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The Role of Land Retirement Programs for Management of Water Resources

by

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1. Introduction

The water resources of the Eastern Snake River Plain Aquifer (ESPA) are at the forefront of the water shortages and dispute in Idaho. The ESPA is the single-most important aquifer in Idaho. Irrigation practices and reduced reliance on surface water diversions have decreased the spring discharge and groundwater levels in the ESPA. Increased pumping withdrawals and reduced seepage from surface water as a result of conversions from surface to sprinkler irrigation have led to a short fall of about 900,000 acre feet recharge every year to the aquifer. In Magic Valley alone, about 1,300 farmers received notice to shut down their pumps, and 113,000 acres kept idle (IGWA, 2004). Finding solution to Idaho's water management problems is critical to the sustainability of agriculture, livestock, and aquaculture sectors in Idaho. These sectors provide many local jobs and contribute significantly to the Idaho's economy. Since they heavily rely on surface and groundwater, their long-term viability depends on the sustainable management of water resources. In particular, serious threat of decline in the groundwater table calls for the management of water resources such that there is a favorable balance between the economic development and environment.

In order to find short-term and long-term solutions to Idaho's water supply and management problems, various public policy proposals have been introduced. For example, shutting down thousands of groundwater pumps that reduce the flows of springs from the ESPA has been considered. Another proposal considered by Idaho legislators has focused on curtailing junior-right water users. This proposal aims at changing the ESPA water budget by 600,000 to 900,000 acre feet annually (Legislative Perspective, 2004). It will cost about $80 to $100 million over 30 years and pay willing farmers and business owners to give up their water rights (IGWA, 2004). Since curtailment of some groundwater pumping is considered as the part of solution, the federal Conservation Reserve Enhancement Program (CREP) has been proposed to make curtailment voluntary. This program would pay annual rental payments to eligible farmers in order to take up to 100,000 acres of land out of production.

Several studies have examined the efficient allocation of groundwater (Brown and Deacon, 1972; Allen and Gisser, 1984; Feinerman and Knapp, 1983; Roseta-Palma, 2003; Kim et al., 1989; Rubio and Casino, 2003). These studies suggest various policies to achieve the desired socially optimal extraction. Policy recommendations include taxes, quotas, subsidies, tradable permits, and standards. Although it is theoretically easy to determine optimal taxes/subsidies, various problems are associated with implementations such as monitoring, heterogeneity in farmer characteristics, high transaction costs, and varying tax/subsidy rates over time to reflect increasing scarcity (Hellegers and Ierland, 2003; Roseta-Palma, 2002, 2003). Thus, there is a need to develop alternative policies and programs that are easy to implement and can avoid many of the problems associated with the market-based policies considered above. An example of such a policy that has been recommended for reducing water use from the agriculture is the voluntary land retirement program.

There has been relatively little attention given to the effectiveness and implications of voluntary land retirement programs as a policy option to manage groundwater. It is important to understand the extent to which land retirement programs are cost-effective in achieving the water allocation goals. Although several studies examined the cost-effective targeting of the Conservation Reserve Program (Babcock et al., 1996, 1997; Ribaudo, 1986, 1989) and the Conservation Reserve Enhancement Program (Khanna et al., 2004; Yang et al., 2005; Yang and

Isik, 2004) for non-point source pollution control, there is currently no study examining the implications of land retirement programs for achieving water quantity goals.

The purpose of this paper is to develop a model of water resource management that incorporates heterogeneity in farmer characteristics to analyze the socially optimal management of groundwater allocation with a land retirement program. First, we formulate an optimal control problem that determines the socially optimal water use and land allocations among alternative crops and compare those to the privately optimal solutions. Second, we introduce an optimal control problem of a least-cost land retirement program that achieves a given level of groundwater stock to examine the implications of land retirement programs and their cost-effectiveness in achieving the optimal water allocations. The developed model is empirically applied to the ESPA.

