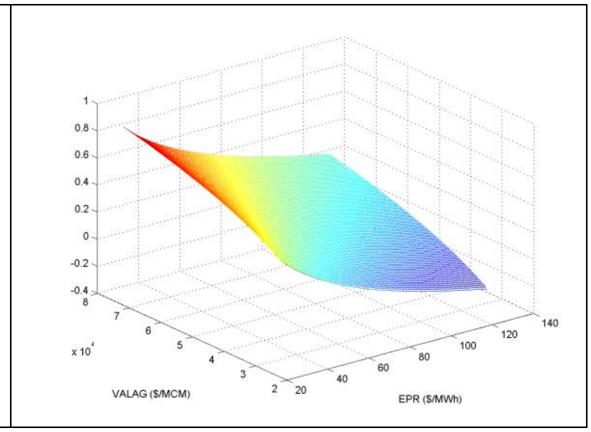


Figure 5.56: Elasticity of NEBt with Respect to VALAG – Translog Function

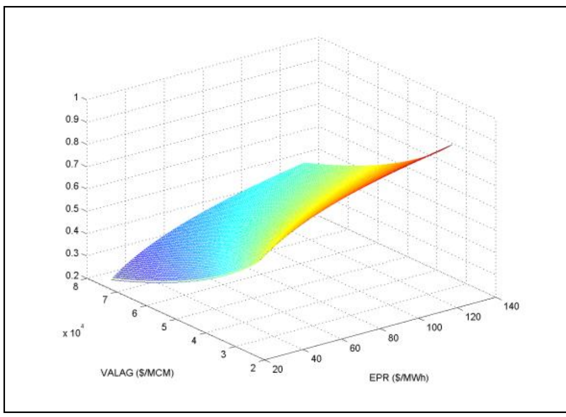


Figure 5.57: Elasticity of NEBs with Respect to EPR – Translog Function

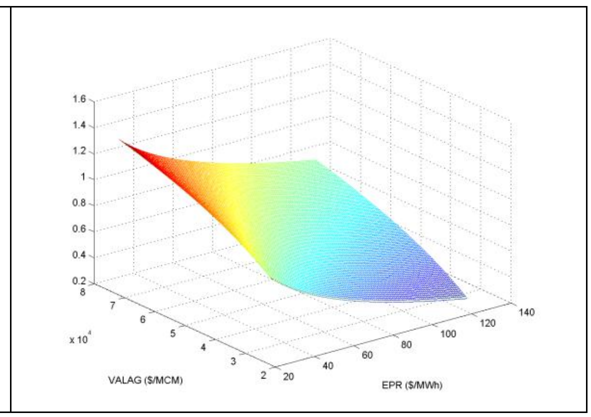


Figure 5.58: Elasticity of NEBs with Respect to VALAG – Translog Function

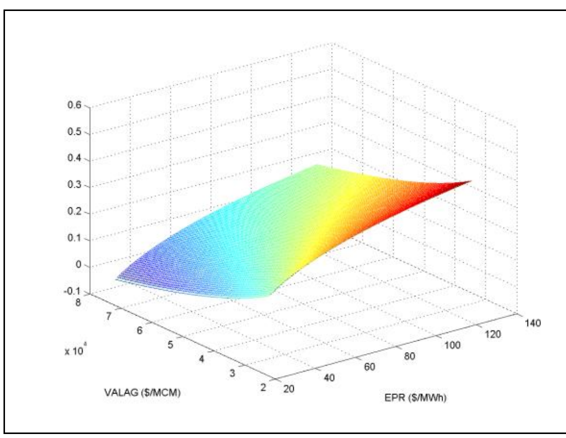


Figure 5.59: Elasticity of NEBi with Respect to EPR – Translog Function

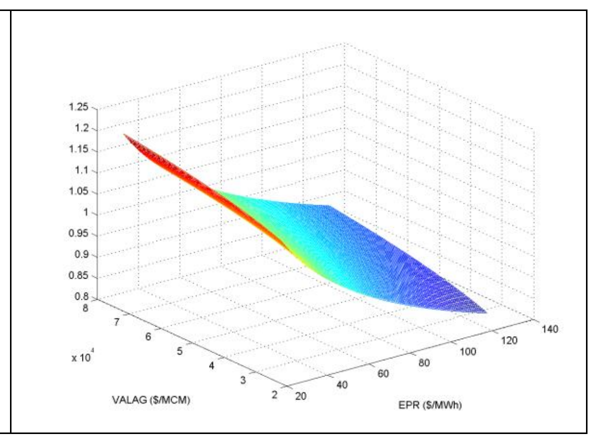


Figure 5.60: Elasticity of NEBi with Respect to VALAG – Translog Function

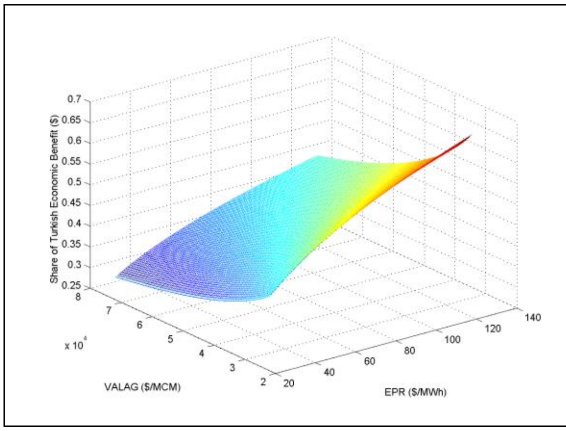


Figure 5.61: SHAREt with Respect to EPR & VALAG – Translog Function

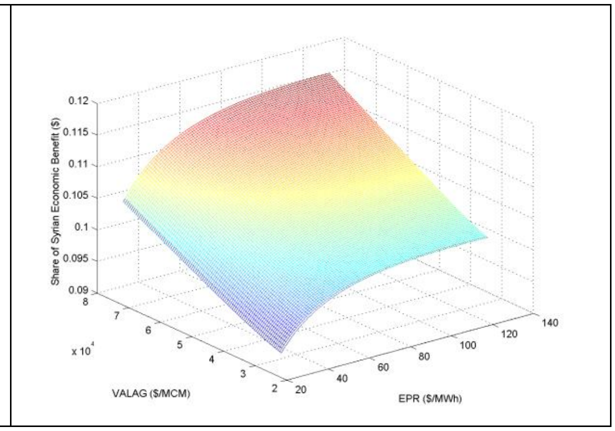


Figure 5.62: SHAREs with Respect to EPR & VALAG – Translog Function

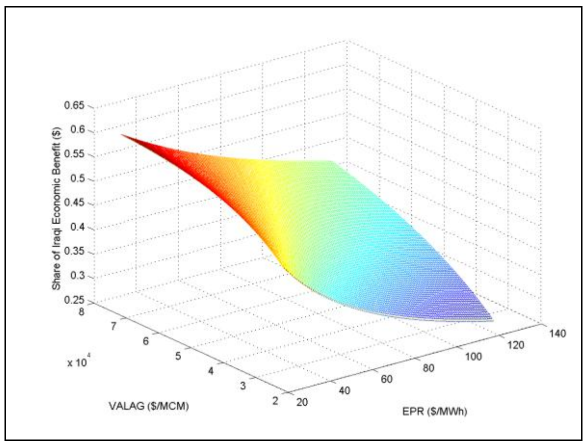


Figure 5.63: SHAREs with Respect to EPR & VALAG – Translog Function

5.4.2.2. Analysis of Benefits by Sector and Country

Agriculture (Tables 5.12 – 5.14)

Agriculture is the main source of benefits from water withdrawal because of it size, and is the main source of political discussions, due to its relevance to the largest number of people. Some interesting results are as follows:

- Tables 5.12 – 5.13 present the regression models for the total and country agricultural benefits (TECBWa, TECBWta, TECBWsa, and TECBWia), all of which are statistically significant and have R^2 values exceeding 0.84. These R^2 are even higher with the translog forms (exceeding 0.94). In Table 5.12, the coefficients of the independent variables are statistically significant in almost all equations, except LNEPR for Iraq and LNCTSS for both Turkey and Iraq, emphasizing the importance of LNVALAG. The sign of the coefficients are also consistent with expectations. The coefficients of LNEPR, LNAGRTC, and LNCTSS are negative for the agricultural benefits. The negative coefficients of EPR, in particular, imply tradeoffs between agriculture and energy. This is apparent in the overall system, and in Turkish and Syrian benefits. CTSS has a significant coefficient for Syrian agricultural benefit, due to the use of the link from the Euphrates to the Tigris.[2]

Table 5.12: Agricultural Benefits Regressions with Four Independent Variables – Log Linear Form

Dependent variable	LTECBWA		LTECBWTA		LTECBWSA		LTECBWIA	
	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	9.792	264.4	-4.458	-5.2	4.356	17.2	11.024	1834.9
LNEPR	-0.114	-102.0	-0.926	-35.4	-0.116	-15.1	0.000	-1.6
LNVALAG	1.263	772.2	2.949	76.1	1.767	157.6	1.001	3773.4
LNAGRTC	-0.099	-28.3	-0.487	-6.0	-0.341	-14.2	-0.002	-3.0
LNCTSS	-0.023	-6.6	-0.051	-0.6	-0.087	-3.6	-0.001	-1.4
R^2	0.9979		0.8441		0.9514		0.9999	
Adj R^2	0.9979		0.8436		0.9513		0.9999	
Prob - F	0		0		0		0	

- The coefficients in Table 5.12 represent constant elasticity figures. The elasticity of Turkish agricultural benefit with respect to VALAG is high, equal to 2.95. In contrast, the elasticity of Turkish agricultural benefit with respect to EPR is –0.93. The elasticity of agricultural benefit in Iraq with respect to VALAG is close to unity. Considering the small variations of Iraqi water withdrawal (Table 5.5), the unit elasticity reflects only the price effect, without change in the water allocation. (The same pattern is observable for the energy benefit of Turkey, where an increase in EPR does not lead to a reallocation of resources, but only causes benefit changes – see Table 5.18).

- In the translog model, LNCTSS is the only insignificant variable, with no prominent interaction effects. In addition to the quadratic effects of LNVALAG, LNEPR, and LNAGRTC, the interactions effects of LNVALAG & LNEPR, LNAGRTC & LNEPR, and LNVALAG & LNAGRTC are statistically significant in all equations in Table 5.13.

Table 5.13: Agricultural Benefits Regressions with Four Independent Variables – Translog Form

Dependent	LTECBWA		LTECBWTA		LTECBWSA		LTECBWIA	
Independent	**Coefficient**	**t - value**	**Coefficient**	**t - value**	**Coefficient**	**t - value**	**Coefficient**	**t - value**
(Constant)	6.011	3.8	-115.284	-3.9	-24.268	-2.7	11.134	36.5
LNEPR	-0.455	-8.0	-12.665	-12.2	-2.946	-9.2	0.002	0.2
LNVALAG	2.391	21.4	31.055	15.1	11.242	17.7	0.977	45.8
LNAGRTC	-0.682	-2.4	-4.785	-0.9	-5.613	-3.5	-0.017	-0.3
LNCTSS	0.108	0.4	0.130	0.0	0.386	0.2	0.022	0.4
LEPRLEPR	-0.022	-11.8	-0.505	-14.3	-0.049	-4.5	-0.002	-5.7
LVAGLVAG	-0.075	-18.3	-1.899	-25.0	-0.728	-31.6	-0.002	-2.8
LATCLATC	-0.036	-1.9	-0.462	-1.3	-0.265	-2.5	-0.006	-1.6
LCTSLCTS	-0.005	-0.3	-0.022	-0.1	0.000	0.0	-0.004	-1.1
LEPRLVAG	0.018	7.2	1.572	34.0	0.206	15.0	0.003	6.3
LEPRLATC	0.035	6.8	-0.249	-2.6	0.147	5.0	-0.005	-5.3
LEPRLCTS	0.016	3.1	0.071	0.7	0.008	0.3	0.003	2.7
LVAGLATC	0.079	10.4	0.988	6.8	0.801	18.7	0.009	6.2
LVAGLCTS	-0.018	-2.3	-0.071	-0.5	0.000	0.0	0.000	0.2
LATCLCTS	0.010	0.6	0.088	0.3	-0.079	-0.9	0.002	0.8
R^2	0.9986		0.9366		0.9786		0.9999	
Adjusted R^2	0.9986		0.9359		0.9783		0.9999	
Prob - F	0.0000		0.0000		0.0000		0.0000	

- The point elasticities with respect to EPR and VALAG are obtained from the first derivatives of the translog regression models with respect to the dependent variables LNEPR and LNVALAG. Table 5.14 provides point elasticity figures of agricultural benefits with respect to EPR and VALAG. The elasticities of the agricultural benefits with respect to EPR are negative in almost all cases. Both Turkish and Syrian agricultural benefits have the highest absolute value elasticities (-2.56). The elasticity of Iraqi agricultural benefits with respect to EPR is almost zero, implying that Iraqi agriculture is not affected by changes in EPR. Iraqi agricultural benefits are positively affected by VALAG, with an elasticity close to unity. The highest elasticity of agricultural benefits is 6.4. The highest elasticities of benefit in Syrian and Iraqi agriculture with respect to VALAG (2.85 and 1.01) are associated with the lowest value of VALAG and the highest value of EPR.

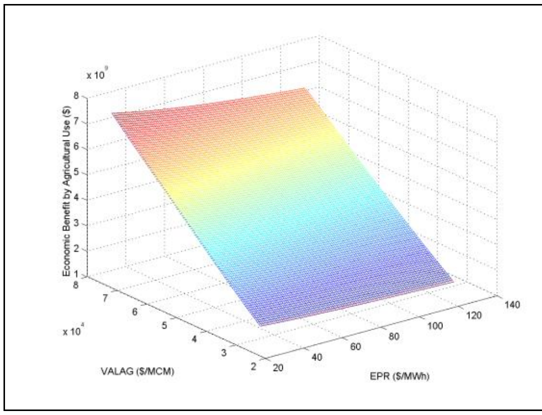


Figure 5.64: TECBWa with Respect to EPR & VALAG – Translog Function

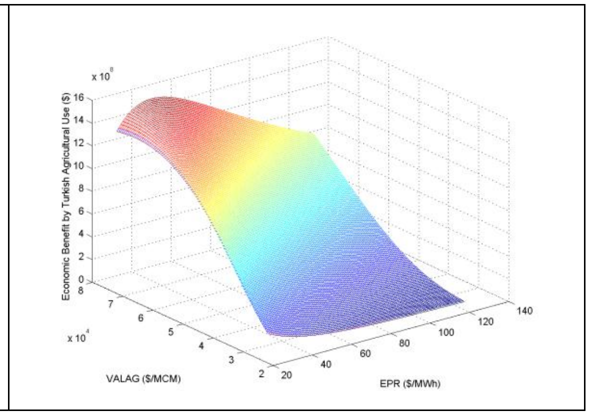


Figure 5.65: TECBWta with Respect to EPR & VALAG – Translog Function

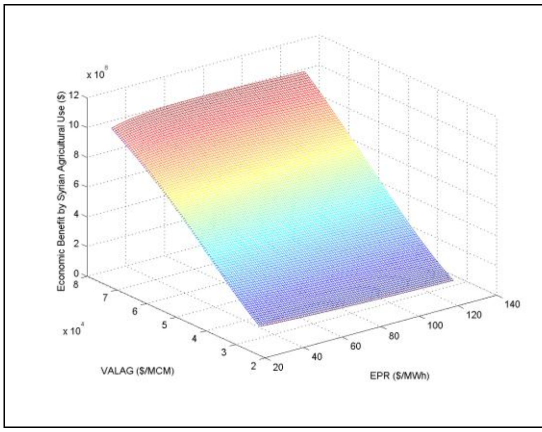


Figure 5.66: TECBWsa with Respect to EPR & VALAG – Translog Function

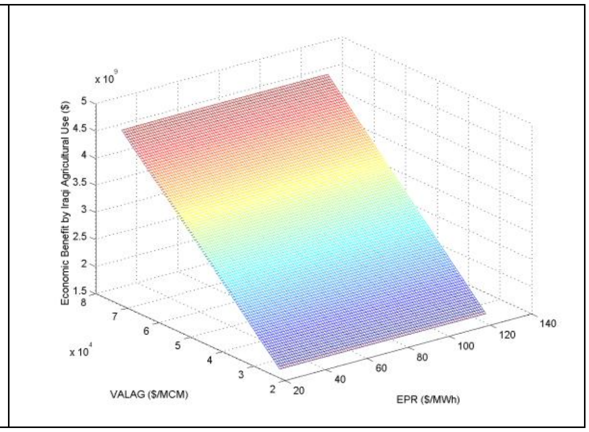


Figure 5.67: TECBWia with Respect to EPR & VALAG – Translog Function

Table 5.14: Point Elasticities of Agricultural Benefits with Respect to Ranges of EPR and VALAG –Translog Function

				With respect to					With respect to		
				EPR	EPR				VALAG	VALAG	R^2
Elasticity of				MIN	MAX				MIN	MAX	
				25	*125*				*25000*	*75000*	
TECBWA	VALAG	MIN	*25000*	-0.077	-0.15	EPR	MIN	*25*	1.34	1.18	0.9986
	VALAG	MAX	*75000*	-0.058	-0.13	EPR	MAX	*125*	1.37	1.21	
TECBWTA	VALAG	MIN	*25000*	-1.2	-2.56	EPR	MIN	*25*	3.8	-0.4	0.9366
	VALAG	MAX	*75000*	0.5	-1.15	EPR	MAX	*125*	6.4	2.2	
TECBWSA	VALAG	MIN	*25000*	-0.13	-0.257	EPR	MIN	*25*	2.6	0.95	0.9786
	VALAG	MAX	*75000*	0.1	-0.06	EPR	MAX	*125*	2.85	1.3	
TECBWIA	VALAG	MIN	*25000*	0.00065	-0.006	EPR	MIN	*25*	1.0033	0.9985	0.9999
	VALAG	MAX	*75000*	0.0036	-0.0029	EPR	MAX	*125*	1.0078	1.003	

