Spatial irrigation management to sustain groundwater and economic returns

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Introduction

What is the opportunity cost of groundwater conservation to achieve greater economic returns for an agricultural landscape with and without “water-saving” irrigation technologies?
Irrigation storage reservoir
Tail-water recovery structure

Surge irrigation
Center pivot irrigation
Introduction

What is the opportunity cost of groundwater conservation to achieve greater economic returns for an agricultural landscape with and without “water-saving” irrigation technologies?

Optimization determines:
• acreage of crops (rice, soybeans, corn, etc.)
• adoption of irrigation technologies subject to water and land availability.
• economic returns and depletion of the aquifer
Land balance equation

\[ \sum_{j} \sum_{k} L_{ijk}(t) = \sum_{j} \sum_{k} L_{ijk}(0) \]

Land demand \hspace{1cm} Land availability

\[ L_{ijk}(t) = \text{amount of land in cell } i \text{ in state } j \text{ using irrigation technology } k \]
**Water balance equation**

\[
\sum_j \sum_k w d_{jk} L_{ijk}(t) \leq GW_i(t) + RW_i(t)
\]

Water demand \hspace{1cm} Water availability

\(GW_i(t)\) = water pumped from the ground
\(RW_i(t)\) = water pumped from the reservoir

**Aquifer stock equation**

\[
AQ_i(t) = AQ_i(t-1) - \sum_{k=1}^{m} p_{ik} GW_k(t) + nr_i
\]

\(AQ_i(t)\) = groundwater in the aquifer
\(p_{ik}\) = groundwater flowing out of site \(i\) and into site \(k\)
\(nr_i\) = natural recharge
Farm Net Benefits Objective

\[
\text{Profit w/o water costs} \quad \text{Reservoir construction cost} \quad \text{Reservoir water pumping cost} \quad \text{Ground water pumping cost}
\]

\[
\max \sum_{t=1}^{T} \delta_t \left( \sum_{i=1}^{m} \sum_{j=1}^{n} \left( pr_{ij} - ca_{ij} \right) L_{ij}(t) - c^w FR_{ij}(t) - c^w RW_{ij}(t) - GC_{ij}(t) GW_{ij}(t) \right)
\]

Subject to: constraints of land and water availability.

Results
Efficiency frontiers

Current landscape

Conventional irrigation only

All irrigation technologies

Present Value of Economic Returns (Billions of Dollars)

Land use for max profits points on the efficiency frontier

Land use (thousands of acres)

Rice  |  Irrigated soybeans  |  Corn  |  Sugarcane  |  Pipe irrigation  |  Center pivot  |  Land leveling  |  Irrigated cotton  |  Wheat  |  Non-irrigated soybeans  |  Non-irrigated land  |  Reservoirs

K  |  E  |  J
Land use for max aquifer points on the efficiency frontier

Crop mix patterns
Percentage of land in reservoirs

Sensitivity analysis: No reservoirs
Sensitivity analysis: Irrigation efficiency

Conservation policies

Aquifer, 2043
Farm net returns
**Conclusions**

- Opportunity cost of groundwater with max profits
  - 71% of max aquifer if conventional irrigation only
  - 79% of max aquifer if all irrigation technologies

- Max profits increase 74% if use all irrigation technologies

- Policies to cost-effectively achieve conservation goal
  - Cost-share pipe hole selection implementation
  - Tax on groundwater