Modeling Water Management Options for the Tigris–Euphrates Rivershed

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Abstract: Political instability of several countries in the Middle East is overshadowing one of the biggest challenges of the upcoming century: Water - a natural resource that is easily taken for granted, but whose scarcity might lead to serious conflicts. This paper investigates an optimal **W**ater **A**llocation of the **T**igris and **E**uphrates **R**ivershed by introducing the **WATER-Model**. A series of scenarios are analyzed to examine the effects of different levels of cooperation. Basin-wide coordinated water usage becomes even more important in times of water shortages which can be caused by a drought or by the filling of a dam.
Data analysis shows that Turkey is most efficient in its water usage. However, water usage for irrigation purposes in Turkey rather than for the domestic and industrial sectors of Iraq or Syria, decreases the overall welfare. The predicted water demand growth in the region will only increase this effect. Especially the Euphrates basin might thus encounter losses of up to 33% due to such non-cooperation. Minimum flow treaties between riparian countries, however, can help increase the region's overall welfare and should therefore be implemented.

Key–Words: Integrated Water Resources Management, Euphrates Tigris rivershed, non linear modeling, transboundary water resources allocation, river basins, Turkey, Syria, Iraq

1 Introduction

Many disputes in the Middle East have been triggered by conflicts over petroleum resources, but in the coming decades a more critical natural resource conflict will arise: The conflict over water. This paper deals with the problematic of a fair distribution of water in the Tigris-Euphrates (TE) Watershed. The TE-Watershed is located inside the former Ottoman Empire. It is now divided between the territories of Turkey, Syria, and Iraq, which are in the upper-, mid- and downstream positions, respectively. [27] Water management in the three riparian states was harmonized until the first half of the 20th century [3]. At the beginning of the 1960s, all riparian states announced individual plans to use water from the rivers for energy and irrigation purposes. The legal regime currently in place is the "Treaty of Friendship and Neighborly Relation" between Iraq and Turkey, which was signed in 1946. It states that Turkey should consult with Iraq on the building of any upstream projects, and make adjustments to satisfy both nations' water needs. [15] This treaty is theoretically still in force, but falls short of providing a legal regime to govern water sharing in the basin. It excludes Syria and does not specify how the terms of "consultation" are defined and adjudicated. [13, 15]
Due to its superior geographical position, large contribution to total runoff, and its economic as well as military power, Turkey is in a position to make hegemonic claims vis-Ã -vis its downstream neighbors [13]. [41] observed a three-fold increase of summer irrigated cropland acreage in the Turkish Harran Plain between 1993 and 2002. This effect is going to increase as Turkey initiated the Southeastern Anatolia Development Project (GAP) to develop land and water resources. It covers the construction of 22 dams and 19 hydro-power plants to irrigate an additional 1.7 million ha and install 7.5 GW of generation capacity. The GAP project shall employ additional an 3.8 million people and increase the per capita income by 209 percent in the Turkish upstream area of the Tigris and Euphrates rivers once it is finished [18, 19]. [1], however, state that the implementation of all water projects in the basin would require divertable water volumes that exceed the average annual runoff of both rivers by about 50 percent.