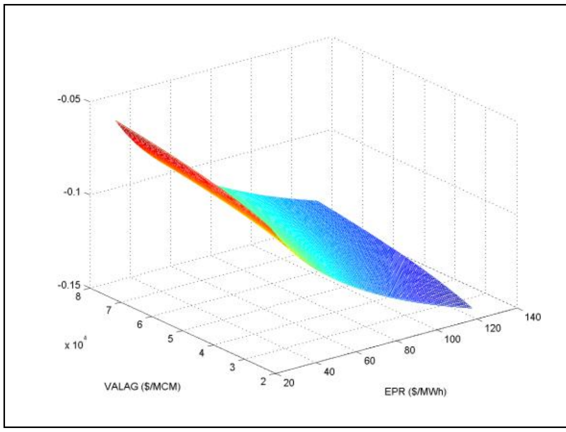


Figure 5.68: Elasticity of TECBWa with Respect to EPR – Translog Function

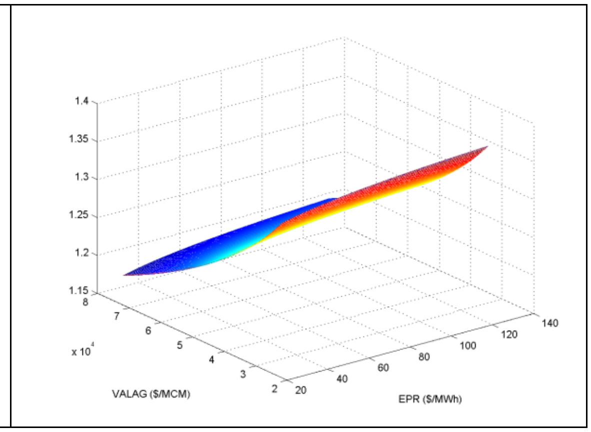


Figure 5.69: Elasticity of TECBWa with Respect to VALAG – Translog Function

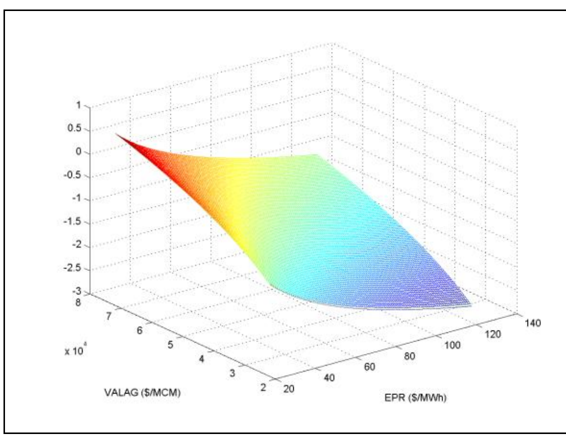


Figure 5.70: Elasticity of TECBWta with Respect to EPR – Translog Function

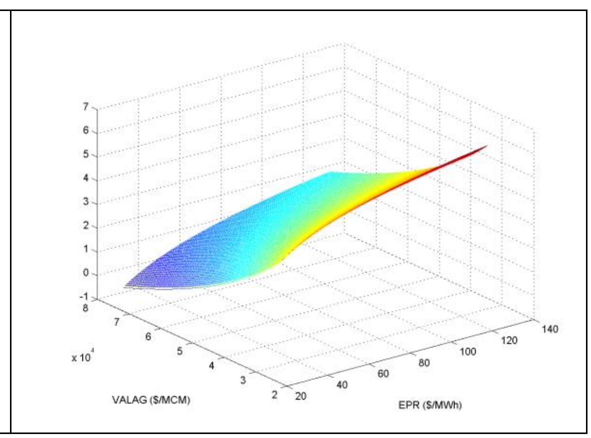


Figure 5.71: Elasticity of TECBWta with Respect to VALAG – Translog Function

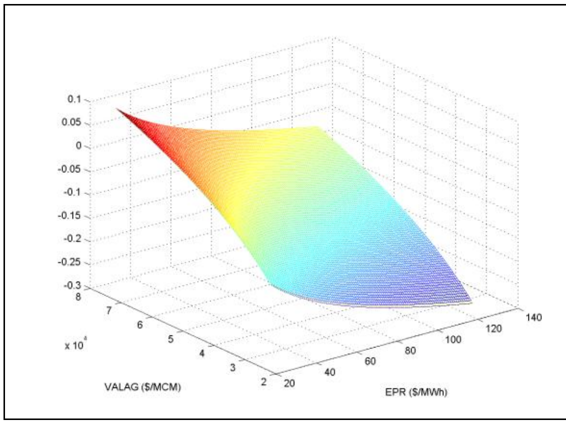


Figure 5.72: Elasticity of TECBWsa with Respect to EPR – Translog Function

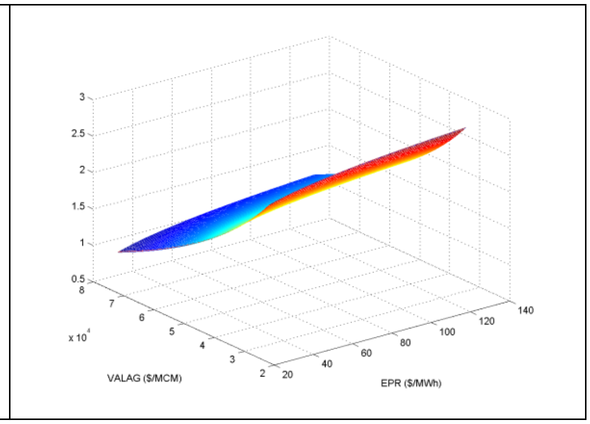


Figure 5.73: Elasticity of TECBWsa with Respect to VALAG – Translog Function

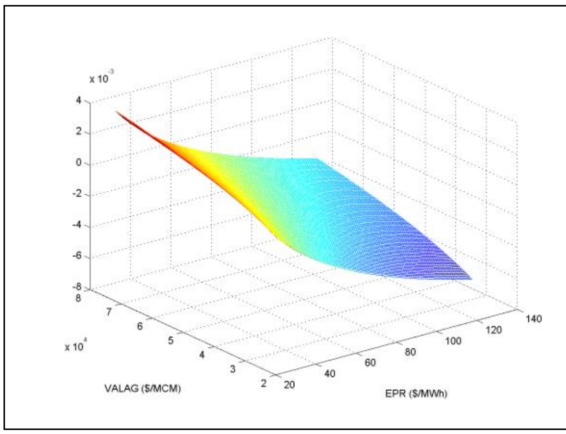


Figure 5.74: Elasticity of TECBWia with Respect to EPR – Translog Function

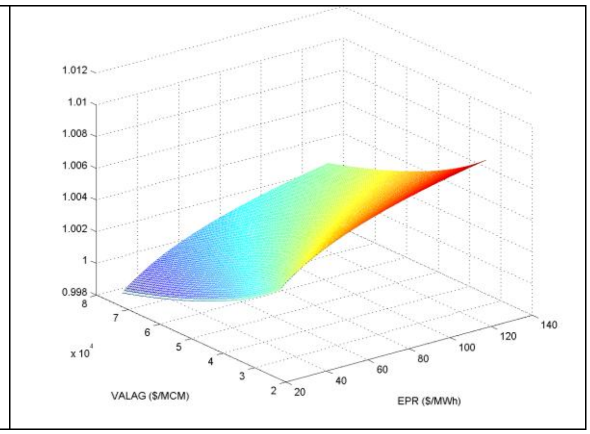


Figure 5.75: Elasticity of TECBWia with Respect to VALAG – Translog Function

Urban Use (Tables 5.15 – 5.17)

Urban use has the highest return flow rate (80%) and the highest economic return for a unit of water withdrawal; therefore, it can be expected that water withdrawal for urban use hits the withdrawal limit, and then does not display significant variations. Thus, the associated R^2 values for the TECBu, TECBtu, TECBsu, and TECBiu equations (0.71, 0.28, 0.0, and 0.63, respectively) are lower than for the other benefits. TECBsu does not show any variation, preventing the estimation of regression models. In terms of significance and sign of coefficients, only EPR is statistically significant and has a negative sign. The variables (LNVALAG, LNAGRTC, and LNCTSS) do not have

Table 5.15: Urban Benefits Regressions with Four Independent Variables – Log Linear Form

Dependent variable	LTECBWU		LTECBWTU		LTECBWIU	
	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	18.953	956.1	17.620	183.0	18.583	984.5
LNEPR	-0.034	-55.9	-0.065	-22.3	-0.027	-47.3
LNVALAG	0.000	0.0	0.000	0.0	0.000	0.0
LNAGRTC	0.000	0.0	0.000	0.0	0.000	0.0
LNCTSS	0.000	0.0	0.000	0.0	0.000	0.0
R^2	0.7078		0.2774		0.6336	
Adj R^2	0.7069		0.2751		0.6325	
Prob - F	0		1.2446E-13		1.317E-279	

significant coefficients. Table 5.16 show that including quadratic and interaction elements into the regression equations does not bring significant improvements, except in the case of LNEPR. The R^2 values for the Turkish and Iraqi equations, TECBWtu and TECBWiu, increase to 0.59 and 0.95 respectively, due to this quadratic effect.

Table 5.16: Urban Benefits Regressions with Four Independent Variables – Translog Form

Dependent	LTECBWU		LTECBWTU		LTECBWIU	
Independent	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	18.890	17.8	15.326	3.9	19.214	49.3
LNEPR	-0.002	0.0	1.099	8.0	-0.347	-25.2
LNVALAG	0.000	0.0	0.000	0.0	0.000	0.0
LNAGRTC	0.000	0.0	0.000	0.0	0.000	0.0
LNCTSS	0.000	0.0	0.000	0.0	0.000	0.0
LEPRLEPR	-0.004	-3.1	-0.145	-31.3	0.040	86.2
LVAGLVAG	0.000	0.0	0.000	0.0	0.000	0.0
LATCLATC	0.000	0.0	0.000	0.0	0.000	0.0
LCTSLCTS	0.000	0.0	0.000	0.0	0.000	0.0
LEPRLVAG	0.000	0.0	0.000	0.0	0.000	0.0
LEPRLATC	0.000	0.0	0.000	0.0	0.000	0.0
LEPRLCTS	0.000	0.0	0.000	0.0	0.000	0.0
LVAGLATC	0.000	0.0	0.000	0.0	0.000	0.0
LVAGLCTS	0.000	0.0	0.000	0.0	0.000	0.0
LATCLCTS	0.000	0.0	0.000	0.0	0.000	0.0
R^2	0.7100		0.5903		0.9461	
Adjusted R^2	0.7068		0.5858		0.9455	
Prob - F	0.0000		0.0000		0.0000	

In Table 5.17, the zero elasticities of urban benefits with respect to VALAG show that there is no direct influence of VALAG on urban benefits. On the other hand, the relatively low R^2 for TECBWtu reduces the significance of these elasticity values. The elasticity of Iraqi urban benefits with respect to EPR is close to zero. If EPR is at the minimum of its range, the elasticities of TECBWiu are negative, and if EPR is at the maximum of its range, the elasticities are positive. This points to the volatility of the impact of EPR on TECBWiu.

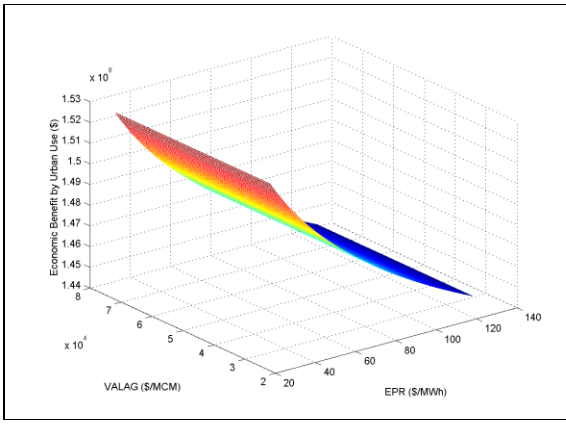


Figure 5.76: TECBWu with Respect to EPR & VALAG – Translog Function

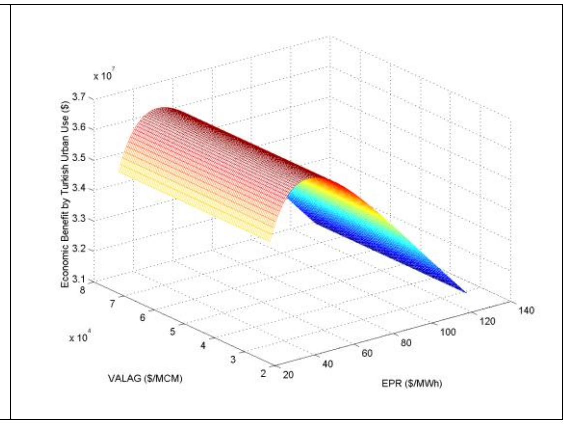


Figure 5.77: TECBWtu with Respect to EPR & VALAG – Translog Function

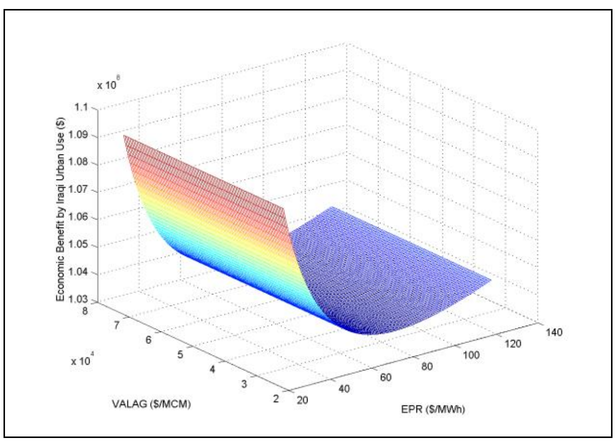


Figure 5.78: TECBWiu with Respect to EPR & VALAG – Translog Function

Table 5.17: Point Elasticities of Urban Benefits with Respect to Ranges of EPR and VALAG – Translog Function

				With respect to					With respect to		
				EPR	EPR				VALAG	VALAG	R^2
Elasticity of				MIN	MAX				MIN	MAX	
				25	*125*				*25000*	*75000*	
TECBWU	VALAG	MIN	*25000*	-0.027	-0.04	EPR	MIN	*25*	0.000	0.000	0.7100
	VALAG	MAX	*75000*	-0.027	-0.04	EPR	MAX	*125*	0.000	0.000	
TECBWTU	VALAG	MIN	*25000*	0.17	-0.3	EPR	MIN	*25*	0.000	0.000	0.5903
	VALAG	MAX	*75000*	0.17	-0.3	EPR	MAX	*125*	0.000	0.000	
TECBWIU	VALAG	MIN	*25000*	-0.09	0.037	EPR	MIN	*25*	0.000	0.000	0.9461
	VALAG	MAX	*75000*	-0.09	0.037	EPR	MAX	*125*	0.000	0.000	

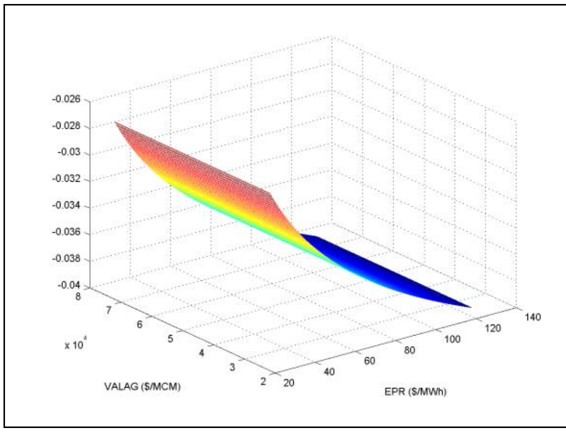


Figure 5.79: Elasticity of TECBWu with Respect to EPR – Translog Function

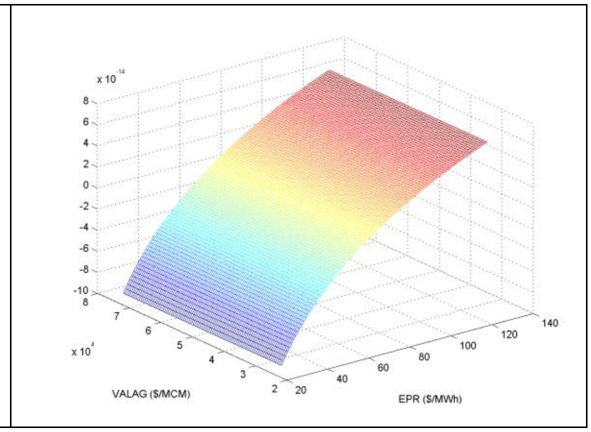


Figure 5.80: Elasticity of TECBWu with Respect to VALAG – Translog Function

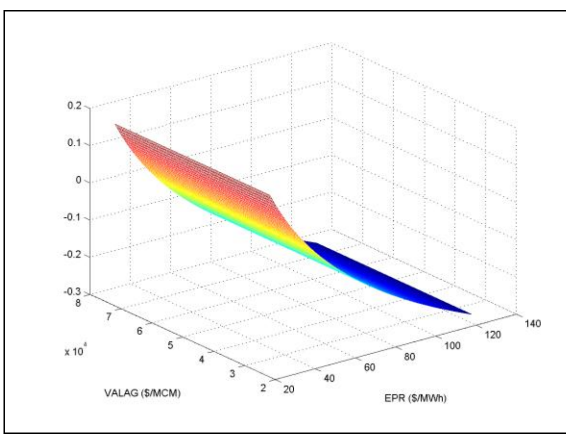


Figure 5.81: Elasticity of TECBWtu with Respect to EPR – Translog Function

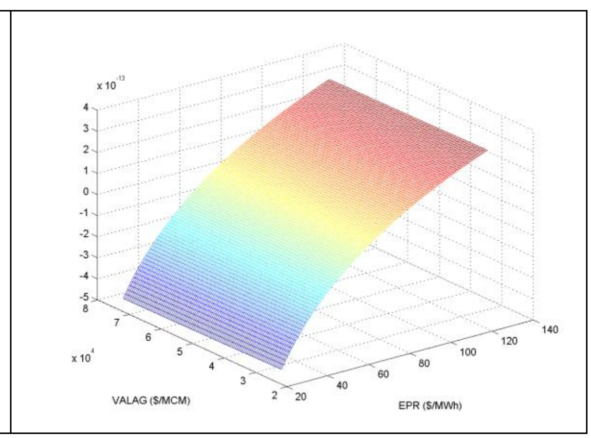
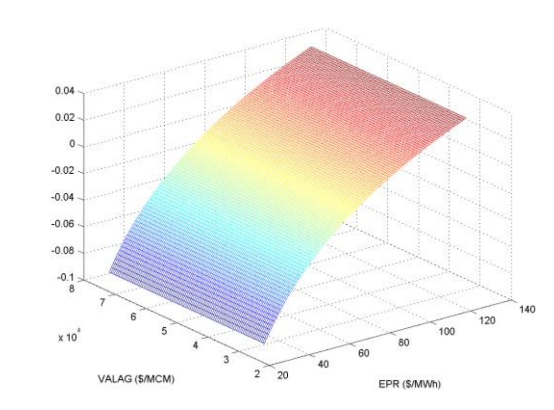


Figure 5.82: Elasticity of TECBWtu with Respect to VALAG – Translog Function



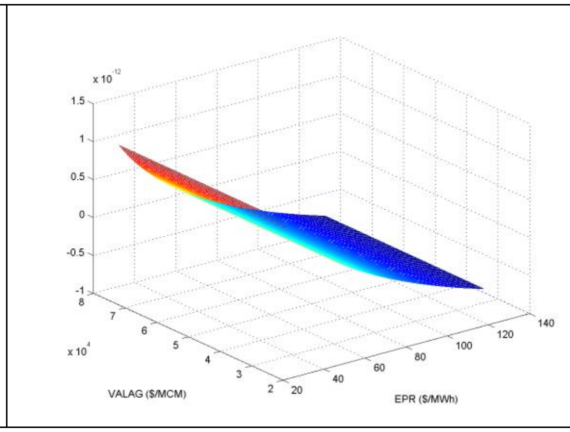


Figure 5.83: Elasticity of TECBWiu with Respect to EPR – Translog Function

Figure 5.84: Elasticity of TECBWiu with Respect to VALAG – Translog Function

Energy (Tables 5.18 – 5.20)

EPR is more important for countries with higher elevations within their border. Turkey has more energy potential than the other two countries. Tables 5.18 – 5.19 show some interesting results, which can be summarized as follows:

- Table 5.18 presents very strong regression equations for TECBe, TECBet, TECBes, and TECBei, with R^2 values very close to 1.00. The associated coefficients, without exception, are statistically significant. The signs of the coefficient point to interesting relations. Only the sign of LNVALAG is negative. In the analyses of the agricultural benefits, LNVALAG is the only variable having positive coefficients throughout the equations in Table 5.12. This further confirms the tradeoff between energy and agriculture.
- The coefficients in Table 5.18 provide constant elasticity figures. The coefficients of LNEPR in all regression equations are slightly little above 1. On the other hand, all the elasticities with respect to VALAG are negative. The positive sign of the transports cost coefficients indicate that higher transportation costs help energy generation by hampering agricultural water withdrawal.

Table 5.18: Energy Benefits Regressions with Four Independent Variables – Log Linear Form

Dependent variable	LTECBE		LTECBET		LTECBES		LTECBEI	
	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	18.363	328.7	17.949	279.9	16.491	336.2	16.811	354.3
LNEPR	1.115	659.0	1.118	575.5	1.099	740.0	1.113	774.7
LNVALAG	-0.166	-67.3	-0.149	-52.6	-0.207	-95.6	-0.224	-107.0
LNAGRTC	0.064	12.1	0.056	9.3	0.091	19.6	0.085	18.8
LNCTSS	0.020	3.8	0.018	3.0	0.013	2.8	0.037	8.3
R^2	0.9971		0.9961		0.9977		0.9979	
Adj R^2	0.9971		0.9961		0.9977		0.9979	
Prob - F	0		0		0		0	

- Because the first order regression equations provide very high R^2, the contributions of the translog forms are marginal. In addition to the quadratic effects of LNVALAG and LNEPR, there is a prominent interaction effect between LNVALAG & LNEPR (Table 5.19).

Table 5.19: Energy Benefits Regressions with Four Independent Variables – Translog Form

Dependent	LTECBE		LTECBET		LTECBES		LTECBEI	
Independent	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	17.053	9.1	16.379	8.1	15.510	6.2	16.409	8.0
LNEPR	0.592	9.0	0.404	5.6	1.378	15.7	0.992	13.6
LNVALAG	0.290	2.2	0.518	3.7	-0.919	-5.3	0.026	0.2
LNAGRTC	0.171	0.5	0.018	0.1	1.270	2.9	0.166	0.5
LNCTSS	-0.073	-0.2	-0.068	-0.2	0.131	0.3	-0.247	-0.7
LEPRLEPR	-0.013	-6.0	-0.018	-7.6	0.001	0.5	0.002	0.7
LVAGLVAG	-0.074	-15.7	-0.095	-18.4	0.018	2.8	-0.039	-7.5
LATCLATC	-0.033	-1.5	-0.039	-1.6	-0.061	-2.1	0.016	0.7
LCTSLCTS	0.001	0.0	0.000	0.0	-0.005	-0.2	0.006	0.3
LEPRLVAG	0.112	39.5	0.131	42.8	0.030	8.1	0.068	21.8
LEPRLATC	-0.063	-10.4	-0.060	-9.2	-0.063	-7.9	-0.077	-11.5
LEPRLCTS	-0.024	-4.0	-0.024	-3.7	-0.031	-3.9	-0.019	-2.8
LVAGLATC	0.070	7.9	0.091	9.5	0.007	0.6	0.012	1.2
LVAGLCTS	0.033	3.7	0.033	3.5	0.025	2.2	0.034	3.5
LATCLCTS	-0.025	-1.3	-0.027	-1.3	-0.031	-1.2	-0.014	-0.7
R^2	0.9989		0.9987		0.9979		0.9986	
Adjusted R^2	0.9989		0.9987		0.9979		0.9986	
Prob - F	0.0000		0.0000		0.0000		0.0000	

- Table 5.20 provides point elasticities of the economic benefits from energy with respect to EPR and VALAG. The elasticities with respect to EPR are positive, with values around one in almost all cases. On the other hand, the elasticities of energy benefits with respect to VALAG are negative in almost all cases, with the highest value for Turkey (-0.35). It can be concluded that higher VALAG values decrease energy benefits, and higher EPR values increase these benefits.

