

Optimizing ag water resource use in the Tigris-Euphrates Basin: Drought Adaptation Strategies



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Objectives

- Learn and apply principle of optimization as framework for improved ag water use decisions.
- Learn the basic structure of the General Algebraic Modeling System (GAMS) software package, to be provided by the instructors.
- Discover what we mean by the economic value of water in agriculture.
- Learn how to put to better use for decision-making data on crops, water, and economics.

Objectives (cont)

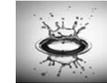
- Learn how to build, use, and interpret optimization models written in GAMS to improve the performance of water use in crop irrigation for local, provincial, and national needs.
- Discover how optimization models can inform better capacity to adapt to water shortages in the lower Tigris-Euphrates Basin.
- (Bridge) Show how to use results so that:
 - farmers can increase income and improve livelihoods.
 - You can measure economic impacts of water shortage sharing methods.

Road Map

- Iraq drought adaptation challenges
- Economic Value of Water
- Introduction to Optimization
- A simple example
- GAMS software
- 6 Optimization Models in GAMS
 - Data needs
 - Math used
 - Results and Interpretation
- Conclusions

Motivation for Optimization Models

Iraq National Development plan (2010)



Water Resources Management Section

<http://www.iauiraq.org/documents/1159/ndp24th.pdf>

5.11.2 Water Policies
Integrated Management

- 4. Applying principles of integrated management of water resources in coordination with all stakeholders, ...p 74.

Water Policies, continued
Wise Use

- 7. ... Make available information so that water users are aware of the importance of the wise use of water ... p. 74

Water Policies
conservation, drought, and salinity
tolerance

- 9. ... expanding application of modern irrigation methods and encourage planting substitute crops that consume less water and resist salinity and drought.

P.74

Water Policies

Climate impacts and growing scarcity

13. Study climate change, and its effects on water supplies into Iraq, and the future living conditions in light of expected scarcity, p. 74.

Water Policies

Research on increased water use efficiency

14. ... increase the standard of irrigation; reduce waste; ... apply research results to new projects, make information available to water users. Establish research centers...p 74

Water Policies

Pricing water to avoid waste and sustain supplies for future generations

15. ... setting a suitable price for water to maintain its wealth... p 75

Economic Value of Water in Ag

- Information on water's economic value enables informed choices on water
 - development
 - conservation
 - allocation
 - purification
 - protection
- when growing demands for all uses occur with
 - increased scarcity
 - climate variability

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Background

- Conceptually correct and empirically accurate estimates of the economic value of water are essential for rational allocation of scarce water across
 - locations
 - uses
 - quality levels
 - quantity levels
 - time periods
- Is economic rationality a good thing?

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Economic Value of Water in Irrigation

- The economic value of water in agriculture is defined as what a rational irrigator is willing to pay. How large a check the farmer is willing to write.
 - Assumes that you want to use water to increase its total economic benefits in agriculture.
 - Irrigation policy debates typically focus on proposed marginal changes to existing supplies, quantities, or rules for sharing shortages.

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Useful examples: value of water

- The economic value of protecting a country's water from under-deliveries by an upstream country is what the country's water users are willing to pay for the greater reliability of water supply.
- The economic value of protecting a region's irrigated agriculture is the gain in farm income and reduced food prices that the protection produces.
- The economic value of changing the current system for sharing water shortages when drought occurs is the gain in farm income and reduced food prices made possible by the new shortage sharing system.

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Which policies need information on economic value of water?