Syria and Iraq therefore claim additional runoff amounts from Turkey. They accuse Turkey for not abiding to international conventions on water sharing and use, such as the "UN Convention on the Law of Non-Navigable Uses of International Watercourses". Scientists and politicians claim that the construction of Turkish dams has already caused a significant change in the water flow of the Euphrates, and also to a lesser extent in the Tigris [43]. This change has come in terms of quality (e.g. higher water salinity and pollution) as well as quantity [10, 15, 30]. [42] state that the water salinity of the Euphrates River, when entering Iraq from Syria, has more than doubled since 1973. In addition, Iraq is trying to compensate the decreasing inflows by diverting flows from the Al Tharthar Lake and irrigation return flows into the Euphrates. This also leads to a further increase in water salination. These values have increased from 1,080 ppm in 1979 to more than 4,500 ppm in 2001 in the downstream regions of the Euphrates at Al Nassiriah. This major threat to the environment and the agriculture will probably worsen with a full implementation of the GAP project. Some studies also predict that global climate change might lead to a longer and hotter dry period, increasing the overall problem of water scarcity in the region [8, 17, 47].
The aim of the two downstream countries is to invert the situation of power asymmetry in the basin through political and diplomatic actions. Syria has blocked international investments in GAP, which diminished Turkey's ability to obtain external funding [53]. Due to this, the implementation of Turkey's water utilization projects was delayed, but the country's economic boom allowed Turkey to turn to domestic financing sources to meet parts of its financial needs. [13, 26, 29, 44] Another opportunity for the downstream countries lies in joint agreements on water and non-water related issues. The protocol on "Matters Pertaining to Cooperation" is one of those; it was signed in 1987 by Turkey and Syria. It guarantees a minimum flow of the Euphrates from Turkey to Syria in exchange for cooperation on border issues, which ranges from smuggling to infiltration into Turkey by separatist groups. [15] Syria also signed an agreement with Iraq in 1990. It guarantees that at least 58 percent of the Euphrates, reaching Syria at its northern border, is passed on to Iraq. [13] Turkey and Syria signed two framework cooperation agreements in 2003 and 2004, which contain arrangements about water conservation in agricultural practice as well as efforts to combat waterborne diseases. [26] The memorandum of understanding was signed in 2009 between Syria and Turkey as well as between Turkey and Iraq, which covers issues such as information exchange, water utilization, hydro power, drought, and water quality. [13, 26] However, despite these bilateral agreements, no trilateral agreement exists, especially with respect to future development along the rivers [53].
This paper analyses welfare losses due to non-cooperative behaviors of countries. It introduces the **WATER-Model** which calculates an optimal **W**ater **A**llocation of the **T**igris and **E**uphrates **R**ivershed. Additional scenario runs furthermore calculate the effects of a water shortage, the completion of the GAP project, as well as the predicted increase of the water demand till 2030. Results point out that a sustainable joint usage of the Tigris Euphrates basin in fact does increase the overall welfare. Non-cooperative behaviour, on the other hand, might cause welfare reductions of up to -33 percent in the Euphrates, and to a lower extent also in the Tigris.
This introduction is followed by a literature overview concentrating on existing river basin models in the Tigris-Euphrates Rivershed. The third chapter is dedicated to an extensive description of the WATER-Model and its mathematical formulation. Additional, more detailed information about the used data sets as well as result tables can be found in [39]. Chapter four describes the scenarios. The results of all model runs are analyzed and interpreted in the fifth chapter before finishing with an overall conclusion in chapter six.

2 Literature Overview

There is a wide range of publications that deal with international relations, hydro politics or international water law issues in the TE-Watershed. [25] analyze the evolution of transboundary water relations over four phases, beginning with the nation building in the region until the phase in which the reorientation of water policies from hostile to cooperative became significant. [16] explores the transnational arrangements between Turkey, Syria and Iraq for the allocation of river resources. The author identifies potential conflicts as well as the role international law can play in resolving them. [50] evaluates Turkey's hegemony on its hydraulic control and security strategy. He argues that Turkey's regional hegemony is constrained and contested from different sides, e.g. due to its need to access capital in the international market in order to realize its ambitious infrastructure plans. In a latter publication, [49] describes the factors that opened up space for the GAP project.
There is a multitude of publications concentrating on different techniques for modeling river basins. In this field, optimization models sometimes combined with

techniques from cooperative game theory are often used to answer the respective research questions [23]. A review about these kind of literature is given by [14] while [7] as well as [22] write about hydro-economic modeling in general. Another approach by [2] uses an agent-based model.

Other recent studies have focused on allocation strategies in various river basins, such as the Nile river basin [12, 20, 52], the Upper Ewaso Ngiro basin in Kenya [38], the Rio Grande basin [48], the Mekong basin [37] or the Maipo River basin in Chile [9]. The following literature review, however, concentrates on different models analysing the TE-Watershed. [21] uses non-cooperative game theory to model Turkish-Syrian interactions regarding terrorism and water. A unique equilibrium stipulates the condition for cooperation between both upstream countries. Iraq benefits from Turkish-Syrian concessions, but is in a limited position of authority due to its downstream position. [11] developed a hydrological model focusing on socio-economic and environmental aspects. Their emphasis is to build a tool for future studies of marsh reflooding and restoration, including health care for the marsh population. The model itself, however, mainly concentrates on Iraq and lacks sufficient data input in the upstream region. [35] program the "Euphrates and Tigris River Basin Model" (ETRBM), which is a linear programming model for maximizing net economic benefits in the TE-Watershed. A later version of it is the Inter-Temporal Euphrates and Tigris River Basin Model (ITETRBM), focusing on the potential political and economic impacts of reservoirs from an inter-temporal perspective [32, 34]. They conclude that basin-wide coalitions can work as substitute for the construction of further costly reservoirs and should therefore be fostered. In [33] the authors combine game theory and a fuzzy modeling approach to also deal with linguistic data in the basin. Another approach with the integration of both game theory and Pareto Frontier concepts is done in [31]. [46] present a methodology based on stochastic dual dynamic programming for analyzing trade-offs under hydrological uncertainty. This methodology is applied to the GAP project. Simulation results show that the completion of all irrigation projects would reduce the total energy output significantly and increase the risk of not meeting minimal outflows to Syria. A subsequent publication presents a stochastic programming approach for assessing the distribution of marginal water values in a cascade of hydroelectric-irrigation reservoirs in the Euphrates in Turkey and Syria [45]. [40] use a simulation model for groundwater flows. They show how enhanced cooperation between Turkey and Syria could impact the Ceylanpinar aquifer which flows beneath both countries.