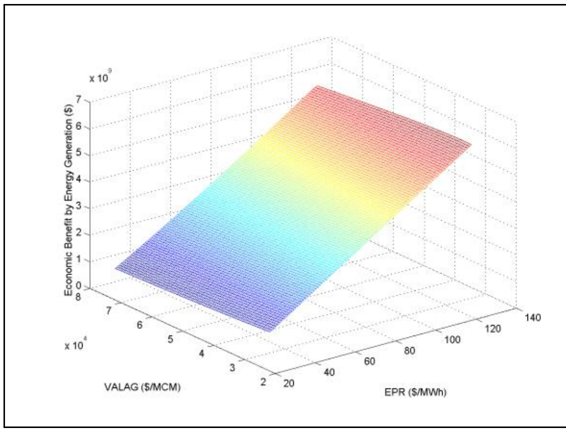


Figure 5.85: TECBe with Respect to EPR & VALAG – Translog Function

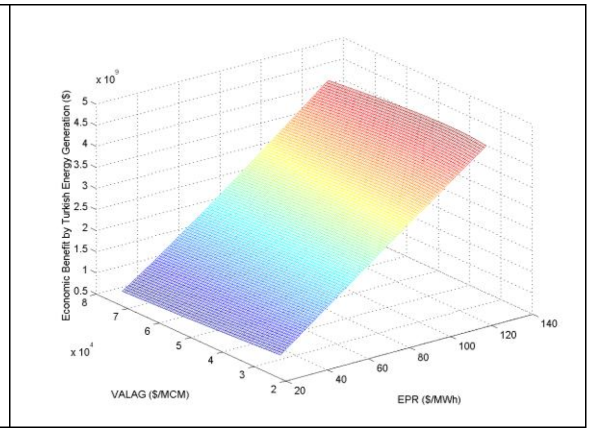


Figure 5.86: TECBet with Respect to EPR & VALAG – Translog Function

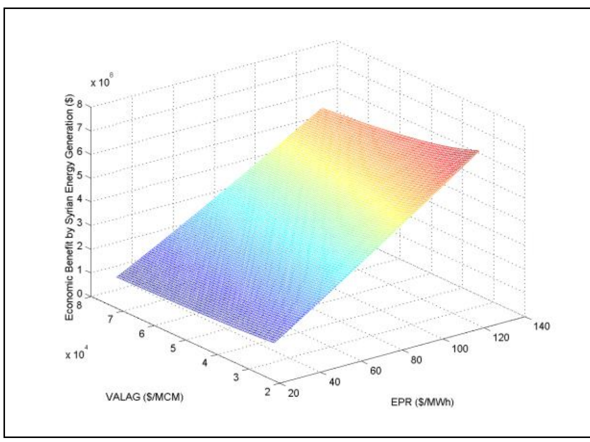


Figure 5.87: TECBes with Respect to EPR & VALAG – Translog Function

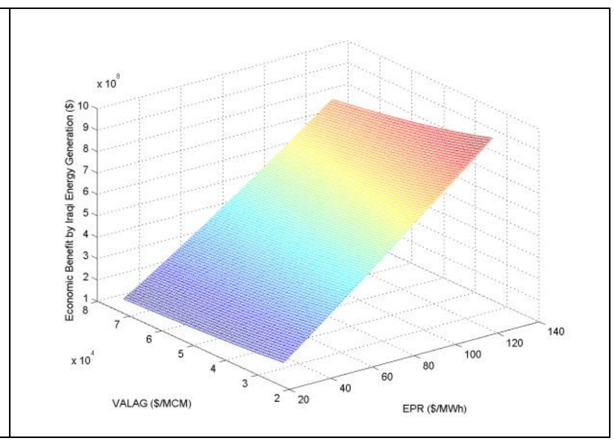


Figure 5.88: TECBei with Respect to EPR & VALAG – Translog Function

Table 5.20: Point Elasticities of Energy Benefits with Respect to Ranges of EPR and VALAG – Translog Function

				With respect to					With respect to		
				EPR	EPR				VALAG	VALAG	R^2
Elasticity of				MIN	MAX				MIN	MAX	
				25	*125*				*25000*	*75000*	
TECBE	VALAG	MIN	*25000*	1.048	1.003	EPR	MIN	*25*	-0.17	-0.33	0.9989
	VALAG	MAX	*75000*	1.17	1.128	EPR	MAX	*125*	0.02	-0.15	
TECBET	VALAG	MIN	*25000*	1.04	0.97	EPR	MIN	*25*	-0.14	-0.35	0.9987
	VALAG	MAX	*75000*	1.18	1.13	EPR	MAX	*125*	0.07	-0.14	
TECBES	VALAG	MIN	*25000*	1.055	1.06	EPR	MIN	*25*	-0.25	-0.21	0.9979
	VALAG	MAX	*75000*	1.0858	1.093	EPR	MAX	*125*	-0.198	-0.16	
TECBEI	VALAG	MIN	*25000*	1.048	1.051	EPR	MIN	*25*	-0.23	-0.32	0.9986
	VALAG	MAX	*75000*	1.12	1.126	EPR	MAX	*125*	-0.125	-0.22	

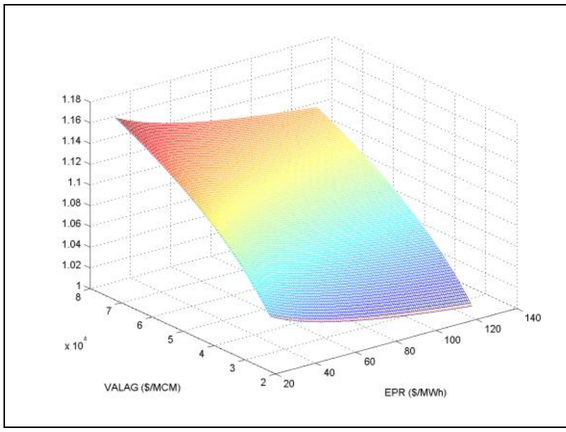


Figure 5.89: Elasticity of TECBe with Respect to EPR – Translog Function

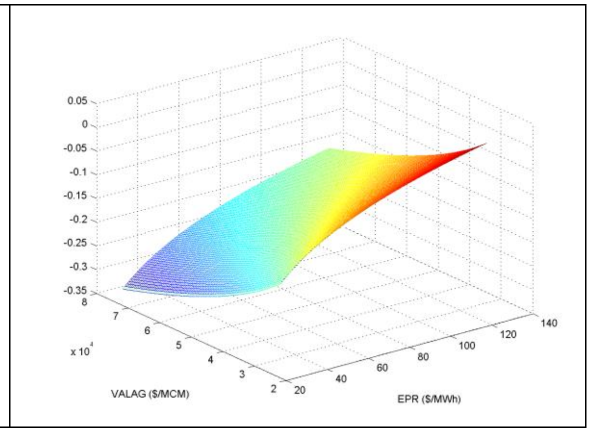


Figure 5.90: Elasticity of TECBe with Respect to VALAG – Translog Function

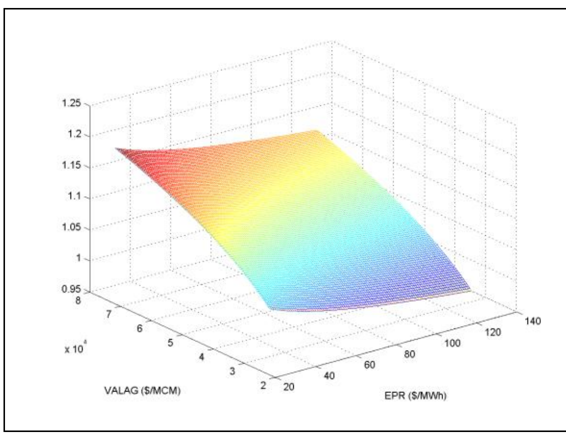


Figure 5.91: Elasticity of TECBet with Respect to EPR – Translog Function

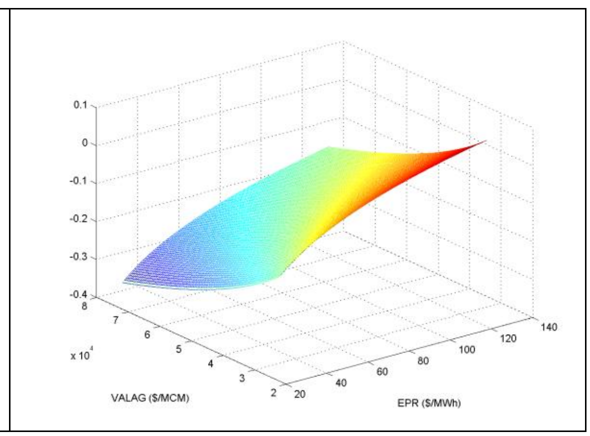


Figure 5.92: Elasticity of TECBet with Respect to VALAG – Translog Function

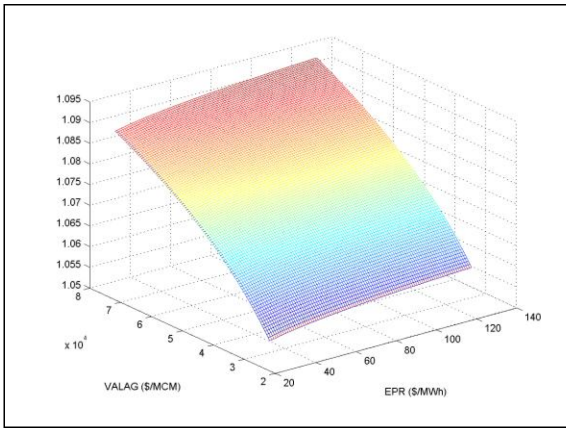


Figure 5.93: Elasticity of TECBes with Respect to EPR – Translog Function

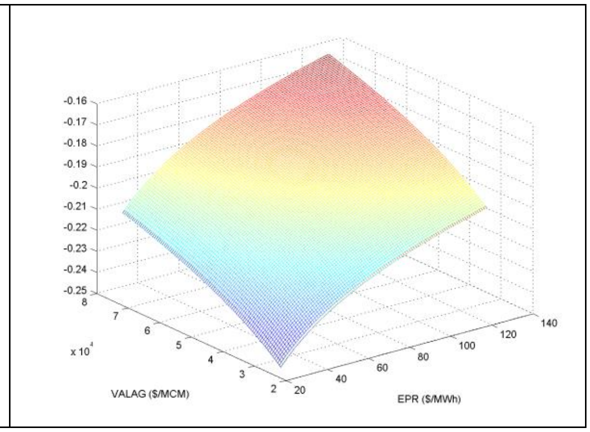


Figure 5.94: Elasticity of TECBes with Respect to VALAG – Translog Function

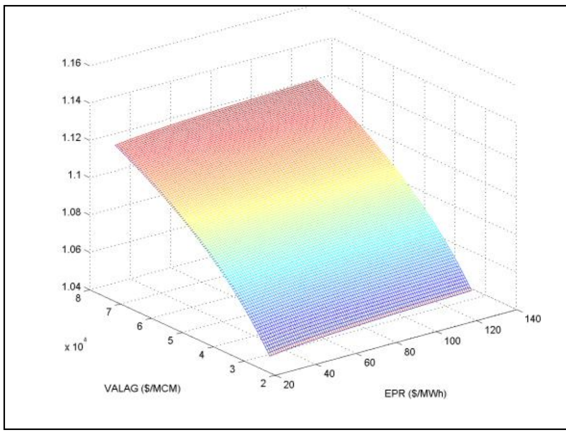


Figure 5.95: Elasticity of TECBei with Respect to EPR – Translog Function

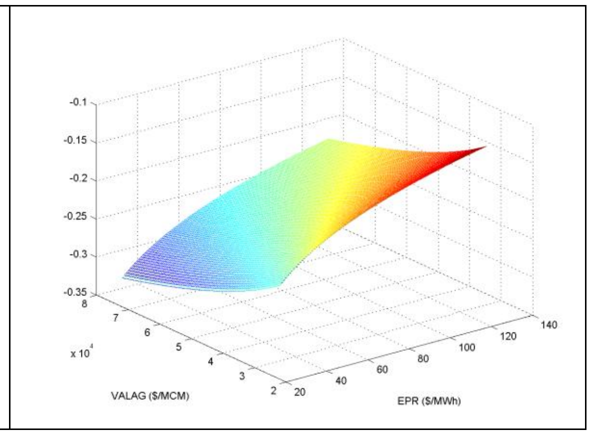


Figure 5.96: Elasticity of TECBei with Respect to VALAG – Translog Function

5.4.2.3. Analysis of Water Resources Use by Countries

The dependent variables are TWT, WTt, WTs, and WTi (Tables 5.21 – 5.22). Some of the interesting results are as follows:

- In Table 5.21, the first three equations, which are the overall, Turkish and Syrian water withdrawals, have reasonable high R^2 values, 0.97, 0.77, and 0.80; however, the equation for Iraqi water withdrawals has a very low R^2 value (0.04), because Iraqi withdrawal displays little variations, which is consistent with the descriptive statistics in Table 5.5. The t-values for the coefficients of all parameters in all the regression equations for TWT, WTt, WTs, and WTi are statistically significant, except for CTSS for Turkey and Iraq. CTSS is only significant in the case of Syrian water withdrawal.

Table 5.21: Water Withdrawals Regressions with Four Independent Variables – Log Linear Form

Dependent variable	LNTWT		LNWTT		LNWTS		LNWTI	
	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value	Coefficient	t - value
(Constant)	9.824	268.8	-3.316	-3.9	4.393	17.4	11.036	1865.1
LNEPR	-0.114	-102.5	-0.949	-37.3	-0.115	-15.1	-0.001	-3.3
LNVALAG	0.260	161.2	1.971	53.1	0.762	68.4	0.001	5.4
LNAGRTC	-0.098	-28.4	-0.685	-8.6	-0.339	-14.2	-0.002	-3.0
LNCTSS	-0.023	-6.6	-0.049	-0.6	-0.087	-3.6	-0.001	-1.4
R^2	0.9666		0.7685		0.7988		0.0378	
Adj R^2	0.9665		0.7678		0.7982		0.0348	
Prob - F	0		0		0		3.9519E-10	

- The constant elasticity figures provided by the coefficients of the regression equations in Table 5.21 show that Turkish water withdrawal is more sensitive to VALAG (1.97) than to EPR (-0.95), and with opposite signs. EPR negatively affects water withdrawals, and VALAG encourages more withdrawal from the river. The same relation can be seen in Figures 5.98, 5.99, and 5.100.
- Table 5.22 shows improvements in the R^2 value for the total, Turkish, and Syrian water withdrawal equations, due to interaction and quadratic effects (from 0.97, 0.77, and 0.80 to 0.98, 0.93, and 0.91, respectively). Both LNVALAG and LNAGRTC have statistically significant interaction effects with EPR in all equations. CTSS is the only variable having mostly statistically insignificant coefficients. However, CTSS has a statistically significant interaction effect with EPR. Higher CTSS and EPR values lead to more energy for both Turkey and Iraq by preventing water transfer from the Tigris to the Euphrates.

Table 5.22: Water Withdrawals Regressions with Four Independent Variables – Translog Form

Dependent	LNTWT		LNWTT		LNWTS		LNWTI	
Independent	**Coefficient**	**t - value**	**Coefficient**	**t - value**	**Coefficient**	**t - value**	**Coefficient**	**t - value**
(Constant)	6.107	3.9	-95.243	-3.7	-24.005	-2.7	11.152	36.9
LNEPR	-0.448	-8.0	-10.690	-11.7	-2.924	-9.2	-0.002	-0.2
LNVALAG	1.369	12.4	25.458	14.1	10.163	16.1	-0.023	-1.1
LNAGRTC	-0.673	-2.4	-4.432	-1.0	-5.572	-3.5	-0.017	-0.3
LNCTSS	0.107	0.4	0.121	0.0	0.385	0.2	0.022	0.4
LEPRLEPR	-0.022	-11.9	-0.524	-17.1	-0.048	-4.5	-0.002	-4.4
LVAGLVAG	-0.073	-18.3	-1.775	-27.1	-0.723	-31.5	-0.002	-2.8
LATCLATC	-0.036	-1.9	-0.708	-2.3	-0.264	-2.5	-0.006	-1.6
LCTSLCTS	-0.005	-0.3	-0.021	-0.1	0.000	0.0	-0.004	-1.1
LEPRLVAG	0.017	7.1	1.504	38.5	0.204	15.0	0.003	6.3
LEPRLATC	0.035	6.8	-0.409	-4.9	0.146	5.0	-0.005	-5.3
LEPRLCTS	0.016	3.1	0.069	0.8	0.008	0.3	0.003	2.7
LVAGLATC	0.077	10.3	1.313	10.8	0.795	18.7	0.009	6.2
LVAGLCTS	-0.018	-2.4	-0.066	-0.5	0.000	0.0	0.000	0.2
LATCLCTS	0.010	0.6	0.081	0.3	-0.078	-0.9	0.002	0.8
R^2	0.9784		0.9247		0.9112		0.1351	
Adjusted R^2	0.9781		0.9239		0.9102		0.1256	
Prob - F	0.0000		0.0000		0.0000		0.0000	

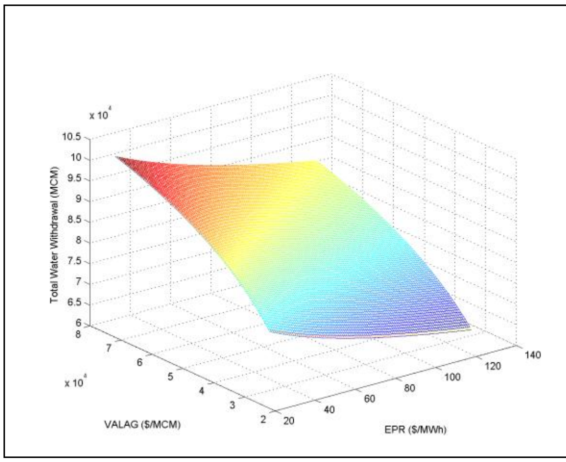


Figure 5.97: TWT with Respect to EPR & VALAG – Translog Function

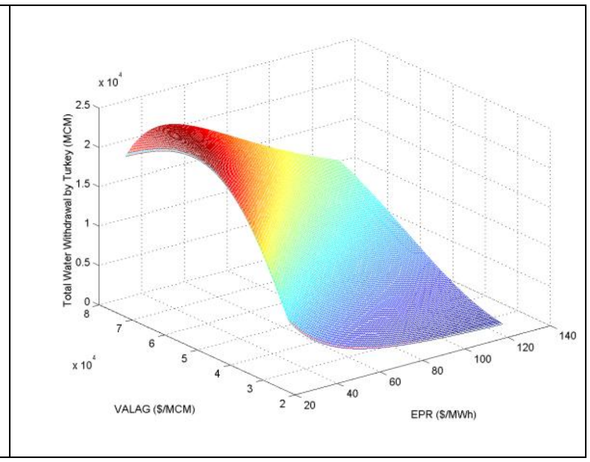


Figure 5.98: WTt with Respect to EPR & VALAG – Translog Function

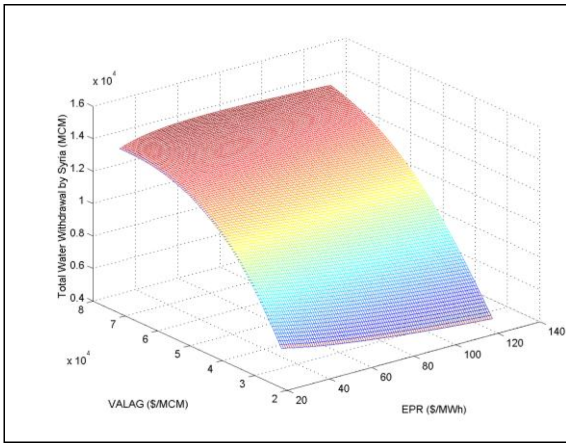


Figure 5.99: WTs with Respect to EPR & VALAG – Translog Function

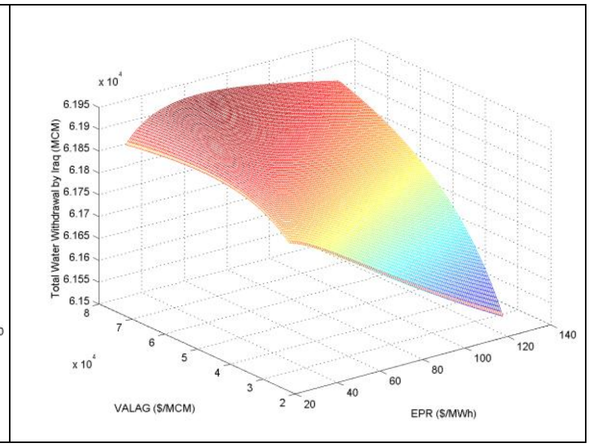


Figure 5.100: WTi with Respect to EPR & VALAG – Translog Function

- *Point elasticity figures:* Table 5.23 provides point elasticities of water withdrawal with respect to EPR and VALAG. The elasticities with respect to EPR are negative in almost all cases, suggesting that EPR deters water withdrawals. The highest negative value of elasticity of water withdrawals with respect to EPR is -2.8, for Turkey (WTt). Iraq has the lowest elasticity of water withdrawal with respect to EPR (almost zero). Iraq has also the lowest elasticity of water withdrawal with respect to VALAG (again very close zero). This result shows that, regardless of the variations in EPR and VALAG, there is no significant water withdrawal variation in Iraq. This is also consistent with the descriptive statistical analyses showing the narrow range of water withdrawals. For Syrian and Turkish withdrawals, the elasticities with respect to VALAG have higher positive values if VALAG is at the minimum of its range. On the other hand, if VALAG is at its maximum (together with a minimum of EPR) the elasticity with respect to VALAG is negative. This implies that higher VALAG values do not necessarily mean increases in withdrawals. There is a critical level where the impact of VALAG is reversed.