- Value of added water infrastructure
 - building
 - Restoring
- Value of changing water institutions
 - Redrafting water laws
 - Stream adjudications (NM)
 - Shortage sharing rules (Iraq)
- Value of changing water regulations
 - Groundwater pumping limits
 - Requiring meters

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Economic Value of Water

- It's the willingness to pay for making a change in the status quo of water
 - Changes in quantity
 - Changes in quality
 - Changes in timing
 - Changes in location
- It's about valuing changes in one of those four dimensions of water use.
- Usually requires an economic model grounded in a physical reality

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Economic value of diverting irrigation water at a lower v higher point in watershed (e.g., Iraq)

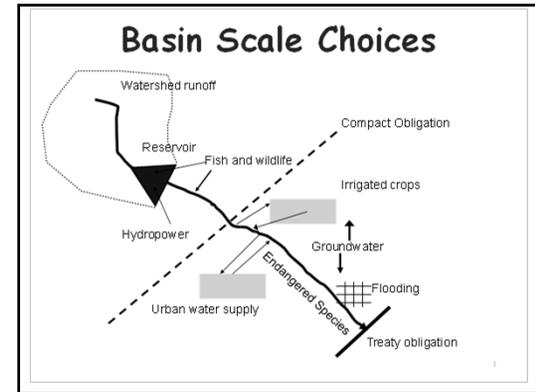
- The willingness to pay for altering the diversion point from an upstream to a downstream region.
 - Farm income gain can be high
 - Gain in food security can be high
 - But existing rules may prevent the change
- So there can be an economic value in changing the rules for sharing shortages.

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Background: Some Ag Water Challenges

- Afghanistan: Identify efficient timing, sizing, and sequencing of water storage projects (especially new storage reservoirs)
- Iraq: Identify agricultural water sharing systems for minimizing costs of adapting to drought in Lower Tigris-Euphrates
- USA: Protecting Farm Income when droughts occur
- Egypt: Identify improvements in water management that increase the Nile's economic productivity.
- Uzbekistan, Tajikistan: Identify Welfare Improving Developments and Allocations of Water in the Basin
- Australia: protecting key ecological assets without losing farm land.

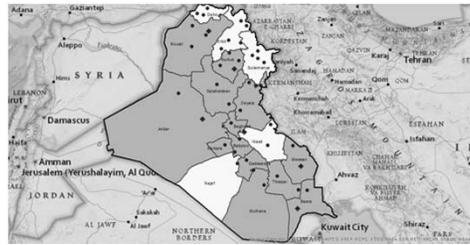
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Data

- Cropping Patterns (land in production by crop and year)
 - Rice, wheat, cotton, sunflower, Maize, Barley, summer vegetables, winter vegetables, and other crops
- Ag Water Use (Lower Tigris-Euphrates)
- Meteorological
 - Temperature, wind, humidity, sunshine
- Economic
 - Prices
 - Yields
 - Costs
 - Water use (ET)
 - Net Revenue per Ha

Iraq Map



Iraq Map



Q: What are we doing to do with this data to find out how to raise the economic value of water for irrigation in Iraq when drought occurs?

Goal: Reduce economic losses

A: Optimization

Optimization

- An optimization problem consists of maximizing or minimizing an objective by systematically choosing input values from an allowed set of choices. Result of optimization:
 - Best choices.
 - Results of best choices (value of objective).
- There are many optimization software packages, we use GAMS (General Algebraic Modeling System).

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Optimization Mathematical Formulation

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Maximize Farm Income, by finding the best amount of land assigned to each crop in each province (L_{ik}) subject to a constraint of limited water

$$\text{Max: Farm Income} = \sum_i \sum_k NB_{ik}$$

$i = \text{province}$

$k = \text{crop}$

$$NB_{ik} = [P_{ik} * \text{Yield}_{ik} - \text{Cost}_{ik}] * L_{ik}$$

$$W_{ik} = Bc_{ik} * L_{ik}$$

$$\sum_i \sum_k W_{ik} \leq W_0$$

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Example Farm Water Data

Water Available (million m3)	Price (\$/ton)	Yield (tons/ha)	Cost (\$/ha)	Income (\$/ha) $P * Y - C$	Water use (1000 m3/ha) Bc
572	Cotton: 906	Cotton: 2.32	Cotton: 1286	$((906 * 2.32) - 1286) = ??$	Cotton: 18.0
	Wheat 225	Wheat 1.39	Wheat: 200	$((225 * 1.39) - 200) = ??$	Wheat: 11.9

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Challenge: Use previous slide's data to optimize total farm income

