Modeling Water Management Options for the Tigris – Euphrates Basin

Pao-Yu Oei
Workgroup for Economics and Infrastructure Policy (WIP, TU Berlin)
Trans-Atlantic INFRADAY Conference
Washington, DC November 11th, 2011
Road Map

• Motivation

• Introduction of WATER – MOD

• Building of Scenarios

• Analysis of the Results

• Conclusion

• Further Research
Motivation

• Euphrates and Tigris supply 50 million people from Turkey, Syria and Iraq

• 90 – 98 % of Euphrates and 50 % of Tigris spring in Turkey

• Constant debates how to regulate a fair water distribution

➢ Need to examine different water management options
"And tell them that water is to be divided between them: 
Each one’s right to drink being brought forward by turns."

The Koran, Alkamar: 28 iv

"Neither Syria nor Iraq can lay claim to Turkey’s rivers any more than Ankara could claim their oil. This is a matter of sovereignty. We have a right to do anything we like. The water resources are Turkey’s; the oil resources are theirs. We don’t say we share their oil resources, and they cannot share our water resources."

Suleyman Demirel, Prime Minister of Turkey, 1992
"Southeastern Anatolia Project" (GAP)

- Turkish investment project
- 9 provinces in the Kurdish South-East
- Original plan to finish by 2010

- Irrigate 1.7 million ha
- Produce 27 billion kWh
- Employ 3.8 million people
- Increase per capita income by 209%

Source: (GAP, 2006)
"Southeastern Anatolia Project" (GAP)

GAP IRRIGATION PROJECTS

- 967,422 ha Remaining % 56.2
- 236,019 ha In Operation % 13.7
- 374,118 ha Ready for Tendence % 21.8
- 142,099 ha Construction % 8.3

HYDROPOWER ENERGY GENERATING PROJECTS

- 240 MW Ready for Tenderance % 3
- 523 MW Remaining % 7
- 1,200 MW Construction % 16
- 5,513 MW In Operation % 74

TOTAL 7,476 MW

FINANCIAL ASPECTS OF GAP

- 37 Billion YTL % 56.4
- 21 Billion YTL % 43.6

Source: (GAP, 2006)
Literature Overview


- "Euphrates and Tigris River Basin Model" (ETRBM) (Kucukmehmetoglu, 2002) from Gebze Institute of Technology, Turkey
  The ETRBM is a linear programming model maximizing net economic benefits from the TE-Watershed.

- Later versions focus on potential political and economic impacts of reservoirs in temporal perspective (Kucukmehmetoglu, 2005 and 2009).
Water Allocation of the Tigris-Euphrates Rivershed

• WATER – MOD

• Seasons, Storage, Evaporation & Precipitation

• Water characteristics (back-flow, min water)

• 50 Nodes

- 16 Transport nodes: Tigris, Euphrates and main tributaries

- 9 Turkish Demand nodes: 7 mil. people, 1,700,000 ha, 430 mcm³

- 7 Syrian Demand nodes: 7 mil. people, 1,000,000 ha, 308 mcm³

- 18 Iraquien Demand nodes: 37 mil. people, 5,500,000 ha, 9700 mcm³
Figure 3:

Euphrates-Tigris river basin

Legend
- International boundary
- Administrative boundary
- Capital, town
- River basin
- Lake
- Intermittent lake
- Wetland
- Salt pan
- River, intermittent river
- Canal
- Dam (capacity > 1 km³)

Zone of irrigation development
Southeastern Anatolia Project (GAP), ongoing
Irrigation scheme

FAO - AQUASTAT, 2009

Disclaimer
The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.
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Water Allocation of the Tigris-Euphrates Rivershed

Decision Tree:

Objective Function:

\[
\max_{d_{irga}, stor_{inria}, stor_{outria}, flow_{ria}} \sum_{r,i,g,a} [d_{area_{irga}} - d_{irga} \cdot c_{irga} - stor_{inria} \cdot c_{stor_{i}}] \\
\forall r
\]

