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# **Regional Irrigation Management with Conjunctive Surface and Groundwater Use**

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# Regional Irrigation Management with Conjunctive Surface and Groundwater Use

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## Introduction

The continuous decline of aquifers as consequence of groundwater extraction for agricultural irrigation is not only an environmental concern, but it also puts at risk farm economic returns. The aim of this study is to investigate the tradeoff between the economic performance of farms and the volume of the aquifer on a spatially explicit landscape for which a large selection of crops and irrigation practices are used. The application of the model is to the Lower Mississippi River Basin (LMRB) in the state of Arkansas, which is the Mississippi Delta's largest user of the aquifer.

## Methods

The spatially explicit model uses a grid of sites that represent spatially specific crop yields associated with soil quality and spatially symmetric cones of depression from groundwater pumping. The available groundwater depends on the pumping decision of farmers in and around each site. We track the amount of land in each of the major crops in the region (irrigated corn, irrigated cotton, rice, irrigated soybean, double crop soybean/winter wheat, non-irrigated sorghum, and non-irrigated soybean) for potential irrigation systems of the region (conventional i.e. gravity with poly-pipe for crops other than rice and flood for rice, sprinkler systems such as center pivot, computerized poly pipe-hole selection, surge, land leveling, alternate wet-dry, multiple-inlet). We also model the presence of on-farm reservoirs built on land previously used for crops to store surface water to reduce reliance on groundwater. The model is solved over a 30 year period from 2013 to 20243.

### Land dynamics.

We allow transition of land into any of the major crops or into reservoirs with any of the specified irrigation systems so that the cumulative amount of land after the transition equals the original amount of land.

### Water dynamics.

We simulate groundwater dynamics on the basis of spatially specific water demand depending on rainfall, natural recharge, irrigation technologies, crops, and the amount of surface water from reservoirs. The area of the reservoirs influences how completely full the reservoir will be from rainfall and runoff. We define the acre-feet of water stored in an acre reservoir as

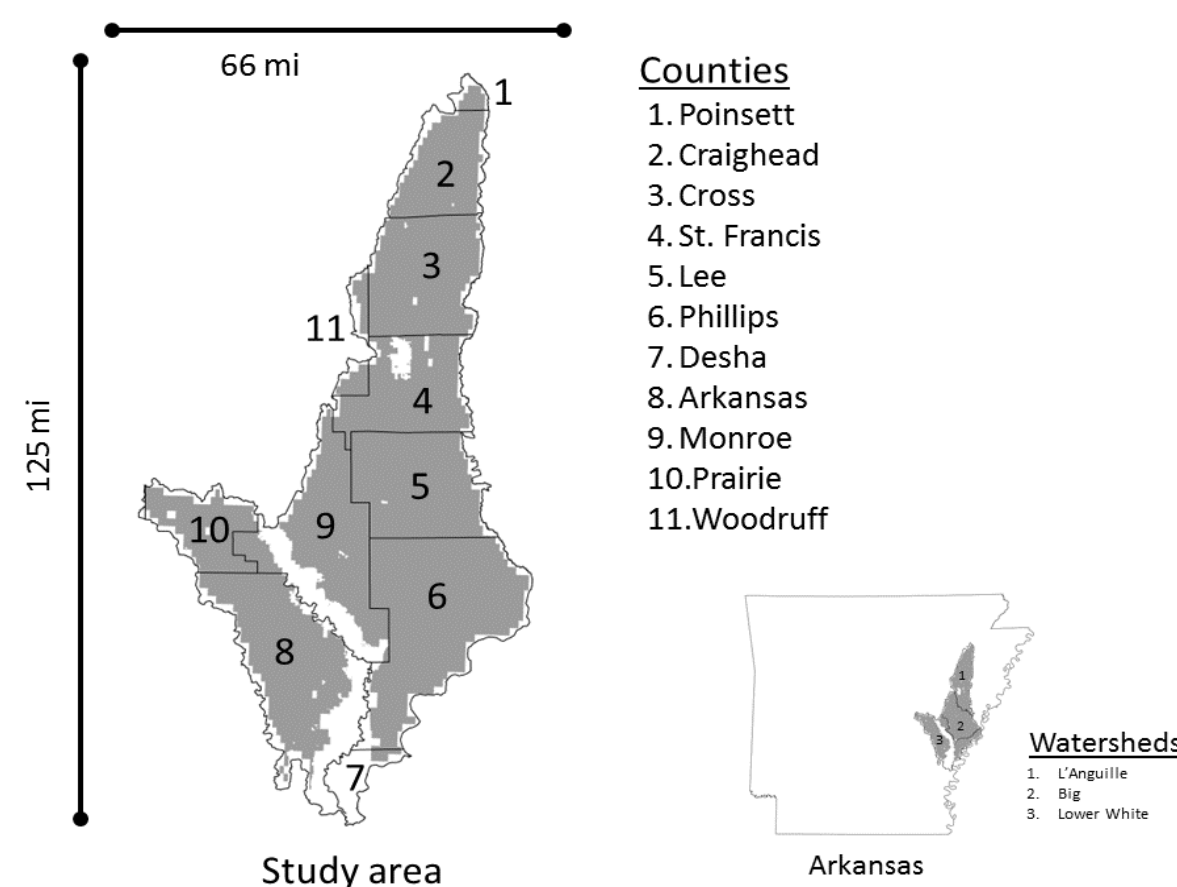
$$(\omega_{\max} + \omega_{\min}) - \sum_j \sum_k \frac{\omega_{\max}}{L_{ijk}(0)} R_i(t),$$