The following section presents a non-linear welfare maximizing model to optimize the "**W**ater **A**llocation of the **T**igris and **E**uphrates **R**ivershed" - also known as WATER-Model. In contrast to the models presented above, this model is used to analyse not only present but also future water demands: Several scenarios include the completion of the GAP project as well as further irrigation projects in Syria and Iraq. Additionally, population growth until 2030 is included in the calculations. Other scenarios analyze the effects of an abrupt reduction of water volumes on the Euphrates river, caused either by a drought or by the filling of a dam. Different model settings enable the analysis of cooperative as well as non-cooperative behaviours of the different countries. This is done by switching from a central planner's perspective into a sequential three-player set-up. A third approach alters the latter by including minimum water flow treaties between neighboring countries. The model covers the entire Euphrates Tigris basin with its riparian neighbors Turkey, Syria, and Iraq. Since the model is also scalable, it can focus on specific regions for additional scenario insights, if needed.

3 Model Formulation

3.1 Network Illustration

The WATER-model consists of two periods, both lasting for six months. January through June can be identified as rainy period, whereas only little rainfall can be seen in the dry period from July through December. The storage option in the included dams and reservoirs enables the model to simulate water storage for upcoming dryer periods and thus still satisfy all minimal demands. Other water in- and outflows depend on tributary inflows, evaporation losses, and backflows from upstream demand centers. Several off-stream usages have been modeled to differentiate between the agricultural, domestic and industrial sectors.

The WATER-Model consists of 16 transport nodes at which tributary inflows as well as storage and evaporation are possible. The demand nodes resemble demand centers for agricultural, domestic and industrial usage, depending on their individual infrastructure and potential. All nine divisions of Turkey that are part of the GAP region are included as nodes that resemble various demand centers: nine domestic, seven agricultural and five industrial. Syria has four regions in the TE-Watershed that are resembled by seven nodes. Among these nodes, seven domestic, six agricultural, and two industrial demand centers are active. Iraq's 18 divisions are shown as

18 nodes resembling 18 domestic, eight agricultural, and six industrial demand centers. A map illustrating the locations of the nodes can be found in [39]. The WATER-Model is fully scalable, enabling an up- or downscaling of the number of nodes, if a closer or wider perspective is needed.

3.2 Mathematical Formulation

We use a quadratically constrained problem (QCP), where an omniscient planner maximizes the overall welfare for all three countries. Welfare is defined as the sum of producer and consumer surplus assuming a linear demand function. It can be calculated as the area below the demand curve subtracted by all variable costs, such as operation and maintenance or pumping costs. The price only depends on the sectoral consumption d at that node as no global water trading market exists. We define a specific demand d_{agir} for every node. It depends on the time period a (rainy or dry), the consumption group g (households, industry or agriculture), the specific node location i (or its alias j), and the region r (Turkey, Syria, Iraq) (see table 2 in the Appendix for further notations of the model). The area below the demand curve is calculated using the following equation including the slope m_{agi} and the prohibitive price n_{agi}:

$$d\_area_{a,g,i,r} = [0.5 \cdot m_{a,g,i} \cdot (d_{a,g,i,r})^2 + n_{a,g,i} \cdot d_{a,g,i,r}] \quad \forall \quad a,g,i,r \tag{1}$$

The area $d\_area_{a,g,i,r}$ has to be subtracted by all costs to calculate the welfare. $c_{a,g,i,r}$ are the variable costs for delivering the water to its consumption nodes including pumping as well as maintenance costs. The model calculates the overall annual welfare for all sectors of each riparian country; thus investment costs are not taken into consideration. The costs for storing one m^3 of water are calculated as the product of the cost parameter c_stor_i and the endogenous storage variable $stor\_in_{a,i,r}$.