Table 5.23: Point Elasticities of Water Withdrawals with Respect to Ranges of EPR and VALAG – Translog Function

				With respect to					With respect to		
				EPR	EPR				VALAG	VALAG	R^2
Elasticity of				MIN	MAX				MIN	MAX	
				25	*125*				*25000*	*75000*	
TWT	VALAG	MIN	*25000*	-0.076	-0.148	EPR	*25*	MIN	0.33	0.18	0.9784
	VALAG	MAX	*75000*	-0.058	-0.13	EPR	*125*	MAX	0.37	0.21	
WTT	VALAG	MIN	*25000*	-1.2	-2.8	EPR	*25*	MIN	2.8	-1.1	0.9247
	VALAG	MAX	*75000*	0.5	-1.2	EPR	*125*	MAX	5.2	1.2	
WTS	VALAG	MIN	*25000*	-0.12	-0.28	EPR	*25*	MIN	1.6	-0.1	0.9112
	VALAG	MAX	*75000*	0.1	-0.06	EPR	*125*	MAX	1.8	0.26	
WTI	VALAG	MIN	*25000*	-0.0005	-0.0055	EPR	*25*	MIN	0.0031	-0.0015	0.1351
	VALAG	MAX	*75000*	0.0027	-0.0024	EPR	*125*	MAX	0.0078	0.0030	

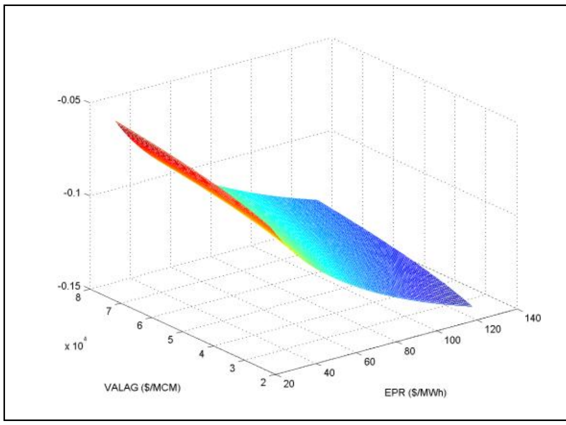


Figure 5.101: Elasticity of TWT with Respect to EPR – Translog Function

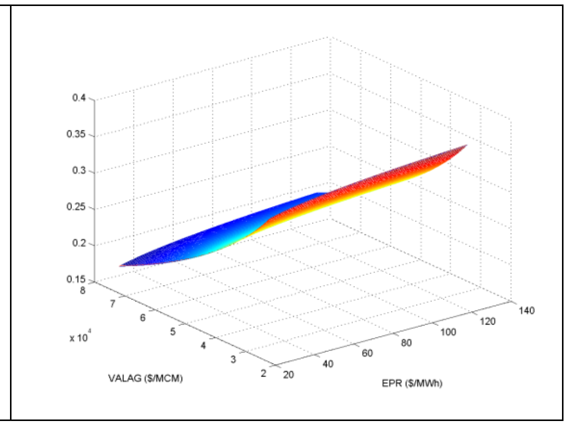


Figure 5.102: Elasticity of TWT with Respect to VALAG – Translog Function

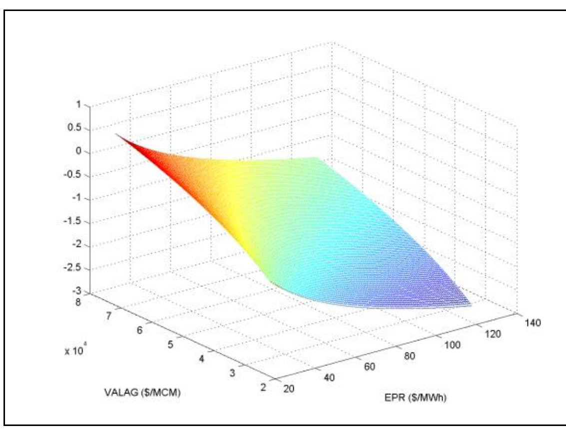


Figure 5.103: Elasticity of WTt with Respect to EPR – Translog Function

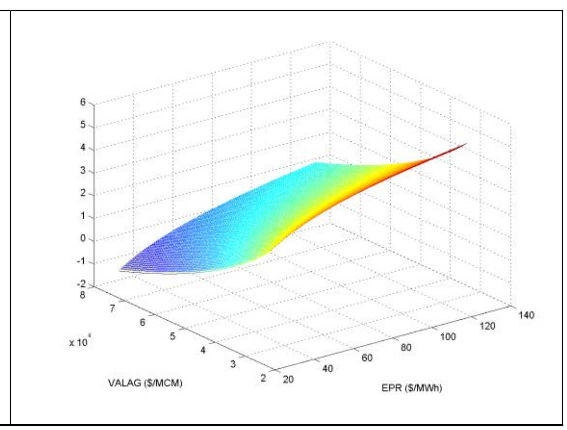


Figure 5.104: Elasticity of WTt with Respect to VALAG – Translog Function

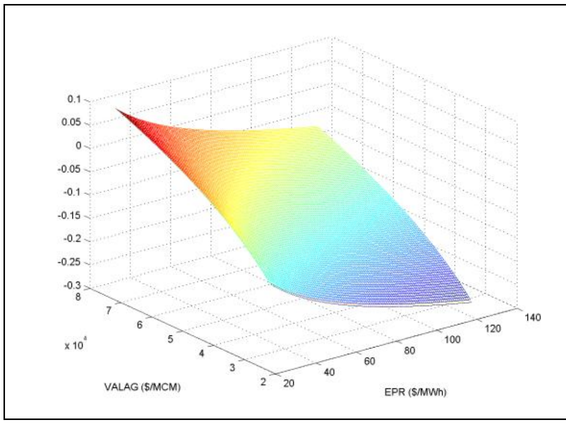


Figure 5.105: Elasticity of WTs with Respect to EPR – Translog Function

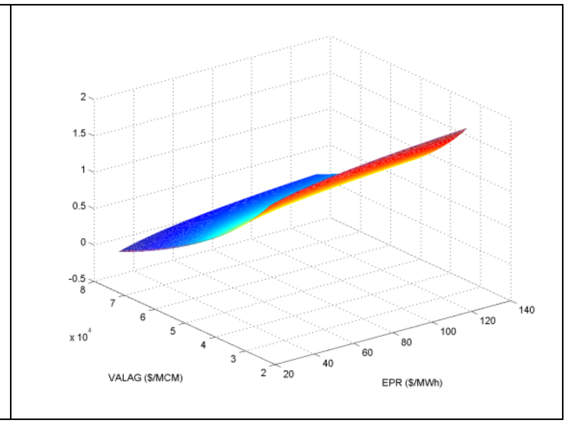


Figure 5.106: Elasticity of WTs with Respect to VALAG – Translog Function

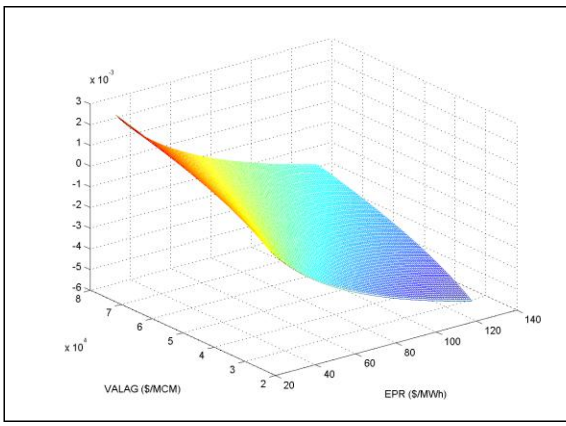


Figure 5.107: Elasticity of WTi with Respect to EPR – Translog Function

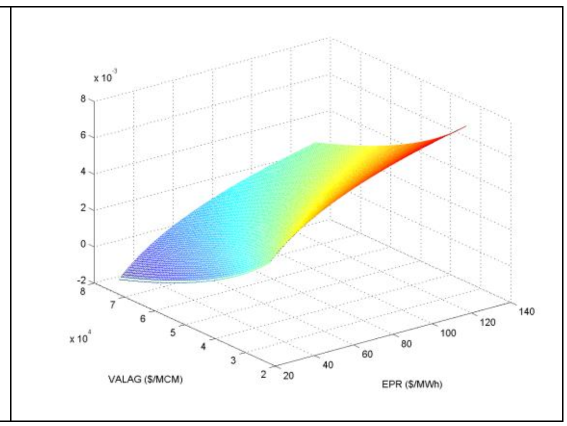


Figure 5.108: Elasticity of WTi with Respect to VALAG – Translog Function

5.4.2.4. Inter-nodal Links

PQs and PQi are the sum of the water quantities transferred to Syria and Iraq, respectively. These two variables provide insight about the links used to eliminate the shortage of water in the Euphrates basin due to high water demand. Tables 5.24 and 5.25 provide the regression results. The logarithmic forms of equations were rejected because of the large number of observations equal to zero, which would be excluded from the analyses. We therefore present the results for the standard linear and quadratic forms. Some of the prominent results are as follows:

- All the computed equations are statistically significant, and have high R^2 for PQs and low R^2 for PQi. In Table 5.24, all the coefficients are significant, except CTSS in the equation for PQi. The coefficients are consistent with the expectations that an increase in EPR discourages water transfer from the Tigris to the Euphrates, because of more energy generation capacity and relatively less water demand for agricultural use in the Tigris basin. Similarly, an increase in AGRTC and/or CTSS raises the cost of water transfer, and therefore has a negative impact on the water transferred over the link to Syria. Only VALAG has a positive coefficient, because of the potential increase in agricultural benefit because of more water transfer to the Euphrates basin, that experiences shortages of water. The coefficients for PQi are relatively smaller than the coefficients for PQs and relatively less significant.

Table 5.24: Water Transfer Regressions with Four Independent Variables –Linear Form

Dependent variable	PQS		PQI	
	Coefficient	t - value	Coefficient	t - value
Constant	2138.336	8.8	5.23716	2.6
EPR	-27.792	-35.8	-0.01882	-3.0
VALAG	0.091	58.5	0.00004	3.0
AGRTC	-1.840	-8.1	-0.00553	-3.0
CTSS	-1.979	-8.7	-0.00221	-1.2
R^2	0.790		0.021	
Adj R^2	0.789		0.018	
Prob - F	0.0000		0.0000	

- The quadratic equations in Table 5.25 include quadratic and interaction effects. Although CTSS is the primary variable defining the cost of transferring water over the link, it has significant interaction effects only with VALAG in the regression equation for PQs. For PQi none of the interaction and quadratic terms involving CTSS are statistically significant.
- Figure 5.109 displays the best-fit models (quadratic) for PQs. Considering the very low R^2 value for PQi (0.087), the coefficients of the PQi equation do not provide much insights and therefore no graph is provided for PQi. On the other hand, the R^2 value for PQs (0.89) is much higher, and therefore the PQs function is graphed with

respect to VALAG and EPR. As is seen on the graph, a higher VALAG value increases the amount of water delivered through the link not only for Syrian use, but also, directly and indirectly (from return flows), for Iraqi use at the farther downstream nodes on the Euphrates.

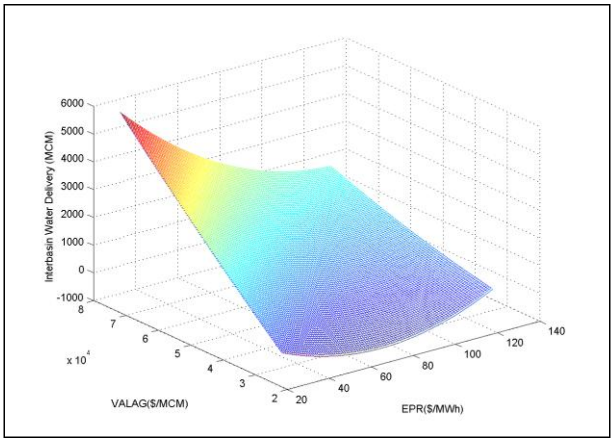


Figure 5.109: PQs with Respect to EPR & VALAG – Quadratic Function

Table 5.25: Water Transfer Regressions with Four Independent Variables – Quadratic Form

Dependent	PQS		PQI	
Independent	Coefficient	t - value	Coefficient	t - value
(Constant)	3113.76	2.20	32.53	2.11
EPR	-76.97	-13.30	-0.25	-4.00
VALAG	0.19	14.91	0.00	2.76
AGRTC	-7.00	-2.74	-0.09	-3.15
CTSS	-2.86	-1.12	-0.00498	-0.18
EPR_EPR	0.37	18.99	0.0006	2.79
VAG_VAG	0.0000002	3.04	0.0000000	2.79
ATC_ATC	0.0030951	1.85	0.0000509	2.79
CTS_CTS	0.0008622	0.51	-0.0000102	-0.56
EPR_VAG	-0.0008472	-25.57	-0.0000016	-4.47
EPR_ATC	0.0446	9.15	0.0002	4.47
EPR_CTS	0.0088	1.81	0.0001	1.79
VAG_ATC	-0.0001	-5.62	0.0000	-4.47
VAG_CTS	0.0000	-2.66	0.0000	-1.79
ATC_CTS	0.0005	0.35	0.0000	1.79
R^2	0.8893		0.0872	
Adjusted R^2	0.8880		0.0773	
Prob - F	0.0000		0.0000	

Variables and Parameters

The lower cases at the end of acronyms, a, u, and e, refer to the agriculture, urban, and electricity generation sectors. And the countries, Turkey, Syria, and Iraq, are referred to by the lower cases t, s, i (e.g. TECBWta, TECBWiu, TECBes).

Variables

NEB:	total benefit net of transportation costs	\$
NBENt:	total benefit net of transportation costs for Turkey	\$
NBENs:	total benefit net of transportation costs for Syria	\$
NBENi:	total benefit net of transportation costs for Iraq	\$
SHAREt:	share of Turkish benefits.	
SHAREs:	share of Syrian benefits.	
SHAREi:	share of Iraqi benefits.	
TECBWa:	total economic benefit from water consumption in agriculture	\$
TECBWta:	total economic benefit from water consumption in agriculture by Turkey	\$
TECBWsa:	total economic benefit from water consumption in agriculture by Syria	\$
TECBWia:	total economic benefit from water consumption in agriculture by Iraq	\$
TECBWu:	total economic benefit from water consumption in the urban sector	\$
TECBWtu:	total economic benefit from water consumption in the urban sector by Turkey	\$
TECBWsu:	total economic benefit from water consumption in the urban sector by Syria	\$
TECBWiu:	total economic benefit from water consumption in the urban sector by Iraq	\$
TECBE:	total economic benefit from energy generation	\$
TECBEt:	total economic benefit from energy generation by Turkey	\$
TECBEs:	total economic benefit from energy generation by Syria	\$
TECBEi:	total economic benefit from energy generation by Iraq	\$
TWT:	total water withdrawal	Mm^3
WTt:	total water withdrawal by Turkey	Mm^3
WTs:	total water withdrawal by Syria	Mm^3
WTi:	total water withdrawal by Iraq	Mm^3
GULF	Water released to the Gulf	
PQs:	total water transfer to Syria by the inter-supply-node link project	Mm^3
PQi:	total water transfer to Iraq by the inter-supply-node link projects	Mm^3

Parameters

EPR:	energy price for electricity	\$ per MWh
AGRTC:	agricultural water transport unit cost	\$ per Mm^3-km

URBTC:	urban water transport unit cost	\$ per Mm^3-km
CTSS:	internodal water transport unit cost	\$ per Mm^3-km
VALAG:	agriculture water unit value	\$ per Mm^3
VALUR:	urban water unit value	\$ per Mm^3

Derived Parameters

EPR_EPR:	EPR^2
VAG_VAG:	$VALAG^2$
ATC_ATC:	$AGRTC^2$
CTS_CTS:	$CTSS^2$
EPR_VAG:	EPR*VALAG
EPR_ATC:	EPR*AGRTC
EPR_CTS:	EPR*CTSS
VAG_ATC:	VALAG*AGRTC
VAG_CTS:	VALAG*CTSS
ATC_CTS:	AGRTC*CTSS
LNEPR:	lnEPR
LNVALAG:	lnVALAG
LNAGRTC:	lnAGRTC
LNCTSS:	lnCTSS
LEPRLEPR:	$(\ln EPR)^2$
LVAGLVAG:	$(\ln VALAG)^2$
LATCLATC:	$(\ln AGRTC)^2$
LCTSLCTS:	$(\ln CTSS)^2$
LEPRLVAG:	lnEPR*lnVALAG
LEPRLATC:	lnEPR*lnAGRTC
LEPRLCTS:	lnEPR*lnCTSS
LVAGLATC:	lnVALAG*lnAGRTC
LVAGLCTS:	lnVALAG*lnCTSS
LATCLCTS:	lnAGRTC*lnCTSS

NOTES

[1] Only one is built (in Iraq) and the others proposed in the literature.

[2] The Tigris constitutes the eastern border of Syria with Turkey.

CHAPTER 6

COOPERATION AND CONFLICT IN WATER RESOURCES ALLOCATION: Game – Theoretic Analyses of the Euphrates and Tigris River Basin

This chapter analyzes the opportunities for cooperation in water resources allocation among the ETRB countries. It applies concepts of cooperative game theory with side payments, as reviewed in Chapter 3. In particular, it analyzes the various possible coalitions that may be formed among Turkey, Syria, and Iraq, and the cases where each country acts alone, providing the least expectation from the Euphrates and Tigris River Basin (ETRB) in terms of water and benefits. It then determines whether a core of benefit allocations exists, wherein all allocations would be acceptable to all countries, thus ensuring a stable allocation, satisfying not only individual but also coalition rationalities. When there is no core solution, a minimum subsidy is introduced to reach a stable solution. Linear programming is used to assess the existence of a core, as well as the minimum subsidy. Whether there is a core or not, a special benefit allocation reflecting the relative power of the three countries, and called the Shapley solution, is also computed.

This chapter also focuses on how the core changes with respect to changing parameters, such as energy price,[1] water resources availability, and value of agricultural benefits. The parameter scenarios are presented in Table 6.1.

Table 6.1: Parameter Scenarios

Energy Prices (EPR)			EPR = $0	EPR = $25	EPR = $100
A	Water Resources (TTF=Bm^3)		Agricultural Productivity (VALAG) Weights		
			Turkey: 1.1	Syria: 1.0	Iraq: 0.9
	59.8	Minimum	A11	A12	A13
	81.9	Average	A21	A22	A23
	92.6	Maximum	A31	A32	A33
B	Water Resources (TTF=Bm^3)		Agricultural Productivity (VALAG) Weights		
			Turkey: 1.0	Syria: 1.0	Iraq: 1.0
	59.8	Minimum	B11	B12	B13
	81.9	Average	B21	B22	B23
	92.6	Maximum	B31	B32	B33
C	Water Resources (TTF=Bm^3)		Agricultural Productivity (VALAG) Weights		
			Turkey: 0.9	Syria: 1.0	Iraq: 1.1
	59.8	Minimum	C11	C12	C13
	81.9	Average	C21	C22	C23
	92.6	Maximum	C31	C32	C33

6.1. Modeling Approach

The assumptions and necessary system designs (parameters and variables) for each individual and coalition strategy are presented in equation form in the following section. They involve, in each case, an adaptation of the ETRBM. Then, based on the results obtained from solving these models, mathematical formulations of both core analyses and the Shapley method are presented.

6.1.1. Models for Individual and Coalition Strategies

Figure 6.1 illustrates country interactions under the different possible configurations of coalition/cooperation. Figure 6.1.a illustrates the case of independent, individual action by each country. In Step 1, Turkey optimally utilizes the resources in its border. Next, in Step 2, Syria, taking the return flows and released water from Turkey as exogenously determined (in Step 1), optimally utilizes this exogenous input and the resources within its border. Finally, in Step 3, Iraq optimally utilizes its internal resources and the water inputs from Turkey and Syria (released and return flow waters), as determined in Steps 1 and 2. The step sequence clearly reflects the dominance of upstream countries over downstream countries. These steps are mathematically illustrated by Equations (6.1) – (6.3).