- Goal: Allocate land among crops that optimizes (maximizes) farm income
- Method:
 - Experiment with 3 possible land allocations
 - For larger problems, GAMS software tries all possible land allocations, then picks the best (optimum)
 - Data source: 1 Iraqi province (Mousil)

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Remember

$$Total\ Income = \sum_i \sum_k [P_{ik} * Yield_{ik} - Cost_{ik}] * L_{ik}$$

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Try 3 combinations of land planted to 2 crops, while using available water: 572 million m³

	Land (1000 ha)	Water Use (million m ³)	Total Farm Income (\$US Thousands)
1	Cotton= 0 Wheat=48.06	572	Cotton: 0 * 815.92 = 0 Wheat: 48.06 * 112.75 = 5,419 Total = 5,419
2	Cotton= 12.0 Wheat= 29.91		Cotton: 12.0 * 815.92 = 9,811 Wheat: 29.21 * 112.75 =3,626 Total = 13,437
3	Cotton= 31.78 Wheat= 0		Cotton: 31.78 * 815.92 = 25,928 Wheat: 112.75 * 0 = 0 Total= 25,928

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Do all 3 of these crop land allocations exactly use up total water we have?

C	Land (1000 ha)	Water Use per ha (1000 m ³)	Total water use (million m ³)
1	Cotton= 0 Wheat=48.06	Cotton: 18.0 Wheat: 11.9	$(0 * 18.0) + (48.06 * 11.9)$ = 572
2	Cotton= 12.0 Wheat= 29.91		$(12.0 * 18.0) + (29.91 * 11.9)$ = 572
3	Cotton= 31.78 Wheat= 0		$(31.78 * 18.0) + (0 * 11.9)$ = 572

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For these 2 crops and 572 million m³ of water, do you see other land allocations that use up all the water supply?

- How many allocations of land to those 2 crops would exhaust 572 million m³ water?
- Answer _____?
- Challenge: We want the best allocation of land among crops
- Key word: _____

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Q: What is Best Use of Land for Maximizing Total Farm Income?

Land in production by Crop (1000 ha):

- Cotton = 31.78, Wheat = 0

Water Use by Crop (million m³):

- Cotton = 572, Wheat = 0

Income by Crop (\$ 1000 US):

- Cotton = \$US 25,928, Wheat = 0

Total Income: = \$25,928 (in 1000s)

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Can you help the farmer make more income with information on the data slide. They have no computers, and need advice.

Exercise: Free cup of tea for anybody who can make more than \$25,928 (in 1000s) with available river water.

5-10 minute exercise.

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Break

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Let's think about the economic value of water in agriculture

- xx

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Let's think about more crops and more provinces

There are more than 2 crops and more than 1 province

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Simple v Complex Models

- Simple Model
 - 2 crops
 - 1 province
 - 1 water supply scenario
- More Complex Models
 - Several crops
 - Several provinces
 - Several water supply possibilities
 - Several possible rules for sharing shortages among provinces

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Basin Inflows Used

- Ag Water Use from Tigris + Euphrates
- Equal to total observed water use in irrigated agriculture from a base year (2006)
- Iraq Data from Saud Amer, January 2012

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Optimization Software

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Optimization Software

- We use GAMS (General Algebraic Modeling System) to model optimization of farm land/water use

GAMS Structure

SETS

(crops, provinces, water supply scenarios, shortage sharing rules, ... time, use)

DATA

(prices, costs, yields, water supply)

VARIABLES

(water use, land use, farm income)

EQUATIONS

(objective functions and constraints)

SOLVER

(LP and NLP)

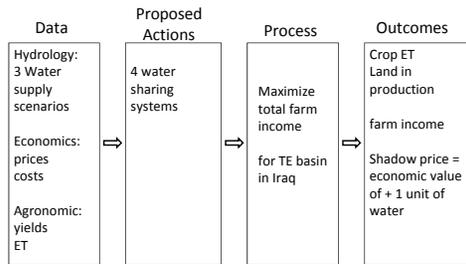
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GAMS