(25)

\[
d_{area_{irga}} = [0.5 \cdot m_{rg} \cdot (d_{irga})^2 + n_{rg} \cdot d_{irga}] \\
\forall i, r, g, a
\]

(26)
Constraints

\[
\sum_{r,j} \text{flow}_{rj} - \sum_{r,j} \text{flow}_{rja} + \sum_{r,g} d_{irg} - \sum_{r,g} (d_{irg-1} \cdot \text{return}_g) - p_{ia} + e_{ia} \\
+ \sum_{r} (\text{stor}_in_{ria} - \text{stor}_out_{ria}) = 0 \quad \perp (\mu_{ia} - \text{free}) \quad \forall i, a
\]

\[
d_{irg} - d_{\text{min}irg} \geq 0 \quad \perp \lambda_{d\text{min}irg} \geq 0 \quad \forall i, r, g, a
\]

\[
-d_{irg} + d_{\text{max}irg} \geq 0 \quad \perp \lambda_{d\text{max}irg} \geq 0 \quad \forall i, r, g, a
\]

\[
-f_{\text{flow}_{ri}a} + f_{\text{max}_ij} \geq 0 \quad \perp \lambda_{f\text{max}_{ri}j} \geq 0 \quad \forall i, j, r, a
\]

\[
f_{\text{flow}_{ri}a} - f_{\text{min}_ij} \geq 0 \quad \perp \lambda_{f\text{min}_{ri}j} \geq 0 \quad \forall i, j, r, a
\]

\[
 b \leq a \\
\sum_{b} (\text{stor}_in_{rib} - \text{stor}_out_{rib}) \geq 0 \quad \perp \lambda_{\text{stor}_{ria}} \geq 0 \quad \forall i, r, a
\]

\[
-\sum_{b} (\text{stor}_in_{rib} - \text{stor}_out_{rib}) + \text{stor}_\text{max}_i \geq 0 \quad \perp \lambda_{\text{stor}_{\text{max}ria}} \geq 0 \quad \forall i, r, a
\]
## Data: Reference Values and Demand

<table>
<thead>
<tr>
<th>Regions</th>
<th>Groups</th>
<th>Reference value [$/cm]</th>
<th>Reference demand [mcm]</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iraq</td>
<td>Households</td>
<td>1</td>
<td>4300</td>
<td>- 0.3</td>
</tr>
<tr>
<td>Syria</td>
<td>Households</td>
<td>1</td>
<td>738</td>
<td>- 0.3</td>
</tr>
<tr>
<td>Turkey</td>
<td>Households</td>
<td>1</td>
<td>620</td>
<td>- 0.3</td>
</tr>
<tr>
<td>Iraq</td>
<td>Industry</td>
<td>1.5</td>
<td>9700</td>
<td>- 0.2</td>
</tr>
<tr>
<td>Syria</td>
<td>Industry</td>
<td>1.5</td>
<td>308</td>
<td>- 0.2</td>
</tr>
<tr>
<td>Turkey</td>
<td>Industry</td>
<td>1.5</td>
<td>430</td>
<td>- 0.2</td>
</tr>
<tr>
<td>Iraq</td>
<td>Agriculture</td>
<td>0.0023</td>
<td>52000</td>
<td>- 0.25</td>
</tr>
<tr>
<td>Syria</td>
<td>Agriculture</td>
<td>0.057</td>
<td>7335</td>
<td>- 0.25</td>
</tr>
<tr>
<td>Turkey</td>
<td>Agriculture</td>
<td>0.066</td>
<td>2960</td>
<td>- 0.25</td>
</tr>
</tbody>
</table>
Two Modeling Approaches

• Sequential three stages approach:
  Every country maximizes its own profit in order of their geographic position

• Mixed Complementarity Problem (MCP):
  Maximizing the overall welfare of all countries
Scenarios

Ecological:

- Different water levels (dry, medium or wet)

Institutional:

- Building a canal from Tigris to Euphrates in Iraq
- Minimum flow treaties between countries
Results: Different water flows

Motivation

WATER-MOD Scenarios Results Conclusion

WATER-MOD Scenarios Results Conclusion

welfare [bil. $ / year]

Iraq
Syria
Turkey

Min Normal Max Min Normal Max

Optimal Strategic

Motivation
Demand & Welfare in the optimal min flow case

<table>
<thead>
<tr>
<th>Demand [mcm]</th>
<th>Turkey</th>
<th>Syria</th>
<th>Iraq</th>
</tr>
</thead>
<tbody>
<tr>
<td>rainy</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>dry</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Welfare [mil. $/year]</th>
<th>Turkey</th>
<th>Syria</th>
<th>Iraq</th>
</tr>
</thead>
<tbody>
<tr>
<td>rainy</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
</tr>
<tr>
<td>dry</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

Demand & Welfare under strategic behaviour

<table>
<thead>
<tr>
<th>Demand [mcm]</th>
<th>Turkey</th>
<th>Syria</th>
<th>Iraq</th>
</tr>
</thead>
<tbody>
<tr>
<td>rainy</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>dry</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Welfare [mil. $/year]</th>
<th>Turkey</th>
<th>Syria</th>
<th>Iraq</th>
</tr>
</thead>
<tbody>
<tr>
<td>rainy</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
</tr>
<tr>
<td>dry</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

Results: Building a canal

Welfare [bil. $/year]

- Optimal
- Strategic
- Canal

Iraq, Syria, Turkey
Results: Minimum flow treaty

Motivation

WATER-MOD

Scenarios

Results

Conclusion

Welfare [bil. $/year]

Strategic, Canal, 50%, 70%, 2x50%, Optimal

Iraq, Syria, Turkey

Berlin Institute of Technology (TU Berlin)
Workgroup for Economics and Infrastructure Policy (WIP)

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11.11.2011
Final Conclusion

• Turkey is able to produce 5 times higher values as Iraq in the agricultural sector per m$^3$ of water.

• A waterflow reduction by 60% reduces the overall income by 5%.

• **Strategic behaviour** is causing the overall national income to be reduced by 35%.

• A canal from Tigris to Euphrates increases the Iraquien industrial & domestic usage.

• Minimum **flow treaties** between countries increase the overall national income by 20%.
Further Research

Water

Allocation of the

Tigris and

Euphrates

Rivershed

WATER – MOD

I am currently working on:

- Ecological constraints
- Hydropower integration
Questions

Water

Allocation of the

Tigris and

Euphrates

Rivershed

WATER – MOD

Thank you very much for your attention!

Are there any questions?
References


ERDEM, Mete (2002): The Tigris-Euphrates Rivers Controversy and the Role of International Law, Public International Law, University of Sheffield, UK.