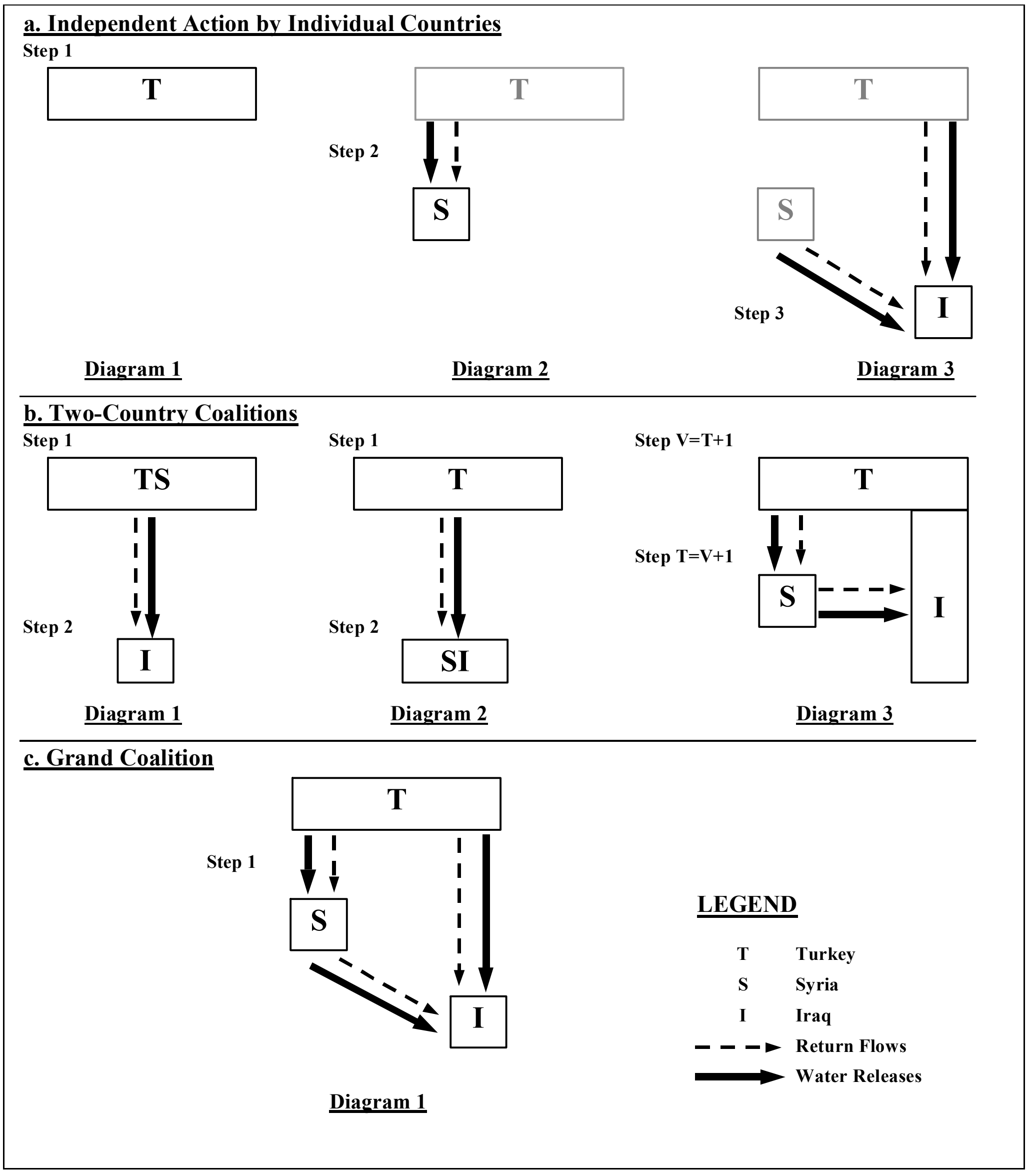


Figure 6.1: Country Interactions Under Different Configurations of Independence and Cooperation

In Figure 6.1.b, the various two-country coalitions are presented. The ***first diagram*** displays the Turkish and Syrian coalition, with Iraq acting independently. In Step 1, Turkey and Syria utilizes the resources available within their territories jointly and optimally. In Step 2, Iraq optimizes the use of the resources available within its territory, together with the exogenous input from Turkey and Syria. This interaction is summarized in Equations (6.4) and (6.5). The ***second diagram*** presents the Syrian and Iraqi coalition, with Turkey acting independently. In Step 1, Turkey optimally uses the available resources within its territory, and releases the unused water for the Syrian and Iraqi coalition, which takes this input as exogenous, and optimally uses all its available resources. Equations (6.6) and (6.7) illustrate this interaction. The ***last diagram*** explains the interactions between the Turkish and Iraqi coalition, and Syria acting independently. Because both the coalition and Syria are affected by each other's decisions and output, a stable solution is represented by a Nash equilibrium, which is reached when the sequential optimizations stop because there is no longer any change in their solutions. This interaction is summarized by Equation (6.8) and (6.9).

Figure 6.1.c illustrates the grand coalition, which is equivalent to the benchmark model. Equation 6.10 summarizes this case mathematically.

In Equations (6.1) – (6.10) below, the tributary inflows TF_j represent the water resources available within a country, and are complemented, where appropriate, by the return flows from the upstream country (e.g., $INTRFts_j^*$ from Turkey to Syria) and by the water flowing in the river and crossing the boundary (e.g., $PQ_{5,7}^*$ from node 5 in Turkey to node 7 in Syria). Exogenously determined inputs are marked by an asterisk.

Individual Country Decisions

$$NEBt = f(TF_j) \qquad \forall\ j \in st \qquad (6.1)$$

$$NEBs = f(TF_j, INTRFts_j^*, PQ_{5,7}^*) \qquad \forall\ j \in ss \qquad (6.2)$$

$$NEBi = f(TF_j, INTRFti_j^*, INTRFsi_j^*, PQ_{9,14}^*, PQ_{10,14}^*, PQ_{13,14}^*, PQ_{21,28}^*, PQ_{27,28}^*) \qquad \forall\ j \in si \qquad (6.3)$$

Two-Country Coalition Decisions

(1) Turkey – Syria (ts)

$$NEBts = f(TF_j) \qquad \forall\ j \in st\ \&\ ss \qquad (6.4)$$

$$NEBiTS = f(TF_j, INTRFti^*_j, INTRFsi^*_j, PQ^*_{9,14}, PQ^*_{10,14}, PQ^*_{13,14}, PQ^*_{21,28}, PQ^*_{27,28})$$

$$\forall\ j \in si \qquad (6.5)$$

(2) Syria - Iraq (si)

$$NEBt = f(TF_j) \qquad \forall\ j \in st \qquad (6.6)$$

$$NEBsi = f(TF_j, INTRFts^*_j, INTRFti^*_j, PQ^*_{5,7}, PQ^*_{21,28}, PQ^*_{27,28}) \qquad \forall\ j \in ss\ \&\ si \qquad (6.7)$$

(3) Turkey - Iraq (ti)

$$NEBsTI = f(TF_j, INTRFts^*_j, PQ^*_{5,7}) \qquad \forall\ j \in ss \qquad (6.8)$$

$$NEBtiS = f(TF_j, INTRFsi^*_j, PQ^*_{9,14}, PQ^*_{10,14}, PQ^*_{13,14}) \qquad \forall\ j \in st\ \&\ si \qquad (6.9)$$

Grand Coalition

$$NEBtsi = f(TF_j) \qquad \forall\ j \qquad (6.10)$$

Benefits

NEBt	net economic benefit of Turkey
NEBs	net economic benefit of Syria
NEBi	net economic benefit of Iraq
NEBts	net economic benefit of Turkey and Syria
NEBiTS	net economic benefit of Iraq given the *TS* coalition
NEBtiS	net economic benefit of Turkey and Iraq given Syria's action
NEBsTI	net economic benefit of Syria given the *TI* coalition
NEBsi	net economic benefit of Syria and Iraq
NEBtsi	net economic benefit of Turkey, Syria, and Iraq

Return Flows

$INTRFts_j$:	international total return flow to node j in Syria from Turkey
$INTRFti_j$:	international total return flow to node j in Iraq from Turkey
$INTRFsi_j$:	international total return flow to node j in Iraq from Syria

River Flows

$PQ_{5,7}$:	water release from Turkey to Syria (*j=5* to *l=7*)
$PQ_{9,14}$:	water release from Syria to Iraq (*j=9* to *l=14*)
$PQ_{10,14}$:	water release from Syria to Iraq (*j=10* to *l=14*)
$PQ_{13,14}$:	water release from Turkey to Iraq (*j=13* to *l=14*)
$PQ_{21,28}$:	water release from Turkey to Iraq (*j=21* to *l=28*)
$PQ_{27,28}$:	water release from Turkey to Iraq (*j=27* to *l=28*)
$PQ_{21,12}$:	link for water transshipment from Turkey to Syria

Subsets[2]

st(j):	supply nodes subset for Turkey
ss(j):	supply nodes subset for Syria
si(j):	supply nodes subset for Iraq

In the following subsections, we present first the objective functions with the new variables and subsets, and then the constraints, the parametric assumptions, and the necessary parametric calculations to coordinates the individual optimizations.

6.1.1.1. Objective Functions

Since there are different assumptions for each different form of actions (individual or cooperative), the necessary country benefit components of the benchmark model are presented separately. The objective function represented by Equation (4.1) in Chapter 4 is subdivided into associated country components. Each Equation (6.11) - (6.17) contains at least a part of Equation (4.1). While maximizing the functions (6.11) – (6.17), Equation (4.2) – (4.10) of the ETRBM and some additional constraints, listed below, are used. For each coalition and individual action, there is a series of parametric assumptions, listed in the next section.

Individual Country Objectives

$$\begin{aligned} NEBt = & \sum_{ta} VALAG \cdot WT_i - \sum_{j,ta} W_{j,i} \cdot DSD_{j,i} \cdot AGRTC \\ & + \sum_{tu} VALUR \cdot WT_i - \sum_{j,tu} W_{j,i} \cdot DSD_{j,i} \cdot URBTC \\ & + \sum_{st,l} EPR \cdot EG_{st} \cdot PQ_{st,l} \end{aligned} \tag{6.11}$$

$$
\begin{aligned}
NEBs = & \sum\nolimits_{sa} VALAG \cdot WT_i - \sum\nolimits_{j,sa} W_{j,i} \cdot DSD_{j,i} \cdot AGRTC \\
& + \sum\nolimits_{su} VALUR \cdot WT_i - \sum\nolimits_{j,su} W_{j,i} \cdot DSD_{j,i} \cdot URBTC \\
& + \sum\nolimits_{ss,l} EPR \cdot EG_{ss} \cdot PQ_{ss,l} \\
& - \left[(PQ_{21,12} \cdot CTSS \cdot DSS_{21,12}) \right]
\end{aligned}
\tag{6.12}
$$

$$
\begin{aligned}
NEBi = & \sum\nolimits_{ia} VALAG \cdot WT_i - \sum\nolimits_{j,ia} W_{j,i} \cdot DSD_{j,i} \cdot AGRTC \\
& + \sum\nolimits_{iu} VALUR \cdot WT_i - \sum\nolimits_{j,iu} W_{j,i} \cdot DSD_{j,i} \cdot URBTC \\
& + \sum\nolimits_{si,l} EPR \cdot EG_{si} \cdot PQ_{si,l} \\
& - \left[(PQ_{28,14} \cdot CTSS \cdot DSS_{28,14}) + (PQ_{31,16} \cdot CTSS \cdot DSS_{31,16}) \right]
\end{aligned}
\tag{6.13}
$$

Subsets

ta(i):	**agricultural demand nodes in Turkey**
tu(i):	**urban demand nodes in Turkey**
sa(i):	**agricultural demand nodes in Syria**
su(i):	**urban demand nodes in Syria**
ia(i):	**agricultural demand nodes in Iraq**
iu(i):	**urban demand nodes in Iraq**

Coalition Objectives

$NEBts = NEBt + NEBs$ **and** $NEBi = NEBiTS$ *(i.e. NEBi given NEBts)* **(6.14)**

$NEBti = NEBt + NEBs$ **and** $NEBs = NEBsTI$ *(i.e. NEBs given NEBti)* **(6.15)**

$NEBsi = NEBs + NEBi$ **(6.16)**

Grand Coalition Objective - Equivalent to Equation (4.1)

$NEBtsi = NEBt + NEBs + NEBi$ **(6.17)**

6.1.1.2. Decision Processes Assumptions

The decision process outlined in the previous section (Figure 6.1) can be classified into two categories: The first involves sequential process, and the second a

Nash equilibrium process. The assumptions and methods of computation for these processes are reviewed in the following subsections.

6.1.1.2.1. Sequential Processes

The assumptions for the different forms of sequential processes, with either individual countries or coalitions of countries, can be summarized as follows:

- **In view of the river basin flows hierarchy, Turkey, which dominates the system by virtue of its upstream location can freely optimize the use of the water resources within its boundaries, and releases the unused water at the borders with Syria and Iraq. In addition, some portion of the water withdrawn in Turkey flows back into the Syrian and Iraqi tributary inflow systems as return flows.**
- **Downstream from Turkey but upstream from Iraq, Syria optimizes the use of the water accumulated in her tributary system, including 1) in-country natural inflows, 2) unused water flowing from Turkey, and 3) return flow water from upstream withdrawals in Turkey.**
- **Finally, Iraq, downstream from both Turkey and Syria, optimally uses the water from 1) in-county natural inflows, 2) unused water flowing from both Turkey and Syria, and 3) water coming as return flows.**
- **The coalition of Turkey and Syria clearly dominates Iraq, which becomes the receiver of both unused and return flow waters, in addition to her own tributary inflows. Conversely, the coalition of Syria and Iraq is dominated by Turkey, from which it receives both river flows (both on the Euphrates and Tigris) and return flows. As discussed earlier, the case of the Turkey-Iraq coalition is more complex because the optimum decisions of the coalition and of Syria depend upon the other party's decision, hence the Nash equilibrium situation.**
- **The grand coalition case is represented by the benchmark model where the aggregate three-country optimal use of water is determined, with individual counties relinquishing their decision-making powers.**

The following subsets are used in the following analyses:

Subsets

dt(i):	demand nodes subset for Turkey
ds(i):	demand nodes subset for Syria
di(i):	demand nodes subset for Iraq

Individual Decisions by Turkey

The function used as the objective is defined by Equations (6.1) and (6.11). Turkey decides to act alone, and does not consider the tributary inflows or evaporations at downstream nodes in Syria and Iraq. In order to focus only on the Turkish portion of the ETRBM, Constraints (6.18) are imposed to eliminate the Syrians and Iraqi tributary inflows and evaporations from the model. Constraint (6.19) prevents withdrawal from downstream nodes, and Constraint (6.20) eliminates the link from Turkey to Syria.

Given Turkey's individual optimization, Equation (6.21) computes the return flows from Turkey's demand nodes to the Syrian supply nodes. Similarly, Equation (6.22) computes the return flows from Turkey's demand nodes to Iraqi supply nodes. The next two equations (6.23 – 6.24) compute the amount of river water flowing into Iraq and Syria, respectively. These values are used as input in later models.

Constraints:

$$\left.\begin{aligned} TF_j &= 0 \\ REL_j &= 0 \end{aligned}\right\} \qquad \forall\ j \in ss \text{ and } si \qquad (6.18)$$

$$WT_i = 0 \qquad \forall\ i \in ds \text{ and } di \qquad (6.19)$$

$$PQ_{21,12} = 0 \qquad (6.20)$$

Outputs (used as inputs in other decision processes):

$$INTRFts_j = \sum_{i \in dt} RFR_{ij} \cdot WT_i^* \qquad \forall\ j \in ss \qquad (6.21)$$

$$INTRFti_j = \sum_{i \in dt} RFR_{ij} \cdot WT_i^* \qquad \forall\ j \in si \qquad (6.22)$$

$$A = PQ^{*}_{21,28} + PQ^{*}_{27,28} \text{ : river flow from Turkey into Iraq} \quad (6.23)$$

$$B = PQ^{*}_{5,7} \text{ : river flow from Turkey into Syria} \quad (6.24)$$

Individual Decisions by Syria Following Turkey's Decisions

Given the individual decisions by Turkey, the function used as objective for Syrian optimum utilization of resources is defined by Equations (6.2) and (6.12). Constraint (6.25) recomputes tributary inflows in Syria by incorporating the return flows from Turkey, as computed in Equation (6.21). Equation (6.26) eliminates tributary inflows and reservoir evaporations in Iraq and Turkey. Then the river water unused by Turkey (B) flows into Syria and is added to Syrian tributary inflows at node j=7 in Equation (6.27). Constraint (6.28) eliminates Turkish and Iraqi withdrawal options, and Constraint (6.29) closes the interbasin link from Turkey to Syria. Given Turkey's and Syria's actions, Equations (6.30) and (6.31) compute model outputs, that will be used as inputs for Iraq (return flows from Syria and unused water released to Iraq).

Constraints:

$$TF_j = TF_j + INTRFts_j \qquad \forall\ j \in ss \quad (6.25)$$

$$\left.\begin{aligned} TF_j &= 0 \\ REL_j &= 0 \end{aligned}\right\} \qquad \forall\ j \in st \text{ and } si \quad (6.26)$$

$$TF_7 = TF_7 + B \quad (6.27)$$

$$WT_i = 0 \qquad \forall\ i \in dt \text{ and } di \quad (6.28)$$

$$PQ_{21,12} = 0 \quad (6.29)$$

Outputs (used as inputs in other decision processes):

$$INTRFsi_j = \sum_{i \in ds} RFR_{ij} \cdot WT^{*}_i \qquad \forall\ j \in si \quad (6.30)$$

$$C = Q^{*}_{9,14} + PQ^{*}_{10,14} + PQ^{*}_{13,14} \text{ : river flow from Syria into Iraq} \quad (6.31)$$

Individual Decisions by Iraq Following Turkey's and Syria's Decisions

After the sequential optimum utilization of river basin resources by Turkey and then by Syria, the function used as an objective for Iraq is defined by Equations (6.3) and (6.13). Constraint (6.32) adds return flows from both Turkey and Syria to Iraq tributary flows. Constraint (6.33) eliminates both Turkish and Syrian tributary inflows and evaporations. Equations (6.34) and (6.35) add the water flowing into Iraq from both Turkey (A) and Syria (C) to the supply nodes j=14 and j=28. Equations (6.36) and (6.37) eliminate both Turkish and Syrian withdrawals, and the interbasin link form Turkey to Syria.

Constraints:

$$TF_j = TF_j + INTRFsi_j + INTRFti_j \qquad \forall\ j \in si \qquad (6.32)$$

$$\left.\begin{array}{l} TF_j = 0 \\ REL_j = 0 \end{array}\right\} \qquad \forall\ j \in st \text{ and } ss \qquad (6.33)$$

$$TF_{14} = TF_{14} + C \qquad (6.34)$$

$$TF_{28} = TF_{28} + A \qquad (6.35)$$

$$WT_i = 0 \qquad \forall\ i \in dt \text{ and } ds \qquad (6.36)$$

$$PQ_{21,12} = 0 \qquad (6.37)$$

Decisions by the Coalition of Turkey and Syria

With Iraq left aside, Turkey and Syria are treated as one single country and the interbasin link from Turkey to Syria becomes internal to this unit. The function used as objective is defined by Equation (6.4). Constraint (6.38) eliminates Iraqi reservoir evaporations and tributary inflows. Constraint (6.39) eliminates Iraqi withdrawals. Equation (6.40) computes the return flows from withdrawals by the Turkish and Syrian coalition, and Equations (6.41) and (6.42) compute the river flows released by the coalition to Iraq.

Constraints:

$$\left.\begin{aligned} \boldsymbol{TF_j} &= \mathbf{0} \\ \boldsymbol{REL_j} &= \mathbf{0} \end{aligned}\right\} \qquad \forall\ \boldsymbol{j \in si} \qquad \textbf{(6.38)}$$

$$\boldsymbol{WT_i} = \mathbf{0} \qquad \forall\ \boldsymbol{i \in di} \qquad \textbf{(6.39)}$$

Outputs (used as inputs in other decision process):

$$\boldsymbol{INTRFi_j} = \sum_{\boldsymbol{i \in dt}} \boldsymbol{RFR_{ij}} \cdot \boldsymbol{WT_i^*} + \sum_{\boldsymbol{i \in ds}} \boldsymbol{RFR_{ij}} \cdot \boldsymbol{WT_i^*} \qquad \forall\ \boldsymbol{j \in si} \qquad \textbf{(6.40)}$$

$\boldsymbol{D = PQ^*_{21,28} + PQ^*_{27,28}}$ **: river flow from the Turkey-Syria coalition into Iraq along the Tigris river** **(6.41)**

$\boldsymbol{E = Q^*_{9,14} + PQ^*_{10,14} + PQ^*_{13,14}}$ **: river flow from the Turkey-Syria coalition into Iraq along the Euphrates river** **(6.42)**

Decisions by Iraq Following the Decisions by the Turkey-Syria Coalition

Given the decisions by the Turkey-Syria coalition, the function used as objective for Iraq is defined by Equation (6.5). Iraq is a passive receiver of upstream water releases and return flows. Constraint (6.43) adds return flows from Turkey and Syria to Iraqi tributary flows, whereas Constraints (6.45) and (6.46) recompute river flows at Iraq border nodes (see Equations 6.41 – 6.42). Constraint (6.44) eliminates evaporations and tributary flows in both Turkey and Syria. Finally, Constraints (6.47) and (6.48) eliminate Turkish and Syrian withdrawals, and remove the interbasin link from Turkey to Syria.