This study contributes to the existing literature on the management of groundwater resources as well as the design and implementation of alternative land retirement policies. It incorporates heterogeneity in resource users in terms of soil characteristics, productivity, costs of production, water use, land availability, and crops produced in modeling groundwater extractions. Most existing studies of groundwater management (e.g., Roseta-Palma, 2002, 2003; Qiuqiong and Scott, 2004) fail to capture this heterogeneity among farmers. We also provide implications of land retirement programs for the water resource management by developing an optimal control model. This is the first investigation of land retirement programs for achieving water quantity goals. The framework developed in this paper can be applied to other regions and water conflicts to analyze the implications of various public policies for finding solutions to water management problems. The results from this paper have important implications for the design and implementations of alternative policies for the management of scarce water resources.

2. Theoretical Model

We consider an aquifer serving as a source of groundwater for irrigation to *M* farmers with $\overline{A}_i$ acreage producing *j* crops. The per-acre groundwater extracted by farmer *i* at time *t* is denoted as g_{ijt}. The pumping lift, d_i, is defined as the initial distance from the surface to the water level. It varies across heterogeneous farmers for a given level of groundwater stock G_t. The cost of groundwater extraction, $C(G_t, d_i)$, depends on the groundwater stock and pumping lift. It is assumed to be convex in G_t ($C_G < 0$ and $C_{GG} > 0$). Let z_i represent the soil characteristics. The production function depends on the applied water (g_{ijt}), water-use efficiency (α_i), and soil characteristics (z_i) as: $y_{ijt} = f(\alpha_i g_{ijt}, z_i)$ with $\frac{\partial f}{\partial g} > 0$ and $\frac{\partial^2 f}{\partial g^2} < 0$. The water-use efficiency defines the fraction of the water that is actually utilized by a crop. The product $\alpha_i g_{ijt}$ represents the amount of applied water that is effectively used (Caswell et al., 1990).

The differential equation describing the groundwater dynamics is the net gain to the aquifer, provided that the natural recharge (*R*) is higher than the total extraction:

$$\frac{dG}{dt} = -\sum_{i,j} A_{ijt}\alpha_i g_{ijt} + R. \tag{1}$$

The per-acre profit of farmer *i* at time *t* for crop *j* is given by

$$\pi_{ijt} = P_j y_{ijt} - C(G_t, d_i) g_{ijt} \tag{2}$$

where P_j is the output price. Let A_{ijt} be the acreage to be allocated to crop *j* such that $\sum_j A_{ijt} \leq \overline{A}_i$.

Optimal Land and Groundwater Allocations

The water planner's problem is to maximize the net present value of the total profits in the region subject to equation (1) and $\sum_j A_{ijt} \le \overline{A}_i$ in order to determine the optimal water use and land allocations among crops as:

$$\max_{g_{ijt}, A_{ijt}} \int_0^N \sum_{i,j} e^{-\rho t} A_{ijt} \left[P y_{ijt} - C(G_t, d_i) g_{ijt} \right] dt \tag{3}$$

where ρ is the discount rate. By augmenting the Hamiltonian, we can write the present-value Lagrangian with the information in the inequality constraint as (Chiang, 1992, p. 278):

$$\Lambda = \sum_{i,j} e^{-\rho t} A_{ijt} \pi_{ijt} e^{-\rho t} + \lambda_1 \left[-\sum_{i,j} A_{ijt} \alpha_i g_{ijt} + R \right] + \lambda_{2i} \left[\overline{A}_i - \sum_j A_{ijt} \right]. \tag{4}$$