$$\max_{\substack{d_{a,g,i,r}, stor\_in_{a,i,r},\\ stor\_out_{a,i,r}, flow_{a,i,j}}} z = \sum_{a,g,i,r} [d\_area_{a,g,i,r} - d_{a,g,i,r} \cdot c_{a,g,i,r} - stor\_in_{a,i,r} \cdot c\_stor_i] \tag{2}$$

This welfare maximization approach is solved with regard to several constraints. The demand constraints guarantee that certain minimum and maximum water deliveries are met every period. Minimum water levels exist for domestic, industrial and irrigation supplies. Maximum water levels are included to ensure that no unrealistically high water levels are extracted at any node.

$$d_{a,g,i,r} - d\_min_{a,g,i} \geq 0 \quad \forall \quad a,g,i,r \tag{3}$$

$$-d_{a,g,i,r} + d\_max_{a,g,i} \geq 0 \quad \forall \quad a,g,i,r \tag{4}$$

The flow constraints ensure a minimum river flow for environmental reasons as well as a maximum possible flow due to specific river basin characteristics.

$$flow_{a,i,j} - f\_min_{i,j} \geq 0 \quad \forall \quad a,i,j \tag{5}$$

$$-flow_{a,i,j} + f\_max_{i,j} \geq 0 \quad \forall \quad a,i,j \tag{6}$$

The first storage constraint ensures that the net storage is always zero or positive; thus water extraction never exceeds the existing water storage. This is done through the introduction of an alias b for a. The second storage constraint ensures that the maximal basin containment is not exceeded.

$$\sum_{b:b\leq a} (stor\_in_{b,i,r} - stor\_out_{b,i,r}) \geq 0 \forall a,i,r \tag{7}$$

$$-\sum_{b:b\leq a} (stor\_in_{b,i,r} - stor\_out_{b,i,r}) + stor\_max_i \geq 0 \quad \forall \quad a,i,r \tag{8}$$

All players are linked via the flow balance, which sums up out- and incoming flows, demand outflows, demand return flows of upstream nodes from the previous period, natural inflows (e.g. effective precipitation), natural outflows (e.g. evaporation), as well as the difference of in- and outflows from storage facilities representing change in storage at each node i in every period a.

$$\sum_j flow_{a,i,j} - \sum_j flow_{a,j,i} + \sum_{g,r} d_{a,g,i,r} - \sum_{j,g,r} (d_{a-1,g,j,r} \cdot return_g) - prec_{a,i} + evap_{a,i} + \sum_r (stor\_in_{a,i,r} - stor\_out_{a,i,r}) = 0 \quad \forall \quad a,i \tag{9}$$

This model is formulated as a quadratically constrained problem and solved with the solver CPLEX and the General Algebraic Modeling System (GAMS). It is scalable and can easily be enlarged (e.g. increasing its number of periods as well as nodes) or adjusted (e.g. focussing on specific regions or sectors). However, all presented scenarios in this paper are run with the same settings to enable a better comparison between them. Additional, more detailed information about the used data sets can be found in [39].

4 Description of Scenarios

4.1 Different Levels of Cooperation

Three different cooperation levels are modeled for each scenario. The first approach represents an omniscient planner who maximizes the overall welfare of the three countries altogether. This *Joint* run therefore always creates the highest possible total welfare values and can be used as reference point for the other scenarios.
The second approach runs the model in three sequential steps, once for each riparian country, in order of their geographical positions. Turkey thus tries to maximize its own welfare, passing all remaining water quantities to Syria. Syria then uses as much of this remaining water as possible, leaving even lower water quantities for Iraq. This second approach is relatively close to real-life not cooperative river usage and will henceforth be referred to as the *Strategic* approach.
The last approach assumes strategic behaviour by all countries, but includes specific water treaties between borders that have to be met at all times. Several bilateral agreements exist to regulate the transboundary water flows in the TE-basin. Experts, however, question the compliance of the treaties from all sides, especially in the recent politically very unstable times. [24, 28, 36] This *Treaty* scenario depicts water treaties of minimum transboundary flows of 60 percent of the original inflow, also including backflows, at each border of the Euphrates and Tigris rivers.