Constraints:

$$\boldsymbol{TF_j = TF_j + INTRFti_j + INTRFsi_j} \qquad \forall\ \boldsymbol{j \in si} \qquad \textbf{(6.43)}$$

$$\left.\begin{aligned} \boldsymbol{TF_j} &= \mathbf{0} \\ \boldsymbol{REL_j} &= \mathbf{0} \end{aligned}\right\} \qquad \forall\ \boldsymbol{j \in st} \text{ \textbf{and} } \boldsymbol{ss} \qquad \textbf{(6.44)}$$

$$\boldsymbol{TF_{14} = TF_{14} + E} \qquad \textbf{(6.45)}$$

$$TF_{28} = TF_{28} + D \tag{6.46}$$

$$WT_i = 0 \qquad \forall\ i \in dt \text{ and } ds \tag{6.47}$$

$$PQ_{21,12} = 0 \tag{6.48}$$

Decisions by the Coalition of Syria and Iraq Following Turkey's Decisions

Both Syria and Iraq are passive receivers of water flowing from Turkey, and are treated as if they were one single country. The function used as objective for the Syria-Iraq coalition is defined by Equation (6.7). Constraint (6.49) adjusts the tributary flows by adding return flows from upstream withdrawals in Turkey. Equations (6.51) and (6.52) add the river water flows released from Turkey to node j=7 and j=28 in Syria and Iraq, respectively. The elimination of evaporations and tributary inflows in Turkey is carried out by Constraint (6.50). Finally, Constraint (6.53) eliminates water withdrawals in Turkey.

Constraint:

$$TF_j = TF_j + INTRFts_j + INTRFti_j \qquad \forall\ j \in ss \text{ and } si \tag{6.49}$$

$$\left.\begin{aligned} TF_j &= 0 \\ REL_j &= 0 \end{aligned}\right\} \qquad \forall\ j \in st \tag{6.50}$$

$$TF_7 = TF_7 + B \tag{6.51}$$

$$TF_{28} = TF_{28} + A \tag{6.52}$$

$$WT_i = 0 \qquad \forall\ i \in dt \tag{6.53}$$

6.1.1.2.2. Nash Equilibrium Process

The case of the Turkey-Iraq coalition is somewhat more complicated than the other cases. Syria is both affected by and affecting the coalition. Therefore, this situation can be defined as a Nash equilibrium problem. The sequential decisions of both parties

take place until they reach an equilibrium. Suppose that Turkey and Iraq have decided on a strategy for water allocation. Part of this strategy involves implicitly an allocation to Syria (via Turkey's decision on how much to release). Syria then optimizes its internal net-benefits. Part of that decision involves how much water it wants to release downstream, i.e., to Iraq. When Syria does this, the original assumptions under which Turkey and Iraq constructed their strategy no longer hold, so they have an incentive to revise their original strategy. This is the next iteration of the Nash process. In turn, this presents Syria with a new initial situation, and thus Syria revises its strategy. This once again changes the situation for the Turkey – Iraq coalition, and further revisions take place. The process continues until an equilibrium is reached, in which (approximately) no country or coalition has an incentive to revise its decisions on water allocations. This equilibrium is purely based on these allocations and is not related to the side payments necessary to create a core for cooperation, as discussed in Section 6.1.2. Note also that there is clearly internal optimization within the Turkey – Iraq coalition, irrespective of Syria's decisions, through the release of the Tigris water from Turkey to Iraq. (For instance, Turkey's use of the Tigris water for agriculture would leave less water for Iraqi uses). To attain this Nash equilibrium, the following two models are iteratively applied.

Individual Decisions by Syria Following the Decisions of the Turkey-Iraq Coalition

The function used as objective for Syrian optimum utilization of resources is defined by Equation (6.8). In order to start the loop, Equations (6.54) and (6.57) are used as starting (initialization) levels of tributary inflow, accounting for return flows and water released from the Turkey-Iraq coalition. In the following iterations, Equations (6.55) and (6.58) replace Equations (6.54) and (6.57), respectively. The tributary inflows and reservoir evaporations in Turkey and Iraq are eliminated from the model using Constraint (6.56). Constraints (6.59) and (6.60) eliminate water withdrawals in Turkey and Iraq and the interbasin link from Turkey to Syria. Equations (6.61) and (6.62) compute the outputs that will be used as inputs to the Turkey-Iraq coalition.

Parameter assumption:

$TF_j = TF_j + INTRFts_j$ (for the initial iteration only) $\forall\ j \in ss$ (6.54)

$TF_j = TF_j + F$ (for the following iterations) $\forall\ j \in ss$ (6.55)

$$\left.\begin{array}{l} TF_j = 0 \\ REL_j = 0 \end{array}\right\} \quad \forall\ j \in st \text{ and } si \qquad (6.56)$$

$TF_7 = TF_7 + B$ (for the initial iteration only) (6.57)

$TF_7 = TF_7 + G$ (for the following iterations) (6.58)

$WT_i = 0$ $\forall\ i \in dt$ and di (6.59)

$PQ_{21,12} = 0$ (6.60)

Outputs (used as inputs in the Syrian decision process):

$INTRFsi_j = \sum_{i \in ds} RFR_{ij} \cdot WT_i^*$ $\forall\ j \in si$ (6.61)

$H = Q_{9,14}^* + PQ_{10,14}^* + PQ_{13,14}^*$: river flow from Syria into Iraq (6.62)

Decisions by the Turkey-Iraq Coalition Following Syria's Decisions

Given Syria's optimum utilization of its resources, the function used as objective here is defined by Equation (6.9). The Turkey-Iraq coalition receives (in Iraq) the return flows and river water released from Syria, and then releases unused water and return flows from Turkey to downstream Syria. Equations (6.63) and (6.65) account for the water coming from upstream Syria to the coalition via releases and return flows. Constraint (6.64) eliminates tributary inflows and evaporations in Syria. Constraint (6.66) eliminates Syrian withdrawals. Constraint (6.67) eliminates the interbasin link from Turkey to Syria. Equations (6.68) and (6.69) compute the outputs that will be used as inputs by Syria in the next iteration.

Constraints:

$$TF_j = TF_j + INTRFsi_j \qquad \forall\ j \in st \text{ and } si \qquad (6.63)$$

$$\left.\begin{array}{l} TF_j = 0 \\ REL_j = 0 \end{array}\right\} \qquad \forall\ j \in ss \qquad (6.64)$$

$$TF_{14} = TF_{14} + H \qquad (6.65)$$

$$WT_i = 0 \qquad \forall\ i \in ds \qquad (6.66)$$

$$PQ_{21,12} = 0 \qquad (6.67)$$

Outputs (used as inputs in the Turkey-Iraq decision process):

$$F = INTRFts_j = \sum\nolimits_{i \in dt} RFR_{ij} \cdot WT_i^* + \sum\nolimits_{i \in di} RFR_{ij} \cdot WT_i^* \qquad \forall\ j \in ss \qquad (6.68)$$

$$G = PQ_{5,7}^* \qquad (6.69)$$

6.1.2. Models for Core, Shapley Value, and Subsidy Determination

The ETRBM has been solved for each of the previous decision processes and over the 27 different parameter scenarios. Using the individual and coalition benefits so obtained, we first test for the existence of a core, using linear programming, which allows the determination of the minimum subsidy to create a non-empty core when the core is initially empty, and of the maximum taxation when there is an initial core. Next, we compute the Shapley allocations of benefits, which reflects the relative power of the three countries, and test whether this allocation is in the core, and thus sustainable.

Consider the total benefits of the grand coalition, *NEBtsi*. This is clearly the maximum aggregate benefit achievable by the three countries. The problem (see Chapter 3, Section 3.1) is to allocate this aggregate benefit among the three countries in a way that will persuade them to accept this allocation. Let X_t, X_s, and X_i be the benefits allocated to Turkey, Syria, and Iraq, respectively. This allocation should then verify that

$$X_t + X_s + X_i = NEBtsi \qquad (6.70)$$

This allocation, to be sustainable, should verify both individual and coalition rationality constraints, so that no country acting alone or within a coalition, has an incentive to reject the allocation. The three coalition constraints are straightforwardly represented by Equations (6.75) – (6.77). The case of the individual rationality constraints is a little more complicated. Indeed, a given country c may act individually under two situations: (a) the other two countries also act individually, and (b) they act as a coalition. The benefits to country c under these two situations need not be the same. We assume that country c aims at guaranteeing to itself the minimum of these two benefits, hence the formulation of the constraints (6.72) – (6.74).

The equality (6.70) and inequalities (6.72) – (6.77) may or may not have solution. In order to find out, the standard approach is to transform this system of inequalities/equality into a linear program (LP), by maximizing or minimizing any linear function of the variables (X_t, X_s, X_i). If the LP has no solution, then the system of in inequalities/equality has no solution, and the core is empty. A variation on this approach is to modify Equation (6.70) by introducing a new variable, Z, leading to Equation (6.78), and to use as the LP objective function Z. Hence, the LP is represented by Equation (6.71) – (6.78):

Maximize

$$F = Z \tag{6.71}$$

subject to

$$X_t \geq \min(NEBt, NEBtSI) = NEBt^{\min} \tag{6.72}$$

$$X_s \geq \min\left(NEBs, NEBsTI\right) = NEBs^{\min} \tag{6.73}$$

$$X_i \geq \min\left(NEBi, NEBiTS\right) = NEBi^{\min} \tag{6.74}$$

$$X_t + X_s \geq NEBts \tag{6.75}$$

$$X_t + X_i \geq NEBti \tag{6.76}$$

$$X_s + X_i \geq NEBsi \tag{6.77}$$

$$X_t + X_s + X_i + Z = NEBtsi \tag{6.78}$$

The variable Z provides information beyond the existence of a core, by indicating the level of subsidies needed to implement the grand coalition when the core is empty, or the level of taxes that can be extracted from the three countries while still maintaining a non-empty core. As exogenous conditions (parameters) vary in the future, the existence of a core and the associated coalition conditions will also vary, and therefore a supra-governmental authority may be needed to maintain the grand coalition. This authority should have taxation and subsidization powers, could search for outside funding sources, and could reallocate taxes as subsidies over the years. If the optimal Z^* is strictly equal to zero, then the core exists but is reduced to only one point, i.e., only one allocation is acceptable. If Z^* is positive, the core is non-empty and made of an infinite number of feasible allocations. The allocation obtained with Z^* is sustainable and allows a supra-governmental authority to extract the maximum benefits from the three countries for saving for future use. In this case, Z^* can be viewed as the maximum tax. If Z^* is negative, then the core is empty. However, if a benefit subsidy in the amount (absolute value) of Z^* were added to $NEBtsi$, then a sustainable allocation would be obtained. Hence, Z^* can be viewed as the minimum subsidy to obtain a sustainable benefit allocation.

To illustrate the application of the Shapley method, consider the case of Iraq as the player joining other coalitions. The first case is that of Iraq joining the "empty" coalitions, with the incremental benefit

$$IB_{i/\phi} = NEBi^{\min} \tag{6.79}$$

Next, Iraq can join either Turkey or Syria, with the incremental benefits:

$$IB_{i/t} = NEBti - NEBt^{\min} \tag{6.80}$$

$$IB_{i/s} = NEBsi - NEBs^{\min} \tag{6.81}$$

Finally, Iraq can join the Turkey-Syria coalition, with the incremental benefits:

$$IB_{i/ts} = NEBtsi - NEBts^{\min} \tag{6.82}$$

These incremental benefits are then weighted by the corresponding probabilities of occurrence – 1/3, 1/6, 1/6, 1/3 for $IB_{i/\phi}$, $IB_{i/t}$, $IB_{i/s}$, and $IB_{i/ts}$, respectively – (see

Equations 3.12 and 3.13 in Chapter 3), and the result is the Shapley allocation of benefits to Iraq.

6.2. Applications

This section first reviews the benefits of and water usage by each country as obtained under the different cooperation scenarios discussed in section 6.1 for each of the 27 parametric scenarios.[3] Next, the existence of a core is analyzed in each case. The minimum subsidy is determined to make the core non-empty, and the Shapley allocations are computed and compared to the other allocations.

6.2.1. Benefits and Water Usage Under Different Cooperation Scenarios

The country benefits and water withdrawals are presented in Tables 6.2 and 6.3, respectively. These tables are organized along the model Table 6.1, and include the results for the 27 parametric scenarios (A11 – C33). For instance, the upper-left block in Tables 6.2 and 6.3 refers to the benefits and water withdrawals under scenario A11.

Table 6.2 presents the benefits for each country and the total benefit (column) for each cooperation scenario: all countries making individual choices (T, S, I) and countries making choices within coalitions (TS, TI, SI, TSI - row). In the cases of two-country coalitions, Table 6.2 also provides the benefits for the remaining country (which are marked with an underline in the table). The cases where the benefits are the same for all cooperation scenarios (T, S, I, TS, TI, SI, TSI) are bold-typed. Italic types are used in the total benefit column to indicate cooperation scenarios where total benefits are equal to those of the grand coalition (TSI). The cases where a country achieves less than 95% of its maximum possible benefits are highlighted, pointing to significant adverse effects. For instance, under parameter scenarios A32, Syria achieves a benefit of \$ 239,928,000 under coalition TI, which represents about 93% of its maximum benefit of \$ 258,236,000 under the grand coalition (TSI). The corresponding withdrawal cases are highlighted in Table

6.3, where bold types are used to indicate equal withdrawals across cooperation scenarios, and italic types the withdrawals corresponding to maximum benefits.

The following observations can be made:

- As expected, Table 6.2 points to benefits increasing with
  a) increasing energy prices (EPR=\$0 → \$25 → \$100),
  b) increasing resources availability (TTF=59.8 → 81.9 → 92.6 Bm^3),
  c) a shift of agricultural productivity from Turkey (case A) to Iraq (case C).

  For instance, the maximum benefit under scenario A11 of \$1,139,167,000 increases to \$7,004,740,000 under scenario C33. The scenarios A31 and B31, corresponding to zero energy price and highest resources availability, lead to the same solution under all five cooperation scenarios (T, S, I, TS, TI, SI, TSI), of course implying a core made of one point only. When EPR=\$0, the difference between the 5 cooperation scenarios (for each parametric scenario) are very small in terms of total benefits, except in the case C11 (\$1,280,585 vs. \$1,301,699,000). Larger differences take place, for individual countries (Syria and Iraq) and in total, when EPR is higher. The largest relative adverse effects (highlights) characterize Syria when EPR=\$25.

Table 6.2: Benefits Under Different Cooperation Scenarios ($1000)

	Coalition	Turkey	Syria	Iraq	Total	Turkey	Syria	Iraq	Total	Turkey	Syria	Iraq	Total
		1				2				3			
A 1	T, S, I	254,509	98,918	784,656	1,138,083	775,635	176,124	889,146	1,840,906	2,642,012	457,449	1,231,575	4,331,037
	TS, I	254,509	98,918	784,656	1,138,083	773,714	183,244	896,653	*1,853,611*	2,640,174	469,890	1,206,183	4,316,247
	TI, S	254,509	98,918	784,656	1,138,083	771,297	164,937	894,049	1,830,282	2,632,618	457,449	1,253,120	*4,343,187*
	SI, T	254,509	98,721	785,937	*1,139,167*	775,635	176,124	889,146	1,840,906	2,642,012	457,449	1,231,575	4,331,037
	TSI	254,509	98,721	785,937	*1,139,167*	773,714	183,244	896,653	*1,853,611*	2,632,618	457,449	1,253,120	*4,343,187*
A 2	T, S, I	255,532	105,423	830,594	1,191,550	1,044,020	226,690	1,002,314	2,273,025	3,712,484	640,196	1,568,091	5,920,771
	TS, I	255,532	105,423	830,594	1,191,550	1,042,099	233,810	1,003,879	*2,279,789*	3,710,646	652,638	1,542,133	5,905,417
	TI, S	255,532	105,423	830,594	1,191,550	1,039,682	215,502	1,008,804	2,263,988	3,703,090	640,196	1,589,636	*5,932,922*
	SI, T	255,532	105,226	831,490	*1,192,248*	1,044,020	226,690	1,002,314	2,273,025	3,712,484	640,196	1,568,091	5,920,771
	TSI	255,532	105,226	831,490	*1,192,248*	1,042,099	233,810	1,003,879	*2,279,789*	3,703,090	640,196	1,589,636	*5,932,922*
A 3	T, S, I	256,024	108,570	834,049	*1,198,643*	1,173,617	251,116	1,043,653	2,468,385	4,229,395	728,459	1,728,899	6,686,753
	TS, I	256,024	108,570	834,049	*1,198,643*	1,171,696	258,236	1,045,218	*2,475,149*	4,227,557	740,901	1,702,942	6,671,399
	TI, S	256,024	108,570	834,049	*1,198,643*	1,169,278	239,928	1,050,142	2,459,349	4,220,000	728,459	1,750,444	*6,698,904*
	SI, T	256,024	108,570	834,049	*1,198,643*	1,173,617	251,116	1,043,653	2,468,385	4,229,395	728,459	1,728,899	6,686,753
	TSI	256,024	108,570	834,049	*1,198,643*	1,171,696	258,236	1,045,218	*2,475,149*	4,220,000	728,459	1,750,444	*6,698,904*
B 1	T, S, I	212,941	98,918	904,815	1,216,675	749,007	172,056	1,033,616	1,954,679	2,635,033	457,449	1,366,866	4,459,348
	TS, I	212,941	98,918	904,815	1,216,675	748,895	183,244	1,030,162	1,962,301	2,628,745	469,890	1,342,690	4,441,326
	TI, S	212,941	98,918	904,815	1,216,675	749,007	172,056	1,033,616	1,954,679	2,629,855	457,449	1,390,718	4,478,022
	SI, T	212,941	98,721	907,023	*1,218,684*	749,007	172,056	1,033,616	1,954,679	2,635,033	453,986	1,370,392	4,459,411
	TSI	212,941	98,721	907,023	*1,218,684*	741,320	187,752	1,038,348	*1,967,419*	2,629,855	453,986	1,394,244	*4,478,085*
B 2	T, S, I	213,715	105,423	982,204	1,301,342	1,017,142	222,622	1,163,380	2,403,145	3,705,255	640,196	1,721,102	6,066,553
	TS, I	213,715	105,423	982,204	1,301,342	1,017,030	233,810	1,156,891	*2,407,731*	3,698,967	652,638	1,695,145	6,046,749
	TI, S	213,715	105,423	982,204	1,301,342	1,017,142	222,622	1,163,380	2,403,145	3,699,303	640,196	1,745,808	*6,085,308*
	SI, T	213,715	105,226	983,746	*1,302,687*	1,017,142	222,622	1,163,380	2,403,145	3,705,255	640,196	1,721,102	6,066,553
	TSI	213,715	105,226	983,746	*1,302,687*	1,017,030	233,810	1,156,891	*2,407,731*	3,699,303	640,196	1,745,808	*6,085,308*
B 3	T, S, I	214,086	108,570	987,320	*1,309,976*	1,146,619	247,048	1,204,978	2,598,645	4,222,046	728,459	1,882,171	6,832,675
	TS, I	214,086	108,570	987,320	*1,309,976*	1,146,507	258,236	1,198,489	*2,603,232*	4,215,758	740,901	1,856,213	6,812,871
	TI, S	214,086	108,570	987,320	*1,309,976*	1,146,619	247,048	1,204,978	2,598,645	4,215,723	728,459	1,907,287	*6,851,469*
	SI, T	214,086	108,570	987,320	*1,309,976*	1,146,619	247,048	1,204,978	2,598,645	4,222,046	728,459	1,882,171	6,832,675
	TSI	214,086	108,570	987,320	*1,309,976*	1,146,507	258,236	1,198,489	*2,603,232*	4,215,723	728,459	1,907,287	*6,851,469*
C 1	T, S, I	173,876	88,148	1,018,560	1,280,585	728,713	172,056	1,167,286	2,068,056	2,631,268	457,449	1,526,771	4,615,487
	TS, I	171,373	98,918	1,024,975	1,295,266	721,211	187,752	1,176,901	*2,085,863*	2,620,530	469,890	1,504,043	4,594,463
	TI, S	173,876	88,148	1,018,560	1,280,585	728,713	172,056	1,167,286	2,068,056	2,629,855	457,449	1,529,077	4,616,381
	SI, T	173,876	87,951	1,023,206	1,285,033	728,713	172,056	1,167,286	2,068,056	2,631,268	453,986	1,531,775	4,617,029
	TSI	153,629	98,721	1,049,350	*1,301,699*	721,211	187,752	1,176,901	*2,085,863*	2,629,855	453,986	1,534,082	*4,617,923*
C 2	T, S, I	174,400	94,653	1,130,390	1,399,443	996,598	222,622	1,318,002	2,537,222	3,701,240	640,196	1,895,658	6,237,094
	TS, I	171,897	105,423	1,133,814	1,411,135	989,096	238,318	1,312,503	*2,539,917*	3,690,502	652,638	1,869,701	6,212,840
	TI, S	174,400	94,653	1,130,390	1,399,443	996,598	222,622	1,318,002	2,537,222	3,699,303	640,196	1,898,820	*6,238,319*
	SI, T	174,400	94,456	1,132,579	1,401,434	996,598	222,622	1,318,002	2,537,222	3,701,240	640,196	1,895,658	6,237,094
	TSI	171,897	105,226	1,136,003	*1,413,126*	989,096	238,318	1,312,503	*2,539,917*	3,699,303	640,196	1,898,820	*6,238,319*
C 3	T, S, I	174,651	97,800	*1,140,591*	1,413,043	1,125,954	247,048	1,359,860	2,732,863	4,217,910	728,459	2,056,987	7,003,356
	TS, I	172,148	108,570	*1,140,591*	*1,421,310*	1,118,452	262,744	1,354,361	*2,735,557*	4,207,172	740,901	2,031,030	6,979,102
	TI, S	174,651	97,800	*1,140,591*	1,413,043	1,125,954	247,048	1,359,860	2,732,863	4,215,723	728,459	2,060,558	*7,004,740*
	SI, T	174,651	97,800	*1,140,591*	1,413,043	1,125,954	247,048	1,359,860	2,732,863	4,217,910	728,459	2,056,987	7,003,356
	TSI	172,148	108,570	*1,140,591*	*1,421,310*	1,118,452	262,744	1,354,361	*2,735,557*	4,215,723	728,459	2,060,558	*7,004,740*