where  $\omega_{\min}$  represent the low end acre-feet of water in an acre of reservoir when only rainfall fills it;  $\omega_{\max}$  is the acre-feet of water an acre reservoir can hold from runoff at full capacity;  $\sum_j \sum_k L_{ijk}(0)$  indicates the total acreage for each site, and  $R_i(t)$  indicates the reservoir acreage in any of the sites.

### Aquifer objective.

We maximize the volume of the aquifer beneath the study area in the final period, in

**Figure 1.** Study area: the LMRB in Arkansas



order to determine the landscape pattern that minimizes the depletion of the aquifer.

### Economic returns objective.

The objective is to determine the number of acres of each crop and reservoirs and irrigation water pumping to maximize the present value of profits of farm production over the 30 year period. Costs include the construction and maintenance of irrigation capital, the fuel for the pumping water from the reservoirs or ground, and all other production costs.

### Efficiency frontier and policy options.

We create an efficiency frontier (aquifer conservation vs. economic returns) with and without water saving technologies for irrigation. We also evaluate policy options for groundwater conservation (cost share on reservoirs, land leveling, and pipe-hole selection vs. a groundwater tax).

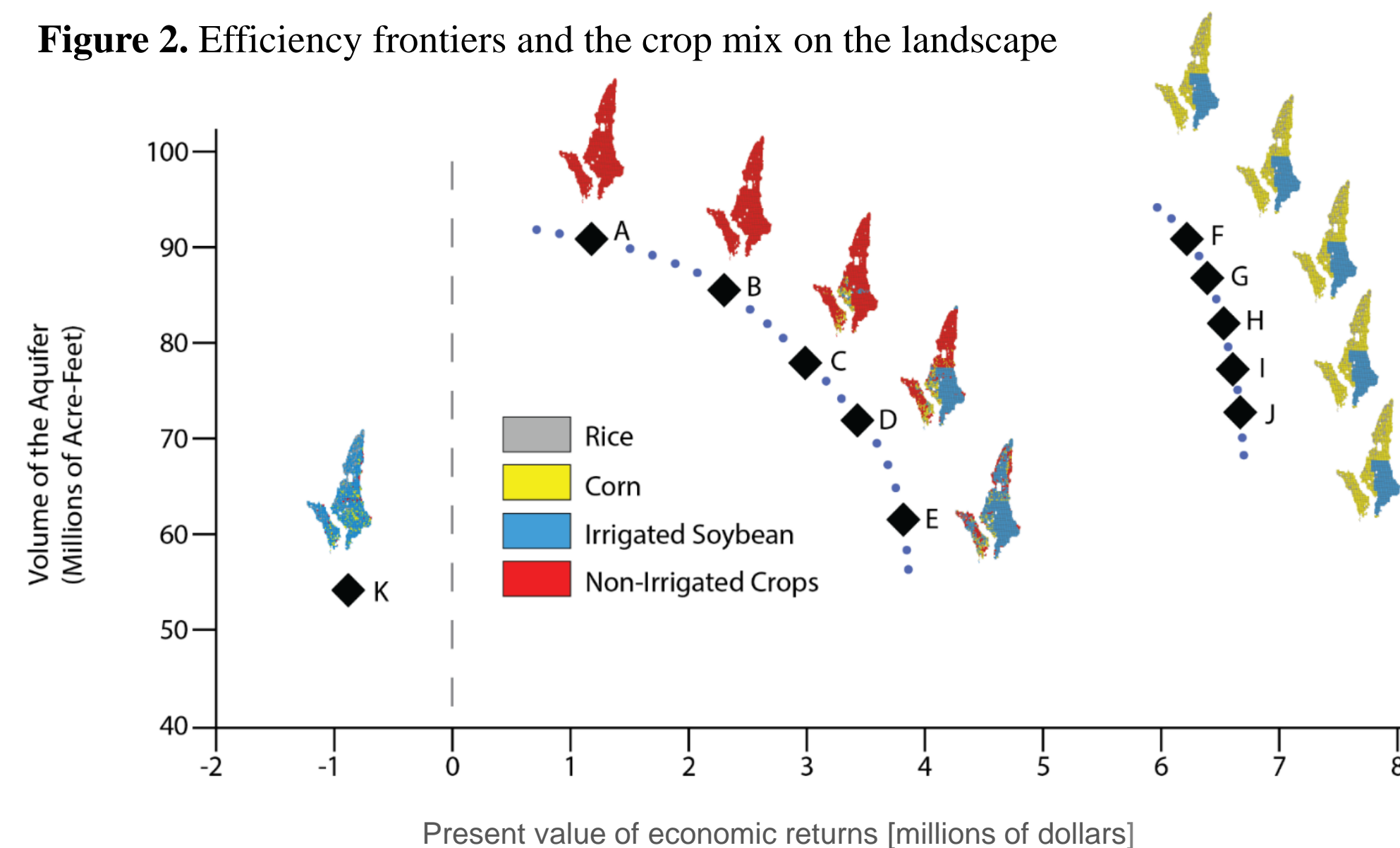
## Data

We use a study area (Figure 1) comprised of three 8-digit hydrologic watersheds in the Arkansas Delta (L'anguille, Big, and the Lower White). The initial acreage of crops in each site comes from the 2013 Cropland Data Layer; average county crop yields for the past 5 years are a proxy for yields of each of the crops; we use a 2% real discount rate. The costs of production by crop excluding irrigation costs come from the 2012 Arkansas Enterprise budgets. The costs for the irrigation systems come from the Natural Resource Conservation Service and irrigation system effects on yield are drawn mostly from studies by the Arkansas Cooperative Extension Service.