4.2 Different Scenario Assumptions

The Business as Usual (*BAU*) scenarios are used as reference points for the other three scenario sets. They depict the current situation in the basin with all described input data from the previous sections (see [39] for a more detailed description of the data input).
The second scenario set describes a strong decrease in the Euphrates' annual flow. Such a shortage can be caused by a drought or by human action. The filling of the AtatÃ$\frac{1}{4}$rk Dam caused huge debates as Turkey stopped the water flows to Syria from January 13^{th} through February 12^{th} in 1990. The Turkish government referred to Article 6 in the protocol, allowing them to reduce the flows temporarily as long as the quantities are passed on in the following month. This sudden water flow reduction, however, led to reduced hydroelectric production in Syria and to additional agricultural losses of 15 percent in Iraq. [24, 28, 36] Estimates point out, that the filling of a newly constructed dam in the Turkish Euphrates might lead to an up to 30 percent decrease in the annual flow [1, 30]. Another possible reason for water shortages could be seen from May through June in 2014: Turkey reduced the volumes of the Euphrates river inflow into Syria as tactical weapon against the Islamic State in Iraq and Sham (ISIS), causing severe water shortages in Syria as well as Iraq [4]. The *GAP* scenarios therefore model the effects of a water shortage caused either by a drought or by human action.
Another major challenge for this region is the ongoing population growth in all countries, leading to additional water demand. The *Growth* scenarios therefore try to analyse possible water allocation problems beyond 2030. Annual country-specific population growth figures varying between two to four percent were taken from [51] and were used to calculate future domestic water needs. The industrial demand is more difficult to predict; consumption is likely to rise due to economic growth, but so is efficiency. We therefore assume industrial consumption to remain constant over time. The completion of the GAP project will lead to additional 1.7 million ha of irrigable Turkish fields in the coming years. Further future irrigation needs for 0.64 million ha in Syria and 0.5 million ha in Iraq were taken from [6]. These predictions for additional irrigation areas were used to calculate the future agricultural reference demand for each country in the *Growth* scenarios.
Growth & GAP (*G & G*) is the last scenario set, and it is a combination of the latter two. Three different levels of cooperation and four different scenario assumptions sum up to twelve different scenario combinations, whose results are described in the following section.

5 Results and Interpretations

5.1 Results of the Different Scenarios

5.1.1 BAU and GAP Scenarios

The outcomes of the BAU-model runs in figure 1 show that the agricultural sector is responsible for the smallest welfare share, even though it has the highest demand share throughout all nations and seasons. The domestic and industrial sector have similar water efficiencies. Because the majority of the TE-Watershed lies inside the territory of Iraq, the demand and welfare figures of the country are strikingly high. These absolute figures should, however, not be over-interpreted as later results prove that Iraq is in fact the least efficient user of water in this region.

Demand figures in the BAU runs differ from historical reference demands. This is due to the fact

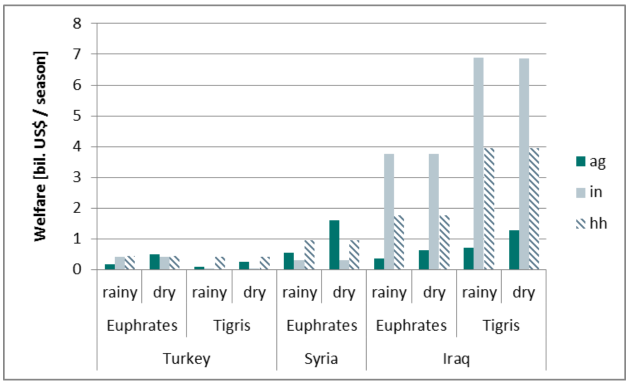

Figure 1: Welfare distribution in the BAU scenario assuming a joint water allocation