Assuming interior solutions (i.e., $g_{ijt} \ge 0$ and $A_{ijt} \ge 0$), we have the following conditions for the maximum principle along with the equation of motion for *G* in (1):

$$\frac{\partial \Lambda}{\partial g_{ijt}} = \frac{\partial \pi_{it}}{\partial g_{ijt}} e^{-\rho t} - \lambda_1 \alpha_i = 0 \tag{5.a}$$

$$\frac{\partial \Lambda}{\partial A_{ijt}} = \pi_{ijt} e^{-\rho t} - \lambda_1 \alpha_i g_{ijt} - \lambda_{2i} \ge 0,\ \ \lambda_{2i} \ge 0,\ \ \frac{\partial \Lambda}{\partial A_{ijt}} \lambda_{2i} = 0 \tag{5.b}$$

$$\frac{\partial \Lambda}{\partial G} = \sum_{i,j} A_{ijt} e^{-\rho t} \frac{\partial \pi_{ijt}}{\partial G} = -\frac{d\lambda_1}{dt}. \tag{5.c}$$

Equation (5.a) states that under the social optimality the marginal benefit of groundwater use is equal to the marginal cost of groundwater extraction plus the shadow price of effectively used groundwater. This shadow price reflects the cost imposed on the future generation by using water now. Equation (5.b) with λ_1 obtained from (5.a) implies that $\pi_{ijt} e^{-\rho t} - g_{ijt} \frac{\partial \pi_{it}}{\partial g_{it}} e^{-\rho t} - \lambda_{2i} \ge 0$, where λ_{2i} is the shadow price of land availability constraint. This indicates that the farmers allocate the land to the crop with the highest ratio of the benefits with the crop production to the costs imposed on future water users. Equation (5.c) gives the dynamics of shadow price of the groundwater stock. The steady-state total extraction and groundwater stock are derived with the assumption of $\frac{\partial g_{ijt}}{\partial t} = \frac{\partial G}{\partial t} = 0$ as: $\lambda = -\frac{\partial C}{\partial G} \sum_{i,j} A_{ij} g_i / \rho$ and $\sum_{i,j} A_{ij} \alpha_i g_{ij} = R$.

Under the private optimal solution, the farmers maximize the expected profits and determine the groundwater use such that the marginal benefit of the water use equals the marginal private cost (i.e., $P_j \frac{\partial f}{\partial g_{ijt}} - C(G_t, d_i) = 0$). The farmers do not take into account the additional cost of groundwater use, namely the cost imposed on the future water use. Thus, the optimal water use under the private optimality is higher than the social optimality. Under the private optimality, the land allocation decision is made such that $\pi_{ijt} e^{-\rho t} - \lambda_{2i} \geq 0$. This implies that the farmers allocate the land to the crop with the highest profit.

Land Retirement Programs for Managing Groundwater

We now develop a least-cost land retirement policy to achieve a given level of groundwater stock. We consider a policy that targets achieving a given level of stock ($\overline{G}$) in N years. We define L_{it} as the acreage to be retired from farmer i at year t such that $\sum_j (A_{ijt} + L_{it}) \leq \overline{A}_i$. Since the retired land may not be brought back to the production, we define a new state variable Γ_{it} as the size of the parcel that is available for the land retirement at time t. The equation of motion for Γ_{it} is $\frac{d\Gamma_{it}}{dt} = -L_{it}$, with $\Gamma_{i0} = \overline{A}_i$. This indicates that the amount of land available over time decreases by L_{it}.

The water planner's problem is:

$$\max_{g_{ijt},A_{ijt},L_{it}} \int_0^N \sum_{i,j} (A_{ijt} - L_{it}) \pi_{ijt} e^{-\rho t} dt \tag{6}$$

subject to

$$\frac{dG}{dt} = -\sum_{i,j} (A_{ijt} - L_{it}) \alpha_i g_{ijt} + R \tag{7}$$

$$\sum_j (A_{ijt} + L_{it}) \le \overline{A}_i \tag{8}$$

$$\frac{d\Gamma_{it}}{dt} = -L_{it} \tag{9}$$

$$L_{it} \le \Gamma_{it} \tag{10}$$

$$G_N = \overline{G}\ . \tag{11}$$

Equation (8) is the total land availability constraint for each farmer. The dynamics of the land available for retirement and the constraint on the maximum amount of land that can be retired over time are given by equations (9) and (10), respectively. The target groundwater stock to be achieved in *N* years is given by equation (11). Augmenting the Hamiltonian leads to the following Lagrangian with the inequality constraint (Chiang, 1992, p. 278):