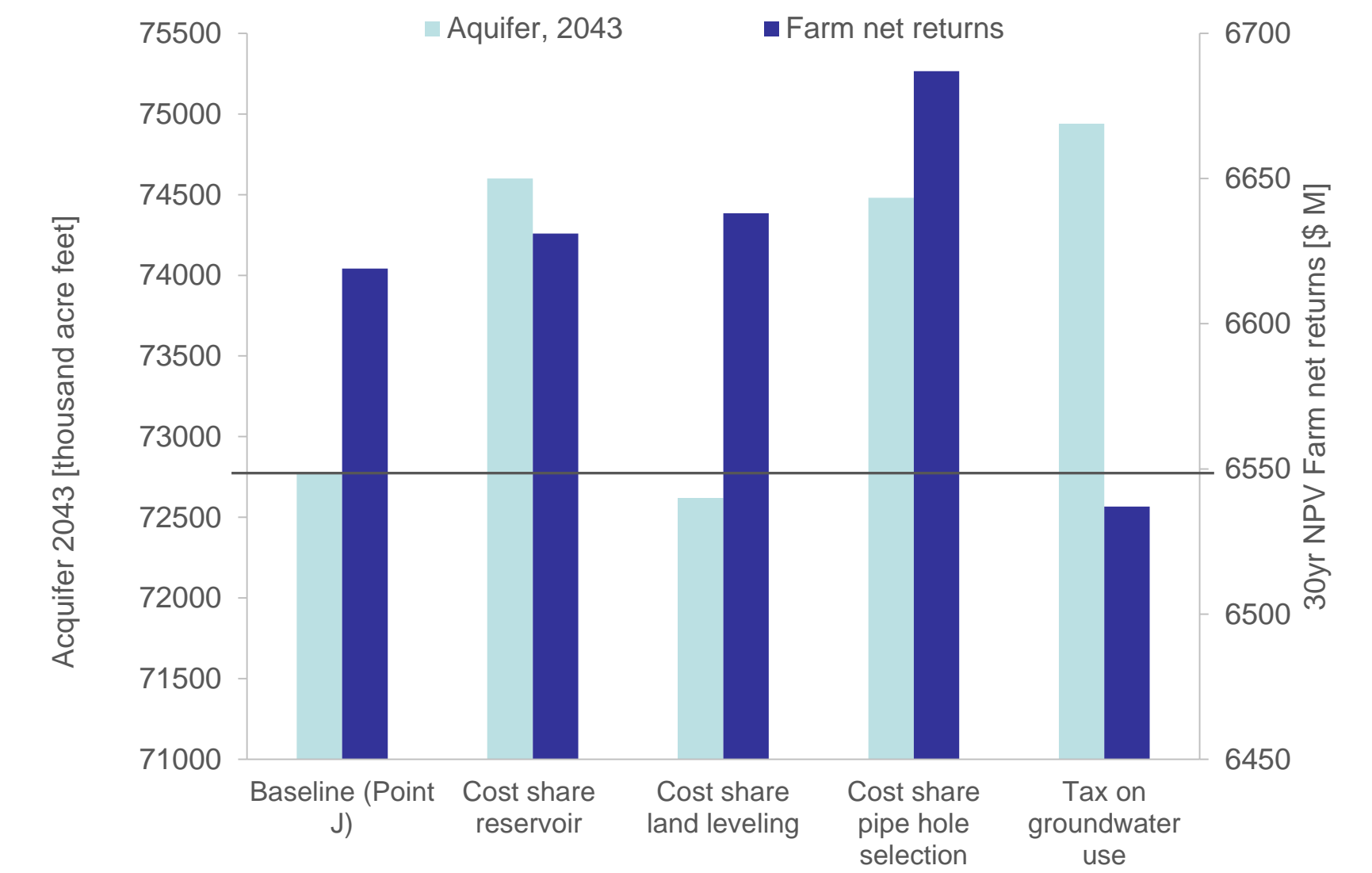
## Results

Shown in Figure 2 are the major crops grown in 20243 for points along an efficiency frontier with only a conventional irrigation system (points A to E) and with all the new irrigation technologies (points F to J) using an optimization model that balances the aquifer and economic return objectives. The spatial underground water flow among sites makes the optimization problem to identify the frontier points complex to solve. Compared to the current landscape (point K), points A to E have less soybeans and more non-irrigated crops, and points F to J have less soybeans and more corn and rice. Access to surface water through reservoirs allows producers to avoid growing non-irrigated crops at point F.