Source: Own illustration based on the results of the WATER-Model

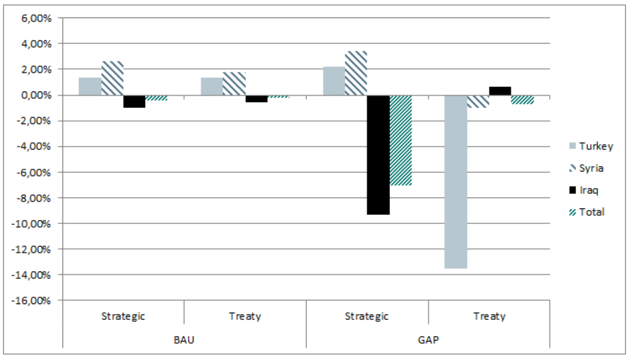

Figure 2: Welfare distribution compared to the joint scenario runs

Source: Own illustration based on the results of the WATER-Model

that the model is solved from an omniscient planner's perspective that optimizes the use of water subject to his constraints. In reality, however, water is extracted from different players and sectors, even when its downstream usage might be more profitable. The input data implies significantly higher return rates for the domestic and industrial sectors in all countries and seasons compared to the agricultural sector. Due to a linear approximation of the value of water demand figures in the BAU runs exceed historical reference demands for the domestic and industrial sector. Consequently, less water is being used for irrigation purposes in the agricultural sector. The lack of more exact local data as well as computational problems of using non-linear cost curves make it very difficult to match the exact historical reference demands. The results of this model therefore only portray a simplified approximation of reality.

In case of low water flows in a region, only the minimum agricultural water demands are met. With increasing water supply, more and more remaining water quantities are also used for irrigation purposes. Irrigation is mostly done in the summer, leading to higher agricultural water demands in the dry season. The Iraqi agriculture sector is the least effective, but still receives a relatively big share of water. This is due to the fact that the water of the Tigris river directly passes from Turkey to Iraq, and is thus not accessible to Syria. Also, Iraq's disposal of tributary inflows into the Tigris river accounts for 55 percent of the river's overall water flow. The Iraqi industrial sector's demand is twice as high as the domestic sector's. The opposite is true for Turkey and Syria, which both lack large industrial complexes along the TE-watershed.

The BAU scenarios assume average inflows of both rivers, zero demand growth, and perfect foresight. Therefore, only slight changes are visible between the different levels of cooperation (see figure 2). The exogenous water shortage, due to a drought or by human action in the Turkish part of the Euphrates, leads to additional water scarcity in the GAP scenarios. However, since these additionally reduced water volumes do not produce any direct value in the model, the overall welfare is reduced compared to the BAU scenarios. Assuming strategic behaviour while comparing the Turkish welfare figures between the BAU and the GAP scenarios shows that they have hardly changed (see table 1). Less water, however, was consumed in the Iraqi downstream regions. Such a shift in water consumption decreases the overall welfare by 7 percent in comparison to a joint water allocation. This decrease of overall welfare is caused by water being used for the less beneficial upstream Turkish agricultural sector instead for the domestic and industrial sectors of Iraq.

5.1.2 Growth and G & G Scenarios

The welfare figures of the Growth and the G & G scenarios are much higher due to the increasing water demand beyond 2030 (see table 1). A comparison between the different scenarios can therefore only be done by comparing relative and not absolute figures.

The water consumption of the Turkish and Syrian domestic and industrial sectors remains nearly the same in all three Growth scenarios. In Iraq, however, a strong reduction throughout all sectors along the Euphrates can be observed when strategic behaviour is modeled. These missing water volumes, as well as smaller amounts from the Syrian agricultural sector, are used by the upstream Turkish agricultural sector. This leads to an overall welfare reduction of 9.6 percent for the whole basin in case of strategic behaviour. The analysis of the reservoir water usage in the different countries shows how the storage capacities of Syria and Iraq can reduce the effects of strategic behaviour. Strategic behaviour of Turkey decreases the inflow figures of the Tigris into Iraq. Iraq, however, manages to compensate most of this effect by storing its water reserves for the dry period. Therefore, in the case of strategic behavior, a greater usage of Tigris reservoirs in Iraq is evident in 50 percent of BAU scenarios and in 30 percent of Growth scenarios. These storage options, as well as the Iraqi inflows into the Tigris, result in lower welfare losses in the Tigris compared to the Euphrates basin.

It is only in the Growth scenarios, esp. when assuming strategic behaviour, that due to the additional demand in the Turkish area, Turkey starts using its reservoirs to meet its higher demands during the dry period. Turkey's reservoir usage leads to additional water scarcity in the downstream regions, and lower usage of Iraqi and Syrian reservoirs. There is nearly no water being stored by Syria in the strategic Growth scenario, as most of the water is consumed directly. Syria, however, does have some own minor tributaries to supply itself with water during the dry period. Iraq has no tributaries on the Euphrates; it therefore continues saving water reserves in the rainy period in order to meet its minimum demand levels in the following dry period.

Similar to the GAP scenarios, the reduction of water volumes in the G & G scenarios leads to additional water scarcity in the basin and a reduction of the overall welfare compared to the Growth scenarios. When assuming strategic behaviour in this case, however, shifts in the Turkish demand can also be observed. No further water can be extracted from the Iraqi share, as theses quantities have already reached the minimum thresholds in the Growth scenarios. The additionally stored water therefore originates from the Turkish agricultural sector and of all the Syrian sectors.