- Development sponsored by World Bank in 1970s
- Went private in 1980s
- More, faster, and better solvers (1980s – today)
- Why GAMS is useful: Expandability
 - Toy sized models expand to real world application (models 1 – 6)
 - Suited for river basin optimization
 - Model structure easy to formulate
 - When more detail needed, add: crops, reservoirs, tributaries, seasons, years, water uses

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Policy Assessment Framework



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Course Plan:

Mission - Find a water allocation that maximizes farm income with available water supplies

- We plan to cover 6 models in the days ahead. All are stimulating and interesting.
- All optimize water use in irrigated agriculture.
- All use information on the economic value of water in irrigated agriculture.
- We'll have many class exercises
- All models and results are based on Iraqi data secured by Dr. Saud Amer in 2012
- Discuss needed model improvements, future classes

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Model 1 (done)

You allocate land among 2 crops

- 2 crops: Wheat and Cotton
- 1 province: Mousil
- 1 Water constraint: 572 million m³
- 572 million m³ = observed use summed over those crops for that province.
- Goal: find the allocation of water among crops that maximizes total farm income.

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Model 2

You allocate water among crops and provinces

- 2 provinces: Mousil and Basra.
- 2 Crops: Wheat and Cotton.
- Water supply: 800.31 Million m³.
- Goal: Maximize total farm income

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Model 3

You assess economic impact of drought on irrigation

- 2 provinces: Mousil and Basra.
- 2 Crops: Wheat and Cotton.
- 2 Water Supplies: Normal (~800) v Dry (~400)
- Constraint: historical upper bound on land in production by crop and province
- Goal: Maximize Total Farm Income

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Model 4

Allows you to economically assess methods of sharing shortages during drought

- 2 provinces: Mousil and Basra
- 2 Crops: Wheat and Cotton
- Constraint: upper bound by crop and province
- 2 water supplies: "Normal" v "Dry"
- 2 shortage sharing methods: upstream priority vs. proportional sharing of shortages
- Automatic multiple solves (over water supply and water sharing rules) inside loops
- Goal: Maximize Total Farm Income

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Model 5:

You simplify display of results

- 2 provinces: Mousil and Basra
- 2 Crops: Wheat and Cotton
- Constraint: upper bound by crop and province
- 2 water supplies: Normal v Dry
- 2 Water sharing: upstream priority vs. proportional
- Same as model 4, but exports results to spreadsheet. Improves reading and interpreting of complex results.
- Saves to spreadsheet shadow price (economic value of additional water) by water supply and water sharing rule
- Goal: Maximize Total Farm Income

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Model 6: Monster

You take a national view of ag/water use with large # of scenarios and water sharing rules

- 13 provinces
- 9 Crops
- Constraint: upper bound by crop and province
- 3 water supplies: Normal, Dry, Drought
- 4 Water shortage sharing rules: upstream priority, downstream priority, proportional sharing, free market trading
- Export results to Excel sheet for display.
- Calculate shadow prices: economic value in ag of added water (\$US/1000 cubic meters) if the added water could be found, developed, pumped, conserved, or negotiated.
- Goal: Maximize Total Farm Income

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Model 6: Monster

Lets you analyze how losses in farm income at the farm and basin levels is affected by various water allocation methods for adapting to drought of various severity.

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Conclusions

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Water Economics Optimization Models

- Comparisons across country/basin/region/project
- Quantifies incentives to meet social aims
- Consistent calculation npv of water programs
- Can be used to guide policy reform (e.g. regulations, pricing, or water sharing rules)
- Several layers of detail targeted by different audiences

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Water Economics Optimization Models

- Can be applied to any country/basin/region/project
- Flexibility of inputs and outputs
- Capacity for sensitivity analysis ($\partial Y_i / \partial a_j$)
- Values water in alternative uses, time periods, crops, locations

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Top 10 Lies told by Water Modelers

1. The model is well-documented with all limits
2. The model is user-friendly
3. The model fits the data
4. Results make sense
5. The model does that
6. We did a sensitivity analysis
7. Anyone can run this model
8. This model links to other models
9. The model will be in the public domain
10. The new version fixes all previous problems



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