$$\begin{aligned}\Lambda = &\sum_{i,j} (A_{ijt} - L_{it}) \pi_{ijt} e^{-\rho t} + \lambda_1 \left[-\sum_{i,j} (A_{ijt} - L_{it}) \alpha_i g_{ijt} + R \right] + \lambda_{2i} \left[\overline{A}_i - \sum_j (A_{ijt} + L_{it}) \right]. \\ &- \lambda_{3i} L_{it} + \lambda_{4i} (\Gamma_{it} - L_{it})\end{aligned} \tag{12}$$

We obtain the following conditions for the maximum principle along with the equation of motion for *G* in (7):

$$\frac{\partial \Lambda}{\partial g_{ijt}} = (A_{ijt} - L_{it}) \frac{\partial \pi_{ijt}}{\partial g_{ijt}} e^{-\rho t} - \lambda_1 (A_{ijt} - L_{it}) \alpha_i = 0 \tag{13.a}$$

$$\frac{\partial \Lambda}{\partial A_{ijt}} = \pi_{ijt} e^{-\rho t} - \lambda_1 \alpha_i g_{ijt} - \lambda_{2i} \geq 0\,,\;\; \lambda_{2i} \geq 0\,,\; \frac{\partial \Lambda}{\partial A_{ijt}} \lambda_{2i} = 0 \tag{13.b}$$

$$\frac{\partial \Lambda}{\partial L_{it}} = -\pi_{ijt} e^{-\rho t} + \lambda_1 \alpha_i g_{ijt} - \lambda_{2i} - \lambda_{3i} - \lambda_{4i} \geq 0\,,\;\; \lambda_{4i} \geq 0\,,\; \frac{\partial \Lambda}{\partial L_{it}} \lambda_{4i} = 0 \tag{13.c}$$

$$\frac{\partial \Lambda}{\partial G} = \sum_{i,j} (A_{ijt} - L_{it}) e^{-\rho t} \frac{\partial \pi_{ijt}}{\partial G} = -\frac{d\lambda_1}{dt} \tag{13.d}$$

$$\frac{\partial \Lambda}{\partial \Gamma_{it}} = \lambda_{4i} = -\frac{d\lambda_{3i}}{dt}. \tag{13.e}$$

Equation (12.a) defines the optimal water use for each farmer. Equation (13.a) describes the Kuhn-Tucker conditions for the optimal land allocation A_{ijt}. The optimal land retirement is determined from equation (13.b). Using equations (13.a) and (13.c), we can find out the factors affecting the choice of land parcel for retirement. Farmer *i*'s land is retired if $-\pi_{ijt} e^{-\rho t} + \lambda_1 \alpha_i g_{ijt} - \lambda_{2i} - \lambda_{3i} - \lambda_{4i} \geq 0$ or $-\pi_{ijt} e^{-\rho t} + \frac{\partial \pi_{ijt}}{\partial g_{ijt}} e^{-\rho t} g_{ijt} - \lambda_{2i} - \lambda_{3i} - \lambda_{4i} \geq 0$. This also implies that the land parcel with the highest benefit to cost ratio, $(\lambda_1 \alpha_i g_{ijt}) / (\pi_{ijt} e^{-\rho t})$, would be selected first for the land retirement. This model describes the optimal targeting of land retirement to achieve the water quantity goal. It requires a rental payment of at least π_{ijt} at time *t* in order to induce farmers to participate in the program.