Strategic behaviour of Turkey in the G & G scenario becomes especially visible in the Euphrates river, which leads to an increase of its welfare by 20 percent but reduces the welfare of Syria (-70 percent) and Iraq (-40 percent). The overall welfare loss in the Euphrates basin sums up to 33 percent while only reaching 14 percent across both river basins, since the Tigris is not affected as much by strategic actions.

5.2 Summary of all Scenarios

Table 1 summarizes the welfare effects of the different scenarios across the river basin. A comparison between the different scenarios, however, can only be done by comparing relative figures as the scenario settings cause different input values for water volumes (GAP and G & G) and demand figures (Growth and G & G). By examining the different scenarios, it becomes clear that strategic behaviour does not cause high welfare losses in the BAU scenarios. It is only when additional water scarcity is caused by water volume reduction (GAP scenario: -7 percent welfare loss) or demand growth (Growth scenario: -9.6 percent welfare loss) that strategic actions influence the overall welfare. Iraq suffers most from such events, as it is located at the downstream part of the rivershed. This becomes even more visible when Iraq experiences water supply reduction not only in its agricultural sector, but also in its domestic and industrial sectors. It is especially the downstream regions in the Euphrates delta that suffer from the higher water extractions in the upstream area: Strategic behaviour of Turkey leads to an increase of its welfare by 20 percent along this river in the G & G scenario. Syria and Iraq, on the other hand, suffer from welfare reductions of -70 and -40 percent, respectively. The overall welfare loss in the Euphrates basin sums up to 33 percent. The Tigris is not as much affected by strategic actions, leading to a basin-wide welfare reduction of 14 percent. Examining the repartition of welfare between the two rivers shows the dependence of Iraq on the Tigris (see figure 1). The Iraqi Tigris

Table 1: Overall welfare in the TE Watershed in all scenario runs [bil. $/year]

		T	S	I	Sum	Change
BAU	Joint	4	5	36	44	
	Treaty	4	5	35	44	-0.2 %
	Strategic	4	5	35	44	-0.4 %
GAP	Joint	4	5	35	43	
	Treaty	3	4	35	43	-0.7 %
	Strategic	4	5	32	40	-7.0 %
Growth	Joint	11	7	44	62	
	Treaty	10	6	45	61	-0.9 %
	Strategic	12	5	39	56	-9.6 %
G & G	Joint	10	5	44	59	
	Treaty	7	6	45	58	-2.7 %
	Strategic	11	2	39	51	-13.8 %

Source: Own calculations with the WATER-Model.

river is much more independent, since Syria has no access to it and half of the Tigris' water springs in Iraqi territory. Therefore, also the majority of its industrial sites are grouped along the Tigris and its tributaries. Water volumes from the Euphrates were temporarily reduced in the past (e.g. due to draughts or human action by Syria and Turkey) and thus have always resembled higher uncertainties for Iraq. Turkey uses water from both rivers, but its main industrial centers lie along the Euphrates. In case of strategic behaviour, its consumption rises, also leading to a welfare reduction in Syria.

The agricultural sector is the main driving force behind the overall welfare changes in between the scenarios. The increasing water shares of the Turkish agricultural sector in case of strategic behaviour cause the overall welfare losses throughout all scenarios. Syria's irrigation increases in the BAU and GAP scenarios, but shrinks sharply as soon as demand growth is assumed. Iraq's agriculture is already forced to its minimum threshold in the GAP scenarios. For the Growth and G & G scenarios, constant minimal agricultural usage can be observed, while additional reductions in the domestic and industrial sectors lead to further Iraqi welfare losses.

The results indicate that most of the welfare losses caused by strategic behaviour, can be evened out when implementing water treaties between countries. This reduces the welfare loss to figures below one percent in the GAP and Growth scenarios. However, this does not hold for each player individually: Turkey observes lower welfare figures when giving up its strategic advantage and adhering to agreed-upon treaties, while Iraq profits from minimum water treaties. Syria, on the other hand, loses minor welfare shares in the GAP scenario, but highly profits from such treaties in the Growth and G & G scenarios due to the rising Turkish demand.

The overall welfare in the event of water treaties is still slightly below the joint optimization runs. The main reason for this is that implementing minimum flow treaties of 60 percent of the original inflow enables higher Iraqi agricultural downstream usage compared to the BAU scenarios. This sector, however, is less efficient in water usage, causing lower overall welfare figures.