References


SIEHLOW (2011)
References


<table>
<thead>
<tr>
<th>Sets</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>periods (rainy, dry)</td>
</tr>
<tr>
<td>f(r)</td>
<td>follower (Syria, Iraq)</td>
</tr>
<tr>
<td>g</td>
<td>groups (industry, agriculture, households)</td>
</tr>
<tr>
<td>i</td>
<td>nodes</td>
</tr>
<tr>
<td>l(r)</td>
<td>leader (Turkey)</td>
</tr>
<tr>
<td>r</td>
<td>regions (Turkey, Syria, Iraq)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>evap_{i,a}</td>
<td>evaporation at node i in period a</td>
</tr>
<tr>
<td>prec_{i,a}</td>
<td>precipitation at node i in period a</td>
</tr>
<tr>
<td>d_{min_{i,g}}</td>
<td>minimum demand at node i for group g in period a</td>
</tr>
<tr>
<td>d_{max_{i,g}}</td>
<td>maximum demand at node i for group g in period a</td>
</tr>
<tr>
<td>f_{min_{i,j}}</td>
<td>minimum flow on arc(i,j)</td>
</tr>
<tr>
<td>f_{max_{i,j}}</td>
<td>maximum flow on arc(i,j)</td>
</tr>
<tr>
<td>stor_{max,i}</td>
<td>maximum storage capacity at node i</td>
</tr>
<tr>
<td>(w_{r,g,i})</td>
<td>value of consumption at node i in region r for group g in period a</td>
</tr>
<tr>
<td>c_{r,g,i}</td>
<td>costs of consumption at node i in region r for group g in period a</td>
</tr>
<tr>
<td>s_{c_t}</td>
<td>costs of storage at node i</td>
</tr>
<tr>
<td>K</td>
<td>disjunctive constraints constant</td>
</tr>
<tr>
<td>p</td>
<td>punishment weighting factor (\in [0; 1])</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>d_{r,g,i}</td>
<td>demand at node i for region in group g in period a</td>
</tr>
<tr>
<td>flow_{r,i,j}</td>
<td>flow controlled by region r on arc(i,j) in period a</td>
</tr>
<tr>
<td>stor_{in,r,i}</td>
<td>incoming storage controlled by region r at node i in period a</td>
</tr>
<tr>
<td>stor_{out,r,i}</td>
<td>outgoing storage controlled by region r at node i in period a</td>
</tr>
<tr>
<td>r_{d}</td>
<td>binary variable for disjunctive constraint on demand</td>
</tr>
<tr>
<td>r_{f}</td>
<td>binary variable for disjunctive constraint on flow</td>
</tr>
<tr>
<td>r_{si}</td>
<td>binary variable for disjunctive constraint on incoming storage</td>
</tr>
<tr>
<td>r_{so}</td>
<td>binary variable for disjunctive constraint on incoming storage</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dual variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\lambda_{d_{min_{r,g,i}}})</td>
<td>dual to minimum demand at node i for region in group g in period a</td>
</tr>
<tr>
<td>(\lambda_{d_{max_{r,g,i}}})</td>
<td>dual to maximum demand at node i for region in group g in period a</td>
</tr>
<tr>
<td>(\lambda_{f_{min_{r,i,j}}})</td>
<td>dual to maximum flow controlled by region r on arc(i,j) in period a</td>
</tr>
<tr>
<td>(\lambda_{f_{max_{r,i,j}}})</td>
<td>dual to maximum flow controlled by region r on arc(i,j) in period a</td>
</tr>
<tr>
<td>(\lambda_{stor_{r,i}})</td>
<td>dual to total storage of dam controlled by region r at node i in period a</td>
</tr>
<tr>
<td>(\lambda_{stor_{max_{r,i}}})</td>
<td>dual to storage capacity of dam controlled by region r at node i in period a</td>
</tr>
<tr>
<td>(\mu_{i,a})</td>
<td>dual to flow balance at node i in period a</td>
</tr>
</tbody>
</table>
Data: Reference Values and Costs

Table 2: Value of $1m^3$ water per country and per sector [US$]

<table>
<thead>
<tr>
<th>Country/Sector</th>
<th>Agriculture</th>
<th>Households</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iraq</td>
<td>0.002</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Syria</td>
<td>0.057</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Turkey</td>
<td>0.066</td>
<td>1</td>
<td>1.5</td>
</tr>
</tbody>
</table>


Table 3: Costs of $1m^3$ water in the agricultural sector per country [US$]

<table>
<thead>
<tr>
<th>Country</th>
<th>Agricultural Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iraq</td>
<td>0.0017</td>
</tr>
<tr>
<td>Syria</td>
<td>0.0075</td>
</tr>
<tr>
<td>Turkey</td>
<td>0.0083</td>
</tr>
</tbody>
</table>

Source: OECD (2010), Beaumont (1998), Ineco (2009), Kucukmehmetoglu (2009), own calculations

Costs for domestic and industrial uses is 0.005 US$/m^3/km (Kucukmehmetoglu, 2009)
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