An alternative land retirement program is to take a given number of acres ($\bar{L}$) out of production in *N* years. Under such a policy, the water planner's decision problem is similar to the one given in equations (6)-(11), with the only difference equation (11) being replaced by $\int_0^N \sum_i L_{it} dt \geq \bar{L}$. The goal of this policy is to retire $\bar{L}$ acres with least cost. This policy does not consider where the land parcels to be retired are located and therefore ignore their contributions to the water degradation in the aquifer. Following the same approach used above, the conditions for the maximum principle can be easily obtained.

We now describe a uniform land retirement strategy that offers a uniform rental rate (*R*) for all the eligible farmers in the region. Under such a strategy, all the farmers with $\pi_{ijt} \leq R$ will participate in the program. The uniform policy is commonly implemented because it is easier to put into practice due to less information requirements. However, this policy may not be cost-effective because it does not target farmers with higher benefit (reduction in water use) to cost (rental payment) ratio. Given the expected profits of each farmer under the private optimality, we can determine the uniform rental rate (*R*) required to achieve a given number of acres retired ($\overline{L}$) in the region. The effectiveness of the uniform policy for water resource management in terms of the cost and water-use reduction is an empirical question. In the next section, we develop an empirical model to analyze the implications of alternative policies for the management of water resources in the ESPA.

3. Empirical Application and Data

The developed model is empirically applied to the ESPA in southern Idaho. We calibrate our theoretical model to the hydrological and soil conditions in the ESPA. The Eastern Snake River Plain extends as a two hundred mile long arc, about 60 miles in width, across southeast Idaho. Composed of layered basalt lava flows and some sediment, it covers an area of approximately 10,800 square mile across 16 counties (Cosgrove et al., 1999; Johnson and Cosgrove, 1999). The aquifer is semi-confined of about 4,000 feet thick at the center of the Snake River plain. It annually supplies about 40,000 acre feet of water for drinking and two million acre feet of water for irrigation and industry (INEEL, 2002). The ESPA is the only source of drinking water for most of the people in southeast Idaho. The ESPA is drained by the

Snake River and its tributaries. Total groundwater storage in the upper 500 feet of the aquifer is estimated at about 200 to 300 million acre-feet (Cosgrove et al., 1999). In most parts of the ESPA, rainfall is insufficient to support commercial levels of agriculture without irrigation.

We define 667 representative farms in 16 counties, with the irrigated and non-irrigated land acreage specified for each farm. These representative farms are determined based on their soil characteristics, location, and sources of water used. The soil maps of each farm in each county are obtained to determine yields of various crops depending on the soil characteristics (NRCS, 2005). The information on crop-specific variable costs such as inputs, planting and harvesting were obtained from the University of Idaho Crop Budgets (2003). The input costs include seed, fertilizers, labor, pesticides, and other production inputs. Using the crop yields, production costs and output prices, we generate crop-specific crop budgets for each representative farm.

The irrigation water used in agriculture in the ESPA comes from both the groundwater and surface water sources. The use of surface water in irrigation is the main source of the recharge in the aquifer. The empirical model considers the sources of water available in each county. Our model also distinguishes between irrigated and non-irrigated crop productions in the ESPA. In some parts of the ESPA, there is currently a small amount of non-irrigated crops acreage. The empirical model will allow farmers to switch to non-irrigated crops in response to the various public policy proposals in these areas. The major crops grown in the region include potatoes, wheat, barley, alfalfa, sugar beets, corn grain, corn silage, and dry edible beans. We define over 72 different crop rotations, with rotations ranging from 2 to 7 years. These rotations incorporate agronomic constraints and include many commonly used rotation practices in the ESPA. Some of the examples of these rotation practices are two-year grains followed by one-year potatoes, four-year grains followed by one-year sugar beets, and grains or beans with alfalfa.