6 Conclusion

Modeling the Tigris-Euphrates Watershed enables us to quantify welfare losses due to extensive upstream water usage of the two rivers. Water disputes in the region clearly stem from the mismatch between demand and supply of water, coupled with the uncoordinated nature of current water development projects. This becomes most visible in the case of the Euphrates River. Calculations show that non-cooperative behaviour of Turkey can lead to total disruption of agricultural usage in downstream areas of Syria and Iraq. Taking into account expected demand growth in the region, our model estimates welfare losses of up to 33 percent along the Euphrates. Turkey, being substantially more developed than its riparian neighbors, is most efficient in its water usage. Nevertheless, passing on sufficient water to Iraqi and Syrian domestic and industrial sectors has the potential of increasing the overall welfare of the region. Calculations point out, that minimum flow treaties of around 60 percent of the average river flows from Turkey to Syria would be needed to achieve this effect. Therefore, further political measures such as transboundary water treaties should be negotiated, and most important, should also be controlled to guarantee a minimum downstream flow of both rivers.

Another option to regulate the fluctuations of the rivers is to build further reservoirs. The Turkish "Southeastern Anatolia Project" (GAP) announced the construction of 22 dams, among which 15 have been completed so far. These have a high economic potential for the surrounding region. Such infrastructure, however, at the same time might become a threat for downstream regions as the control of water volumes can be used as tactical weapon. Scenario analysis reveal that the filling of reservoirs can cause high welfare losses if these actions are not done on a basin-wide coordinated basis.

Agreements between the three countries are needed as soon as possible, as the fast population growth also leads to increasing water scarcity in the region. Water salinity figures in some parts of the Iraqi Euphrates have quadrupled in the last thirty years. This has led to an increased deterioration of Iraq's marshlands. A recoupment of farmlands, on the other hand, would have the potential of creating thousands of unskilled jobs. A sustainable joint usage of the Tigris Euphrates basin therefore increases the overall welfare of the region. It should also be in the interest of international institutions such as the World Bank and the EU to promote cooperation between all adjacent countries. Turkey's potential ratification of the "UN Convention on the Law of Non-Navigable Uses of International Watercourses" might be an important next step in such a process. Additional instruments such as loans for the finalization of the GAP project have to be pushed forward to reward and compensate Turkey for guaranteeing certain minimum water releases to its downstream neighbors.

Further research is needed to identify and evaluate various possibilities for joint water and non-water related trilateral agreements. Such studies should ideally be done in close co-operation with local partners from all affected countries. The current political situation, however, makes this very difficult. Civil war in Syria and advances of the ISIS have already caused a death toll of about 250 thousand people. In addition, probably more than 7 million people are currently displaced within Syria, while 5 million refugees have fled to neighboring countries. These shocking statistics only increase the demand for fast action, also with respect to a fair water distribution. Supplying these people with sufficient clean water is an essential part for preventing diseases as well as securing peace in the region.

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8 Appendix

Table 2: Notations of the WATER-Model

Sets	Description
a, b	periods (rainy, dry)
g	groups (industry, agriculture, households)
i, j	nodes (demand, transport, supply)
r	regions (Turkey, Syria, Iraq)
Parameters	
$c_{a,g,i,r}$	costs of consumption
c_stor_i	costs of storage at node i
$d\_max_{a,g,i}$	maximum demand at node i for group g
$d\_min_{a,g,i}$	minimum demand at node i for group g
$d\_ref_{a,g,i}$	known reference demand at node i
$evap_{a,i}$	evaporation at node i in period a
$f\_max_{i,j}$	maximum flow on arc(i,j)
$f\_min_{i,j}$	minimum flow on arc(i,j)
$m_{a,g,i}$	slope of linear demand function
$n_{a,g,i}$	prohibitive price at node i
$prec_{a,i}$	precipitation at node i in period a
$p\_ref_{g,i}$	known reference price at node i
$return_g$	return flow factor for group g
$stor\_max_i$	maximum storage capacity at node i
η_g	price elasticity of demand
Variables	
$d_{a,g,i,r}$	demand at node i in region r
$d\_area_{a,g,i,r}$	area below demand function at node i
$flow_{a,i,j}$	flow on arc(i,j) in period a
$stor\_in_{a,i,r}$	incoming storage controlled
$stor\_out_{a,i,r}$	outgoing storage controlled
z	welfare