- **In terms of total water withdrawals, Table 6.3 points to constant maximum withdrawals for Iraq under all case of maximum resources availability, and, more generally, little variations in Iraqi withdrawals in all other cases. In contrast, water withdrawals by Turkey declines significantly with an increasing energy price, simply because power generation provides Turkey larger benefits than agriculture. There is a general inverse relationship between total withdrawal and total benefit, in general due to the larger benefits from power generation (and thus larger river flows).**

Table 6.3: Water Withdrawals Under Different Cooperation Scenarios (Mm^3)

	Coalition	Turkey	Syria	Iraq	Total	Turkey	Syria	Iraq	Total	Turkey	Syria	Iraq	Total
		1				2				3			
A 1	T, S, I	16,862	6,399	48,794	72,055	13,093	5,899	51,964	70,955	3,027	5,228	53,727	61,981
	TS, I	16,862	6,399	48,794	72,055	10,163	5,899	54,133	70,195	4,807	5,899	54,132	64,837
	TI, S	16,862	6,399	48,794	72,055	11,313	5,228	51,384	67,925	505	5,228	53,727	59,460
	SI, T	16,862	5,899	49,164	71,925	13,093	5,899	51,964	70,955	3,027	5,228	53,727	61,981
	TSI	16,862	5,899	49,164	71,925	10,163	5,899	54,133	70,195	505	5,228	53,727	59,460
A 2	T, S, I	16,962	6,831	61,374	85,167	13,193	6,331	61,934	81,458	3,127	5,660	61,899	70,686
	TS, I	16,962	6,831	61,374	85,167	10,263	6,331	61,934	78,528	4,907	6,331	61,899	73,137
	TI, S	16,962	6,831	61,374	85,167	11,413	5,660	61,934	79,007	605	5,660	61,899	68,164
	SI, T	16,962	6,331	61,633	84,926	13,193	6,331	61,934	81,458	3,127	5,660	61,899	70,686
	TSI	16,962	6,331	61,633	84,926	10,263	6,331	61,934	78,528	605	5,660	61,899	68,164
A 3	T, S, I	17,010	7,040	62,038	86,088	13,241	6,540	62,038	81,819	3,175	5,869	62,003	71,047
	TS, I	17,010	7,040	62,038	86,088	10,311	6,540	62,038	78,889	4,955	6,540	62,003	73,498
	TI, S	17,010	7,040	62,038	86,088	11,461	5,869	62,038	79,368	653	5,869	62,003	68,525
	SI, T	17,010	7,040	62,038	86,088	13,241	6,540	62,038	81,819	3,175	5,869	62,003	71,047
	TSI	17,010	7,040	62,038	86,088	10,311	6,540	62,038	78,889	653	5,869	62,003	68,525
B 1	T, S, I	16,862	6,399	48,794	72,055	8,383	5,228	53,554	67,164	3,027	5,228	56,038	64,293
	TS, I	16,862	6,399	48,794	72,055	10,163	5,899	54,133	70,195	4,807	5,899	56,618	67,323
	TI, S	16,862	6,399	48,794	72,055	8,383	5,228	53,554	67,164	235	5,228	56,038	61,501
	SI, T	16,862	5,899	49,164	71,925	8,383	5,228	53,554	67,164	3,027	4,428	56,630	64,084
	TSI	16,862	5,899	49,164	71,925	8,309	5,899	55,507	69,714	235	4,428	56,630	61,293
B 2	T, S, I	16,962	6,831	61,374	85,167	8,483	5,660	61,934	76,077	3,127	5,660	61,899	70,686
	TS, I	16,962	6,831	61,374	85,167	10,263	6,331	61,934	78,528	4,907	6,331	61,899	73,137
	TI, S	16,962	6,831	61,374	85,167	8,483	5,660	61,934	76,077	235	5,660	61,899	67,794
	SI, T	16,962	6,331	61,633	84,926	8,483	5,660	61,934	76,077	3,127	5,660	61,899	70,686
	TSI	16,962	6,331	61,633	84,926	10,263	6,331	61,934	78,528	235	5,660	61,899	67,794
B 3	T, S, I	17,010	7,040	62,038	86,088	8,531	5,869	62,038	76,438	3,175	5,869	62,003	71,047
	TS, I	17,010	7,040	62,038	86,088	10,311	6,540	62,038	78,889	4,955	6,540	62,003	73,498
	TI, S	17,010	7,040	62,038	86,088	8,531	5,869	62,038	76,438	235	5,869	62,003	68,107
	SI, T	17,010	7,040	62,038	86,088	8,531	5,869	62,038	76,438	3,175	5,869	62,003	71,047
	TSI	17,010	7,040	62,038	86,088	10,311	6,540	62,038	78,889	235	5,869	62,003	68,107
C 1	T, S, I	15,082	5,728	48,207	69,017	7,629	5,228	53,554	66,410	505	5,228	56,038	61,771
	TS, I	16,862	6,399	48,794	72,055	7,555	5,899	55,507	68,960	2,285	5,899	56,618	64,802
	TI, S	15,082	5,728	48,207	69,017	7,629	5,228	53,554	66,410	235	5,228	56,038	61,501
	SI, T	15,082	5,228	48,585	68,895	7,629	5,228	53,554	66,410	505	4,428	56,630	61,563
	TSI	13,472	5,899	51,675	71,046	7,555	5,899	55,507	68,960	235	4,428	56,630	61,293
C 2	T, S, I	15,182	6,160	60,969	82,311	7,729	5,660	61,934	75,323	605	5,660	61,899	68,164
	TS, I	16,962	6,831	61,374	85,167	7,655	6,331	61,934	75,920	2,385	6,331	61,899	70,615
	TI, S	15,182	6,160	60,969	82,311	7,729	5,660	61,934	75,323	235	5,660	61,899	67,794
	SI, T	15,182	5,660	61,228	82,070	7,729	5,660	61,934	75,323	605	5,660	61,899	68,164
	TSI	16,962	6,331	61,633	84,926	7,655	6,331	61,934	75,920	235	5,660	61,899	67,794
C 3	T, S, I	15,230	6,369	62,038	83,637	7,777	5,869	62,038	75,684	653	5,869	62,003	68,525
	TS, I	17,010	7,040	62,038	86,088	7,703	6,540	62,038	76,281	2,433	6,540	62,003	70,976
	TI, S	15,230	6,369	62,038	83,637	7,777	5,869	62,038	75,684	235	5,869	62,003	68,107
	SI, T	15,230	6,369	62,038	83,637	7,777	5,869	62,038	75,684	653	5,869	62,003	68,525
	TSI	17,010	7,040	62,038	86,088	7,703	6,540	62,038	76,281	235	5,869	62,003	68,107
					1				2				3

Equations (6.72) – (6.74) indicate how the minimum benefits achievable by each country are computed. These minimum benefits are presented in Table 6.4. Figure 6.2 provides a graphical illustration of these benefits and the effects of changing energy prices (EPR), productivities in agricultures (VALAG), and water resource availabilities (TTF). Countries are differentiated by colors (blue for Turkey, yellow for Syria, and red for Iraq). The corresponding water withdrawals are presented in Table 6.5 and are illustrated in Figure 6.3 using the same colors as in Figure 6.2, but with some country bars represented by frames in order to improve image readability.

The following observations can be made:

- Table 6.4 shows that Syria's minimum benefits are the same (1) under cases A and B when EPR=$0 (no effect of Turkey's agricultural productivity), (2) under cases B and C when EPR=$25 (no effect of Iraq's agricultural productivity), and (3) under cases A, B, and C when EPR=$100 (no effect of any productivity change). Correspondingly, in Table 6.5, water withdrawals display similar patterns, albeit slightly extended: Syrian withdrawals do not vary across cases A, B, and C when EPR=$25 and EPR=$100. Additionally, both Turkey and Iraq display no withdrawal differences under cases A and B when EPR=$0. In the third column (EPR=$100), Turkey displays no withdrawal variations in cases A and B, and Iraq does the same in cases B and C. However, water withdrawals in Turkey decline significantly in case C13 – C33, pointing to a substitution of energy benefits for agricultural benefits.
- As it suggested by Table 6.4 and Figure 6.2, Iraq is the country getting benefits from water withdrawals, and Turkey is the country taking advantage of higher energy prices. The position of Syria is in-between and relatively stable in terms of benefits and water withdrawals. Furthermore, the agricultural productivity differences have a stronger impact on Iraq than on Turkey in terms of benefits.

Table 6.4: Minimum Country Benefits ($1000)

Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq
A11	254,509	98,918	784,656	**A12**	775,635	164,937	889,146	**A13**	2,642,012	457,449	1,206,183
A21	255,532	105,423	830,594	**A22**	1,044,020	215,502	1,002,314	**A23**	3,712,484	640,196	1,542,133
A31	256,024	108,570	834,049	**A32**	1,173,617	239,928	1,043,653	**A33**	4,229,395	728,459	1,702,942
B11	212,941	98,918	904,815	**B12**	749,007	172,056	1,030,162	**B13**	2,635,033	457,449	1,342,690
B21	213,715	105,423	982,204	**B22**	1,017,142	222,622	1,156,891	**B23**	3,705,255	640,196	1,695,145
B31	214,086	108,570	987,320	**B32**	1,146,619	247,048	1,198,489	**B33**	4,222,046	728,459	1,856,213
C11	173,876	88,148	1,018,560	**C12**	728,713	172,056	1,167,286	**C13**	2,631,268	457,449	1,504,043
C21	174,400	94,653	1,130,390	**C22**	996,598	222,622	1,312,503	**C23**	3,701,240	640,196	1,869,701
C31	174,651	97,800	1,140,591	**C32**	1,125,954	247,048	1,354,361	**C33**	4,217,910	728,459	2,031,030

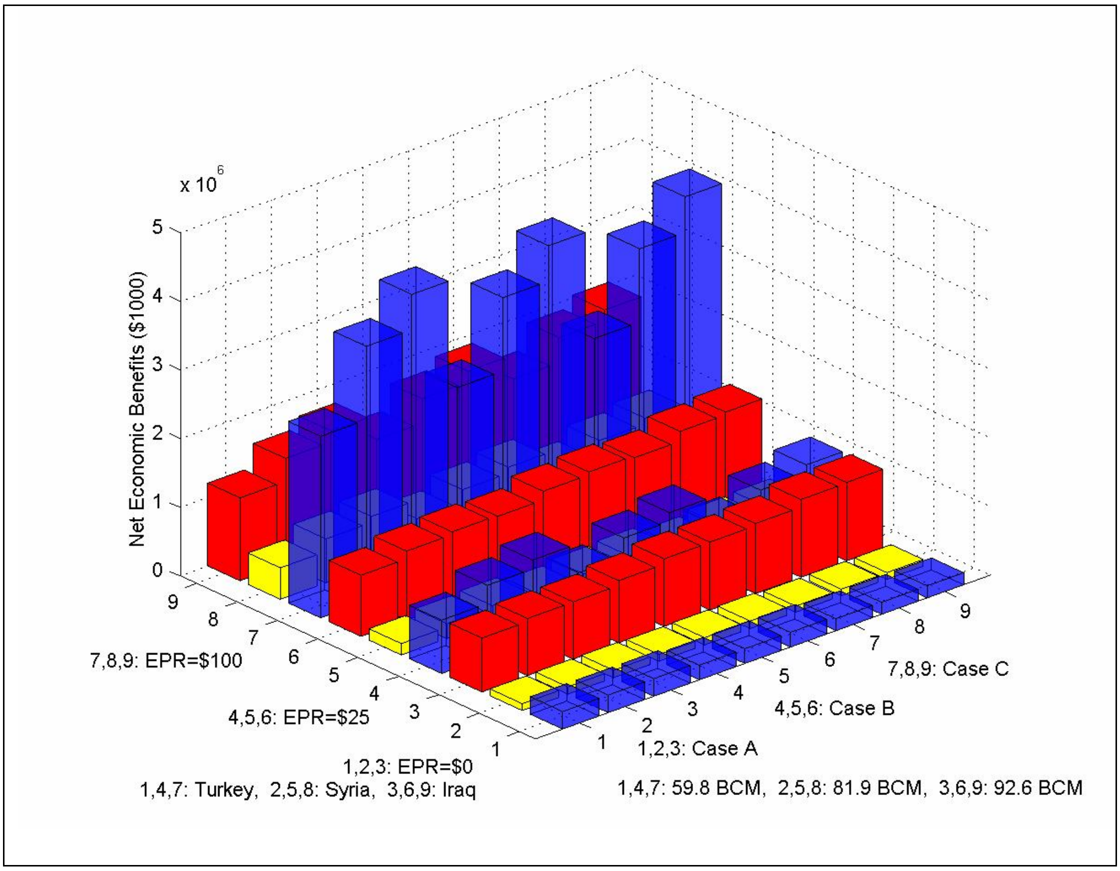


Figure 6.2: Minimum Country Benefits

Table 6.5: Water Withdrawals Corresponding to Minimum Country Benefits (Mm^3)

Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq
A11	16,862	6,399	48,794	**A12**	13,093	5,228	51,964	**A13**	3,027	5,228	54,132
A21	16,962	6,831	61,374	**A22**	13,193	5,660	61,934	**A23**	3,127	5,660	61,899
A31	17,010	7,040	62,038	**A32**	13,241	5,869	62,038	**A33**	3,175	5,869	62,003
B11	16,862	6,399	48,794	**B12**	8,383	5,228	54,133	**B13**	3,027	5,228	56,618
B21	16,962	6,831	61,374	**B22**	8,483	5,660	61,934	**B23**	3,127	5,660	61,899
B31	17,010	7,040	62,038	**B32**	8,531	5,869	62,038	**B33**	3,175	5,869	62,003
C11	15,082	5,728	48,207	**C12**	7,629	5,228	55,507	**C13**	505	5,228	56,618
C21	15,182	6,160	60,969	**C22**	7,729	5,660	61,934	**C23**	605	5,660	61,899
C31	15,230	6,369	62,038	**C32**	7,777	5,869	62,038	**C33**	653	5,869	62,003

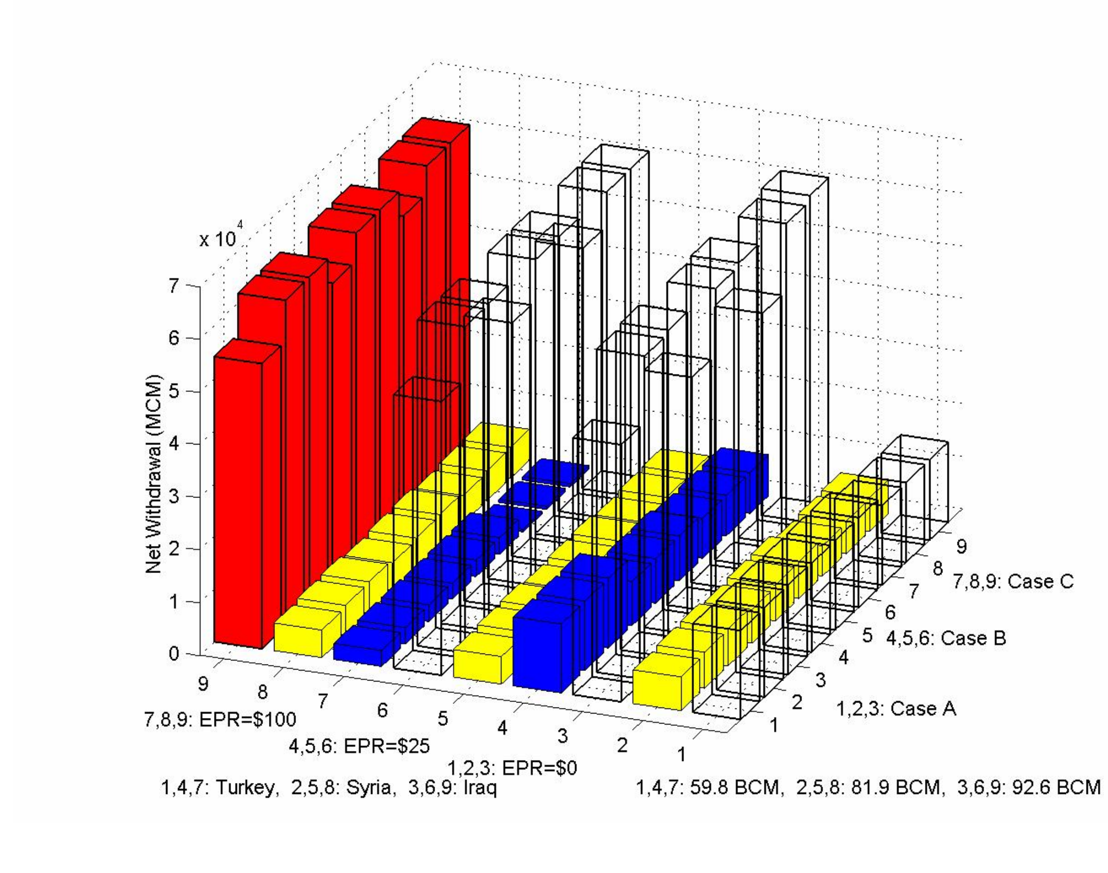


Figure 6.3: Water Withdrawals Corresponding to Minimum Country Benefits

6.2.2. Core Analyses and Shapley Allocations

This section presents the results obtained by (1) solving the linear program (6.71) – (6.78) and (2) applying the Shapley formula [see Equations (6.79) – (6.82)]. For each of the 27 different parameter scenarios, we first find out whether the core exists, and, if it does, whether it is reduced to a unique allocation. If it does not, we measure the minimum subsidy needed to create a core. Finally, we check whether the Shapley allocations are in the core. Tables 6.6 - 6.11 present the results.

In Table 6.6 the highlighted cells indicate the cases where there is no core. Out of the 27 cases, 6 have no core (B22, B32, C22, C32, C23, C33), 12 have a single-allocation core, and 9 have a multiple-allocation core (i.e., there is an infinite number of allocations in the core). A core always exists under (1) EPR=$0, and (2) agricultural productivity case A (Turkey is more productive). Most of the non-core cases take place when Iraq is more productive (case C), when EPR=$25 or $100, and when resources are more abundant. This is not surprising, as countries, under such conditions, can form subcoalitions that provide them strong benefits from both energy and agriculture, making it impossible to find an allocation sufficiently attractive to induce them to participate in the grand coalition.

Table 6.7 presents the optimal values of the Z variable in the linear program (6.71) – (6.78). Positive Z values characterize multiple-allocation cores, and present the maximum extractable taxes leading to a residual single-allocation core. Negative Z values characterize non-existing core, and represent the minimum subsidies that would have to be added to the grand coalition benefits to create a single-allocation core. Finally, zero Z values characterize single-allocation cores. Table 6.7 shows that positive Z values vary between 0.00% and 0.99% of the grand coalition benefits, whereas negative Z values vary between 0.00% and 0.06% of these benefits.

Table 6.6 also indicates whether the Shapley allocation is in the core or not. When energy is not a factor (EPR=$0), all Shapley allocations are in the core. On the other hand, in the third column (EPR=$100) none of the Shapley allocations are in core. This is so because, under high energy prices, the Shapley method assigns more power to Turkey and Syria, and less to Iraq, hence assigns more benefits to Turkey and Syria and less benefits to Iraq, thus putting the allocation out of the core.