**Figure 2.** Efficiency frontiers and the crop mix on the landscape

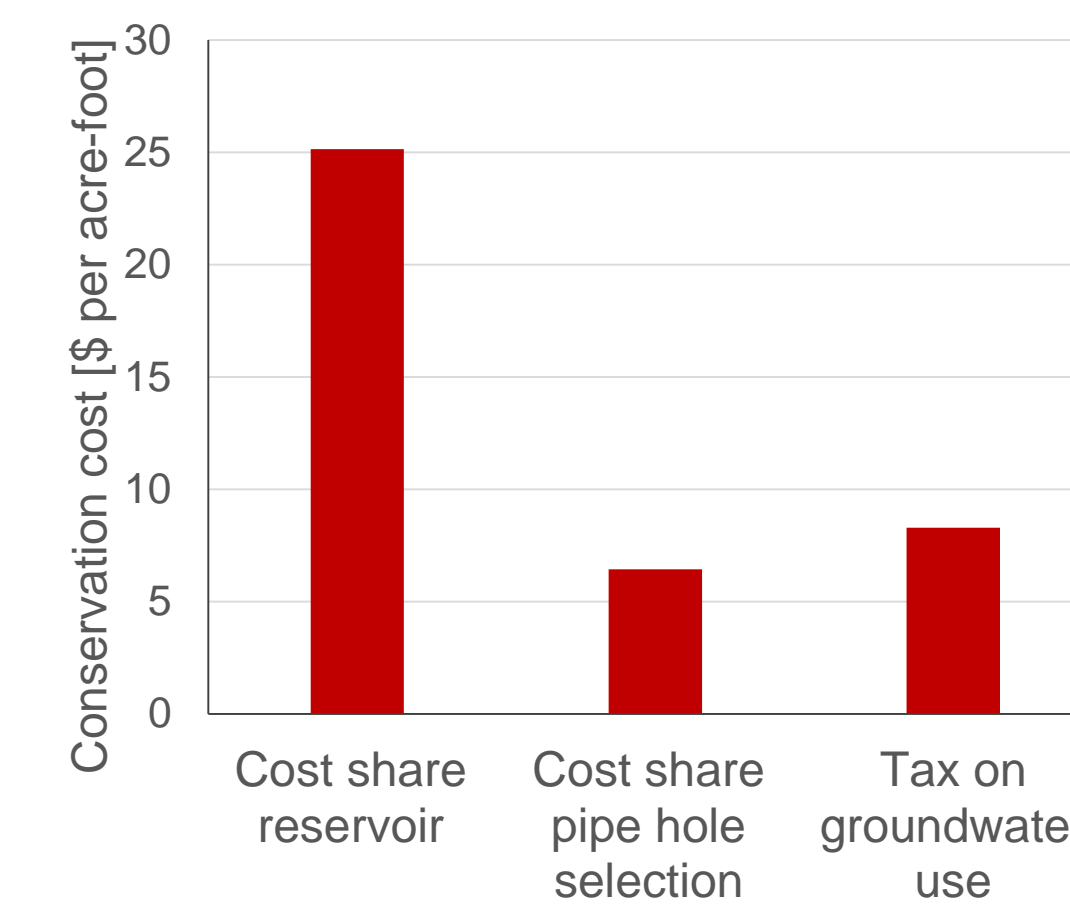


**Figure 3.** Conservation policies' effect on the aquifer and farm net returns

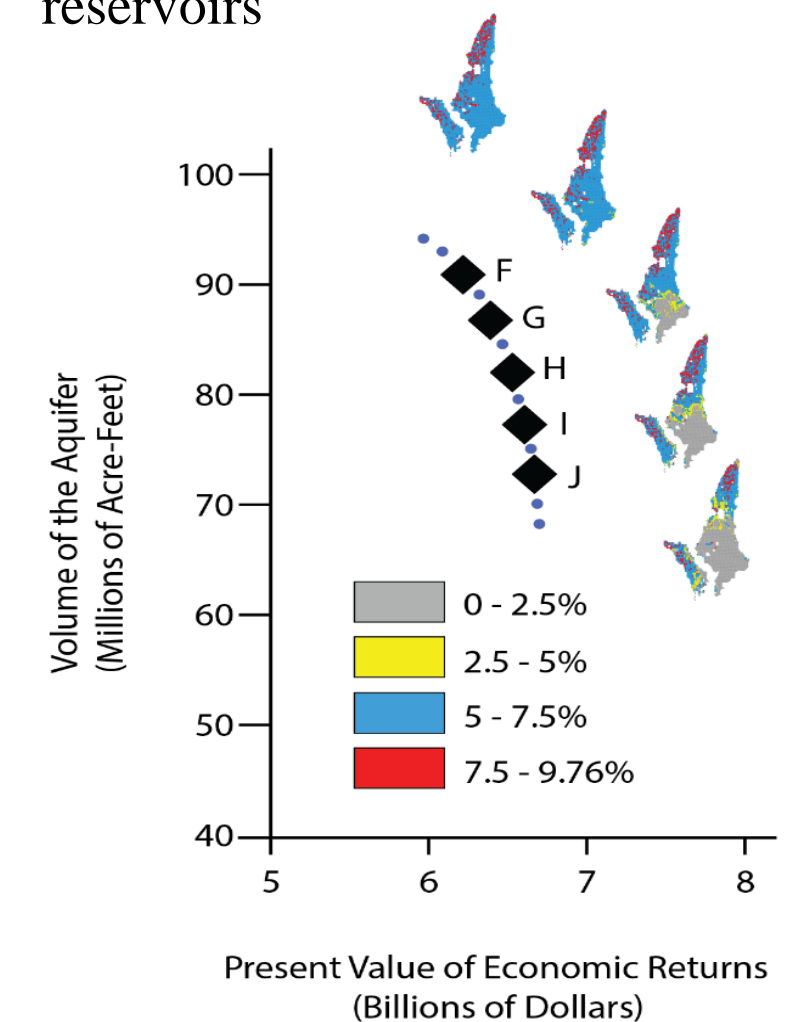


The policy option that generates the highest farm returns and the third highest aquifer level is the cost share for the pipe-hole selection program (Figure 3). The combination of these two elements results in the most cost-effective policy option to prevent groundwater depletion (Figure 4). The second cheapest policy option to preserve the aquifer is a tax on groundwater use. Figure 5 shows that there is a shift of reservoirs largely in the northern and western sections of the study area toward reservoirs throughout the study area as the aquifer objective is emphasized more relative to the economic objective.

**Figure 4.** Groundwater conservation cost



**Figure 5.** Percentage land in on-farm reservoirs



## Conclusions

We find the possibility to maintain a high level of the aquifer and generate large economic returns through careful spatial management of crops. If water saving technologies are used, a reduction of only 3% in economic returns is required to raise the percentage of aquifer volume sustained on the landscape to above 90% of the maximum attainable. The first best policy option to attain the groundwater conservation goal is the cost share for pipe-hole selection, the second best is a tax on water use.