The per-acre crop yield is assumed to be represented by a quadratic function as:

$$y_{ij} = \phi_{0j} + \phi_{1j}(\alpha_i w_{ij}) + \phi_{2j}(\alpha_i w_{ij})^2 . \qquad (14)$$

The parameters of the production function for all the crops considered in this study are calculated from the data representing the crop production in the ESPA. The University of Idaho crop budgets were used to determine the parameters of the production function (University of Idaho Crop Budgets, 2003). The information about the irrigation water requirements for various crops was obtained from the study by Allen and Brockway (1983). We assume that (a) there is no yield when the consumptive water use is zero for potatoes, sugar beets, corn grain, corn silage, and dry edible beans (i.e., $\phi_{0j} = 0$), (b) a maximum yield can be obtained with a given effective annual water use, and (c) the yield curve is a symmetric quadratic function so that the production is zero at twice the effective water use. Since wheat, barley, and alfalfa can be produced without irrigation water in some parts of the ESPA, the coefficients ϕ_{0j} for these crops represent the yields that can be obtained without applying water.

We assume that the efficiency of water use (α_i) is a function of technology choice and land quality represented by an index δ_i. Using the data from NRCS (2005), we generate a soil quality index and determine the distribution of soil quality for the entire region. The soil quality index δ_i is then scaled to correspond to the water use efficiency with the traditional technology (i.e., $\alpha_{1i} = \delta_i$) and can assume values from 0 to 1. In the region, the farmers use both the furrow technology and the sprinkler technology. When the efficiency of water use with the traditional furrow technology is 0.60, the adoption of a sprinkler irrigation system increases efficiency of water use to 0.85 (Neibling, 1998). We use this information to calibrate a constant elasticity function to relate the efficiency with the furrow irrigation to that with the sprinkler irrigation as $\alpha_{2i} = \delta_i^{0.318}$.

In the empirical application, we focus on the implications of land retirement programs for a given year, rather than determining the time paths of cropland to be retired. We assume that the water planner's problem is to achieve the water quantity goal in one year (i.e., N=1 in the theoretical model). We solve the decision problem in a two-stage framework. We first determine the optimal groundwater use for each farmer. We then determine the optimal allocations of land among various crops and analyze the implications of land retirement programs.

4. Results

We first determine the optimal cropping and rotation practices in the region to provide the base model results. This model maximizes the total returns in the region subject to the land availability constraint for each farm to determine the optimal cropping and rotation practices as well as the optimal water use for each farm. The results from this model will be compared to the land retirement policies to be developed below. Table 1 summarizes the acreage allocated to the irrigated and non-irrigated crops in each county in the ESPA. The farm-level rotation practices are aggregated to obtain the county-level land allocated to the irrigated and non-irrigated crops. The common optimal rotation practices followed by the representative farms with the rotations ranging from 2 to 7 years include alfalfa/potatoes/corn silage/wheat or barley, alfalfa/potatoes/wheat/barley, barley/wheat/potatoes, corn silage/wheat/potatoes, wheat/barley barley/corn/potatoes, barley/potatoes/beans, and wheat/alfalfa/barley. The total land allocated to the irrigated and non-irrigated crops are close to the actual land use in 2002. Thus, our base model replicates the existing farming conditions in the ESPA very well.

Alternative Land Retirement Programs

Table 2 presents the results of three alternative land-retirement programs; the uniform land retirement policy, the least-cost land retirement program with the acreage goal, and the program that reduces the total water use by 10%. The uniform land retirement policy examines the implications of a uniformly offered rental payments to all the eligible farmers in the region. This program is usually implemented with a bidding cap. For example, a soil-based bid cap is set at the county level in the Conservation Reserve Program. We consider a policy that offers a uniform rental rate to all the eligible farmers in order to retire 100,000 acres irrigated cropland. This target land is chosen because the current policy proposal aims at retiring 100,000 acres of cropland out of production in the ESPA. Non-irrigated land is not eligible for participation in the program. Under such a program, all the farmers with the expected profits from crop production less than the uniform rental rate will participate in the program. All the participating farmers will receive the same rental rate regardless of their productivity or water use in the region. We build a heuristic procedure to determine the uniform bid cap that would induce 100,000 acres irrigated cropland retirement. First, a low bid cap (rental rate) is set, land parcels with the expected profits below the bid cap are selected, and the total acreage enrolled is calculated. The rental rate is then increased by small increments until the acreage goal in the region is achieved. The uniform rental rate is found to be $147/acre. The farmers taking their land out of production are located in five counties, namely Blaine, Butte, Clark, Gooding, and Lincoln.