Table 6.6: Core Analysis Summary[4]

	Core Existence	Single or Multiple Core	Shapley in or out of the Core		Core Existence	Single or Multiple Core	Shapley in or out of the Core		Core Existence	Single or Multiple Core	Shapley in or out of the Core
A11	YES	Single	IN	A12	YES	Multiple	IN	A13	YES	Single	NOT IN
A21	YES	Single	IN	A22	YES	Multiple	NOT IN	A23	YES	Single	NOT IN
A31	YES	Single	IN	A32	YES	Multiple	NOT IN	A33	YES	Single	NOT IN
B11	YES	Single	IN	B12	YES	Multiple	IN	B13	YES	Multiple	NOT IN
B21	YES	Single	IN	B22	NO			B23	YES	Single	NOT IN
B31	YES	Single	IN	B32	NO			B33	YES	Single	NOT IN
C11	YES	Multiple	IN	C12	YES	Multiple	IN	C13	YES	Multiple	NOT IN
C21	YES	Multiple	IN	C22	NO			C23	NO		
C31	YES	Single	IN	C32	NO			C33	NO		

The highlighted areas show the cases without a core.

Table 6.7: Core Analyses: Taxes versus Subsidies (in Parenthesis) and their Percentages of the Grand Coalition Benefits ($1000)

Scenario	Tax/Subsidy Z	Z/B (%)	Grand Coalition Benefit (B)	Scenario	Tax/Subsidy Z	Z/B (%)	Grand Coalition Benefit (B)	Scenario	Tax/Subsidy Z	Z/B (%)	Grand Coalition Benefit (B)
A11	0	0.00	1,139,167	A12	7,507	0.40	1,853,611	A13	0	0.00	4,343,187
A21	0	0.00	1,192,248	A22	1,565	0.07	2,279,789	A23	0	0.00	5,932,922
A31	0	0.00	1,198,643	A32	1,565	0.06	2,475,149	A33	0	0.00	6,698,904
B11	0	0.00	1,218,684	B12	5,118	0.26	1,967,419	B13	63	0.00	4,478,085
B21	0	0.00	1,302,687	B22	(951)	-0.04	2,407,731	B23	0	0.00	6,085,308
B31	0	0.00	1,309,976	B32	(951)	-0.04	2,603,232	B33	0	0.00	6,851,469
C11	12,847	0.99	1,301,699	C12	9,614	0.46	2,085,863	C13	366	0.01	4,617,923
C21	5,416	0.38	1,413,126	C22	(1,402)	-0.06	2,539,917	C23	(239)	0.00	6,238,319
C31	0	0.00	1,421,310	C32	(1,402)	-0.05	2,735,557	C33	(160)	0.00	7,004,740

Table 6.8 presents the allocations corresponding to (1) the minimum country benefits (Table 6.4), (2) the single core solution (possibly with subsidies), and (3) the Shapley method. The following three tables (6.9, 6.10, and 6.11) present the differences between the three pairs of benefit allocations (Table 6.9 for the differences between the single core allocations and the minimum country benefits; Table 6.10 for the differences between the minimum country benefits and the Shapley allocations; and Table 6.11 for the differences between the Shapley and the single core allocations). These results are converted into bar charts in Figure 6.4, in which Turkey, Syria, and Iraq are represented with blue, yellow, and red colors, respectively. Each group of bars encompasses, from left to right, the impacts of increasing energy prices on the three countries (e.g. A11, A12, and A13).

Tables 6.9, and 6.10 point to the incremental benefits derived by each country joining the grand coalition or accepting the Shapley allocation, respectively, over the minimum benefits derived from individual action. These benefits are further illustrated in Figures 6.4.a and 6.4.b, where the length of the bars measures the magnitude of the country incremental benefit. It is clear that Iraq is the major beneficiary of these

allocations when the energy price is highest (EPR=$100), with Turkey as a significant secondary beneficiary when Turkey's agricultural productivity is also highest (case A). However, Turkey's incremental benefits are strongly reduced under Iraq's strong agricultural productivity (case C). The incremental benefits to Syria are strong when all productivities are equal (case B) and EPR=$25.

Tables 6.11 and Figure 6.4.c shows that Iraq is always negatively affected under the Shapley allocation under high energy prices (EPR=$100), whereas Turkey generally benefits from the Shapley allocation, which reflects the power of its upstream position. Syria benefits from the Shapley allocation at higher energy prices (EPR=$100).

Table 6.8: Minimum Benefit, Core, Shapley, and Tax Allocations ($1000)

	Allocation	Turkey	Syria	Iraq	Turkey	Syria	Iraq	Turkey	Syria	Iraq
			1			2			3	
A1	Minimum	254,509	98,918	784,656	775,635	164,937	889,146	2,642,012	457,449	1,206,183
	Core	254,509	100,002	784,656	776,199	180,759	889,146	2,652,616	457,449	1,233,123
	Shapley	254,509	99,460	785,198	782,695	177,309	893,607	2,654,087	463,448	1,225,652
	Z	0	0	0	3,170	718	3,619	0	0	0
A2	Minimum	255,532	105,423	830,594	1,044,020	215,502	1,002,314	3,712,484	640,196	1,542,133
	Core	255,532	106,121	830,594	1,046,172	229,738	1,002,314	3,723,087	640,196	1,569,638
	Shapley	255,532	105,772	830,943	1,049,365	225,365	1,005,059	3,724,653	646,290	1,561,979
	Z	0	0	0	720	155	690	0	0	0
A3	Minimum	256,024	108,570	834,049	1,173,617	239,928	1,043,653	4,229,395	728,459	1,702,942
	Core	256,024	108,570	834,049	1,175,768	254,164	1,043,653	4,239,998	728,459	1,730,447
	Shapley	256,024	108,570	834,049	1,178,961	249,791	1,046,398	4,241,564	734,552	1,722,788
	Z	0	0	0	745	158	662	0	0	0
B1	Minimum	212,941	98,918	904,815	749,007	172,056	1,030,162	2,635,033	457,449	1,342,690
	Core	212,941	100,928	904,815	752,461	179,678	1,030,162	2,641,187	457,449	1,379,386
	Shapley	212,941	99,923	905,820	755,675	178,725	1,033,019	2,649,425	462,535	1,366,125
	Z	0	0	0	1,966	465	2,687	37	6	19
B2	Minimum	213,715	105,423	982,204	1,017,142	222,622	1,156,891	3,705,255	640,196	1,695,145
	Core	213,715	106,768	982,204	1,022,680	228,160	1,157,842	3,711,408	640,196	1,733,703
	Shapley	213,715	106,096	982,877	1,021,599	227,079	1,159,054	3,719,984	645,548	1,719,776
	Z	0	0	0				0	0	0
B3	Minimum	214,086	108,570	987,320	1,146,619	247,048	1,198,489	4,222,046	728,459	1,856,213
	Core	214,086	108,570	987,320	1,152,157	252,586	1,199,440	4,228,199	728,459	1,894,810
	Shapley	214,086	108,570	987,320	1,151,075	251,505	1,200,652	4,236,794	733,811	1,880,864
	Z	0	0	0				0	0	0
C1	Minimum	173,876	88,148	1,018,560	728,713	172,056	1,167,286	2,631,268	457,449	1,504,043
	Core	177,695	92,596	1,018,560	728,713	180,250	1,167,286	2,631,796	458,625	1,527,137
	Shapley	180,810	97,305	1,023,584	736,014	179,358	1,170,491	2,635,787	462,291	1,519,845
	Z	1,785	960	10,103	3,392	827	5,395	209	37	120
C2	Minimum	174,400	94,653	1,130,390	996,598	222,622	1,312,503	3,701,240	640,196	1,869,701
	Core	180,675	96,645	1,130,390	1,000,695	226,719	1,313,905	3,702,704	640,436	1,895,419
	Shapley	179,675	100,924	1,132,527	999,778	225,802	1,314,336	3,706,462	644,807	1,887,050
	Z	689	387	4,341						
C3	Minimum	174,651	97,800	1,140,591	1,125,954	247,048	1,354,361	4,217,910	728,459	2,031,030
	Core	174,651	106,067	1,140,591	1,130,051	251,145	1,355,764	4,219,454	728,619	2,056,827
	Shapley	178,785	101,934	1,140,591	1,129,135	250,228	1,356,194	4,223,212	733,069	2,048,458
	Z	0	0	0						

Z shows the allocation of the tax, using as weights the Shapley values, and provides additional

country benefits, which may be added to the core allocations.

Table 6.9: Core Allocations Minus Minimum Country Benefits ($1000)

Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq
A11	0	1,084	0	**A12**	565	15,822	0	**A13**	10,604	0	26,940
A21	0	698	0	**A22**	2,151	14,236	0	**A23**	10,603	0	27,505
A31	0	0	0	**A32**	2,151	14,236	0	**A33**	10,603	0	27,505
B11	0	2,010	0	**B12**	3,454	7,622	0	**B13**	6,154	0	36,696
B21	0	1,345	0	**B22**	5,538	5,538	951	**B23**	6,153	0	38,558
B31	0	0	0	**B32**	5,538	5,538	951	**B33**	6,153	0	38,597
C11	3,819	4,448	0	**C12**	0	8,193	0	**C13**	528	1,176	23,094
C21	6,275	1,992	0	**C22**	4,097	4,097	1,402	**C23**	1,464	239	25,718
C31	0	8,267	0	**C32**	4,097	4,097	1,402	**C33**	1,544	160	25,798

The highlighted area shows where the side payments go.

Table 6.10: Shapley Allocations Minus Minimum Country Benefits ($1000)

Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq
A11	0	542	542	**A12**	7,060	12,372	4,461	**A13**	12,075	5,999	19,469
A21	0	349	349	**A22**	5,344	9,863	2,745	**A23**	12,169	6,093	19,846
A31	0	0	0	**A32**	5,344	9,863	2,745	**A33**	12,169	6,094	19,846
B11	0	1,005	1,005	**B12**	6,668	6,668	2,858	**B13**	14,392	5,086	23,434
B21	0	672	672	**B22**	4,457	4,456	2,163	**B23**	14,729	5,352	24,631
B31	0	0	0	**B32**	4,456	4,456	2,163	**B33**	14,748	5,352	24,650
C11	6,933	9,157	5,024	**C12**	7,301	7,301	3,205	**C13**	4,519	4,843	15,802
C21	5,275	6,271	2,137	**C22**	3,180	3,180	1,833	**C23**	5,223	4,610	17,350
C31	4,133	4,133	0	**C32**	3,180	3,180	1,833	**C33**	5,302	4,610	17,429

Table 6.11: Shapley Allocations Minus Core Allocations ($1000)

Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq
A11	0	(542)	542	**A12**	6,496	(3,450)	4,461	**A13**	1,471	5,999	(7,471)
A21	0	(349)	349	**A22**	3,193	(4,373)	2,745	**A23**	1,565	6,093	(7,659)
A31	0	0	0	**A32**	3,193	(4,373)	2,745	**A33**	1,565	6,094	(7,659)
B11	0	(1,005)	1,005	**B12**	3,214	(954)	2,858	**B13**	8,238	5,086	(13,262)
B21	0	(672)	672	**B22**	(1,082)	(1,082)	1,212	**B23**	8,576	5,352	(13,927)
B31	0	0	0	**B32**	(1,082)	(1,082)	1,212	**B33**	8,595	5,352	(13,947)
C11	3,115	4,709	5,024	**C12**	7,301	(892)	3,205	**C13**	3,991	3,667	(7,292)
C21	(1,000)	4,279	2,137	**C22**	(916)	(916)	431	**C23**	3,758	4,371	(8,369)
C31	4,133	(4,133)	0	**C32**	(916)	(916)	431	**C33**	3,758	4,450	(8,369)

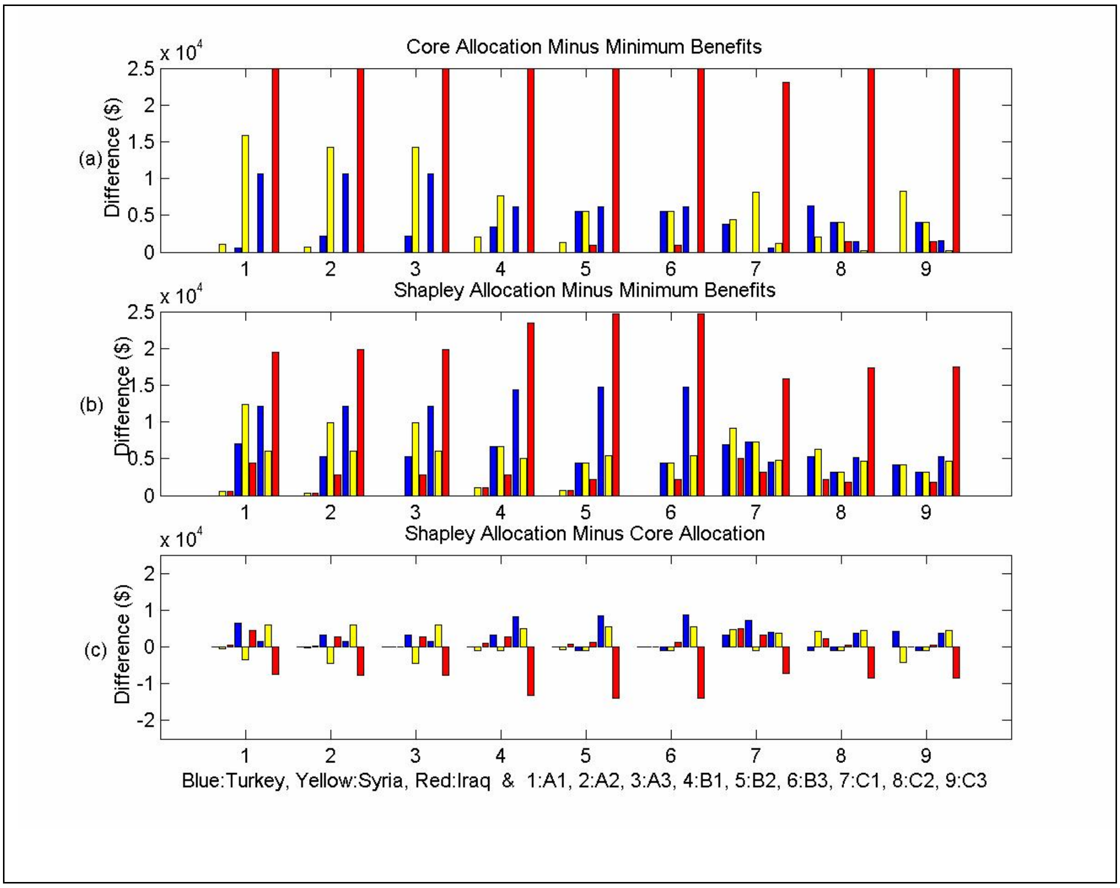


Figure 6.4: Differences Between Shapley, Core, and Minimum Benefits

6.3. Summary

The primary focus of this chapter has been to asses whether it is possible to find a distribution of the total ETRBM benefits to the three riparian countries – Turkey, Syria, and Iraq – that will provide them incentives to join the water allocation plan that provides the maximum aggregate benefits. This assessment has required an in-depth analysis of the decision-making processes of the three countries and any of their coalitions, through extensive adaptations of the ETRBM. Using concepts and methods of cooperative game theory, we find that, out of the 27 parameter scenarios considered, 21 were characterized by a non-empty core, where such cooperation can be rationally induced. The 6 empty-

core cases can be transformed into core cases with a small subsidy, at most 0.06% of the total joint benefit. These cases correspond to high energy prices and high Iraqi agricultural productivity. In these cases, subcoalitions become very attractive, and it becomes impossible to find and acceptable allocation achieving the grand coalition. The Shapley allocation, which is based on the incremental economic power of the participants, also reflects these energy and agricultural productivity effects.

NOTES

[1] **A $0 MWh energy price is considered to analyze optimal withdrawals when energy production is not relevant, that is, when it does not compete with agricultural and urban uses.**

[2] **Subsets for Demand and Supply Nodes by Countries:**
ta(i) = tea(i) + tta(i); tu(i) = teu(i) + ttu(i); sa(i) = sea(i); su(i) = seu(i); ia(i) = iea(i) + ita(i); iu(i) = ieu(i) + itu(i);
dt(i) = tea(i) + teu(i) + tta(i) + ttu(i); ds(i) = sea(i) + seu(i); di(i) = iea(i) + ieu(i) + ita(i) + itu(i);
st(j) = te(j) + tt(j); ss(j) = se(j); si(j) = ie(j) + it(j);
snt(j)= ss(j) + si(j); sns(j)= st(j) + si(j); sni(j)= st(j) + ss(j).

[3] **While we cannot prove that a Nash equilibrium always exists, in most of the 27 considered scenarios such an equilibrium was reached in at most 3 iterations; but there were two cases where the equilibrium was reached in 8 iterations.**

[4] **In the scenarios where there is no core solution, verifying whether Shapley values are in the core is irrelevant.**

CHAPTER 7

CONCLUSION

The Middle East as a place of confluence of different ethnic and religious groups has been the cradle of civilization. On the other hand, the region has also been the place of invasions and internals conflicts. Since the beginning of the 20^{th} century, the region has been facing all forms of conflicts, due not only to differences of ethnicity and religion, but also to natural resources, such as agricultural land and petroleum. Towards the end of the century, this pattern has been complicated by the increasing population, and thus increasing demand for water resources. The new item in the conflict list is the allocation of scarce water resources.

With technological improvements to control the Euphrates and the Tigris rivers, countries have started to engage into ambitious projects throughout the basin. Towards the second half of the century, Turkey has become the latest participant to develop these resources in the upstream basin, sparkling the debate on water resource allocation among the three riparian countries, Turkey, Syria and Iraq. The fact that the reservoir filling periods in Turkey coincided with drought years causing shortages of water in the downstream countries, exacerbated the disputes and raised fears of an armed confrontation. Although these disputes have never resulted in a direct war, they brought about extensive tensions among the parties.

The Euphrates and Tigris River Basin Model (ETRBM), developed in this dissertation, thus originates from a real world dispute. Its goal is to build a methodological backbone to analyze countries choices and impacts on each other.

The ETRBM not only unifies structurally the three-country resources, but also combines the two separate river basin into one system, using interbasin links. Furthermore, the ETRBM provides a mode of communication, to the parties in the basin, but also in the region out of basin.

The major contribution of this dissertation is first the development of the ETRBM as a backbone model, and, second, the illustration of its application, using the best available data. The applications are related to (1) the sensitivity of the water allocation benefits to the model parameters, and (2) the analyses of the relative positions and powers of the riparian countries and of whether there are natural core allocation solutions.

In the sensitivity analyses, it has been found that the most important parameters in the basin are the energy price (EPR) and the agricultural water use value (VALAG), followed by the water delivery cost to agricultural districts (AGRTC). As expected, AGRTC has a strong impact on the demand nodes farther away from the supply nodes. In the case of overall system optimization, the model shows that upstream withdrawals are more expensive than downstream withdrawals, due to the opportunity cost of energy generation. In other words, in a unified river basin system, upstream withdrawals are seen as a loss for the overall system. It is observed that, in Turkey and Syria, energy is a substitute for agriculture: a higher energy price leads to more water release from upstream to downstream, so as to take advantage of high elevations, and this results in more water resources available downstream for agriculture and urban uses. Similarly, in terms of the elasticity of the country benefits, Turkey's benefit is found to be more elastic to energy prices, whereas Iraqi and Syrian benefits are more elastic to the value of water in agricultural use. The model also shows that urban withdrawals provide the highest per unit benefits. Therefore, there is little variation in urban withdrawals with changing parameters. With regard to interbasin water transfer links, the sensitivity analyses suggest that an upstream link between Turkey and Syria provides more benefits than the downstream interbasin links within the borders of Iraq.

The model is also applied to demonstrate the relative positions and powers of the riparian countries and whether there are natural core allocation solutions. Countries powers are analyzed by laying out individual and coalition strategies. It has been shown that, in any coalition alternative, Turkey is the best country to make a coalition with. Iraq is also a beneficiary of any coalition. The system shows that staying out of a two-country coalition results in lost benefit. The benefits derived from the various individual and coalition strategies are used in a linear programming model to determine the existence of a core under 27 alternative parameter scenarios. It is shown that a core exists in 21 cases. In the 6 cases where there is no core, a very small subsidy added to the grand coalition benefits can be used to create a core. In addition to the core analysis, the Shapley allocation, that reflects the power of the participants, has also been calculated, and compared to core and minimum benefit allocations. Iraq turns out to be the strongest beneficiary of the core allocation

Future research in this area focus on the following:

- More details for the demand nodes, by selecting smaller sized demand nodes in order to differentiated the subportions of large irrigation districts;
- Inclusion of projected future water demands resulting from population growth and economic development;
- Incorporation of different agricultural products configurations, such as annual multiple-crops in the same agricultural districts. Similarly, urban areas can be differentiated with respect to distinct economic activities that require water;
- Incorporation of spatially identified groundwater resources;
- Multi-period river basin analyses, including (1) multi-year and (2) multi-season, and incorporation of reservoir capacities to even out water demand within the year and over multiple years;

- **Analyses of water exports from the basin and their, potential impacts on other riparian countries;**
- **Environmental issues, such as salinization, drainage, and the Gulf area sea water intrusion, will be introduced into the model;**
- **Evaluation of impacts of important projects (e.g., Urfa Tunnels) and government programs such as agricultural and urban water uses subsidies.**

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