Under the least-cost land-restriction model, the objective is to retire 100,000 acres irrigated croplands with least cost. This program minimizes the total rental payments given to the farmers subject to the target land area. The rental payments are equal to the per-acre expected profits from crop production determined with the base model. With the least-cost land retirement program, the same counties under the uniform policy are chosen to retire cropland. However, the average rental payment is $88/acre, which is much lower than that of the uniform policy. The uniform policy costs more than 65% compared to the least-cost land retirement program. Thus, targeting will significantly reduce the total rental payments made to the farmers in achieving the land retirement goal.

We also examine the implications of a policy that reduce the total water use by 10% with the least-cost land retirement program in the region. This model minimizes the cost of the program in terms of the total rental payments provided to the farmers in order to achieve the 10% water-use reduction goal as compared to the baseline. The results indicate that 212,142 acres need to be retired in order to achieve the 10% reduction in the total water use in the ESPA. The average rental payment is found to be about $143/acre. These results indicate that increased water-use reduction goal requires retiring more productive croplands out of production, which leads to an increase in the rental payments.

To examine the cost-effectiveness of the least-cost land retirement program, we develop a model to achieve the same water reduction provided with the least-cost land-restriction model. This model maximizes the total returns in the region subject to the water-use reduction constraint to determine the optimal cropping and rotation practices in the region. The model allows the flexibility in achieving the water quantity goal by changing cropping and rotation practices and allowing some land parcels to be idle. Under the least-cost land retirement model with the 100,000 cropland retirement target, the total water use in the ESPA decreases by 4.62%. With this model, no land needs to be idle to achieve the water quantity goal. Changing cropping and rotation practices in the region would allow achieving this goal with the least cost. The results presented in Table 3 summarize the optimal aggregate cropping practices in 16 counties. As compared to the base model results, the total acreage allocated to irrigated crops alfalfa, wheat, sugar beets, and corn silage decrease, while the lands under corn, dry edible beans and barley increase. The changes in cropping and rotation practices lead to these changes in the land allocations among crops.

Implications of Land Retirement Programs

Table 4 presents the implications of alternative land-retirement policies for the gross social welfare, farm income, and water use in the ESPA. The total gross social welfare in the region decreases by 1.36% under the uniform strategy and the least-cost land retirement policy with the acreage goal, and 4.8% under the least-cost policy with the water-use reduction goal. The optimal policy attains the water quantity goal achieved under the land restriction model with the costs of about 0.66% of the baseline gross social welfare in the region. The cost of achieving the water quantity goal with the least-cost land retirement policy with the acreage goal is about $8.1 million, which is about two times higher than the cost of the optimal policy.

The total farm income from agricultural production plus the rental payments received in the region increases by $5.5 million, which is about 0.9% of the base farm income under the uniform strategy. With the least-cost land retirement policy with the acreage goal, the total farm income with the rental payments included does not change as compared to the baseline. The farm income under the optimal policy decreases by 0.66% of the baseline farm income.

These results suggest that the cost-effectiveness of land retirement programs could be improved with targeting the farmers with the highest benefit to cost ratios. The water reduction goal of the land retirement programs can also be achieved without idling croplands through changing cropping and rotation practices. This indicates that conservation programs that focus on on-farm conservation of water could be considered as an alternative policy to the land retirement programs. Such conservation programs would provide incentives to the farmers to switch to crops with less water requirements.

5. Conclusions

This paper develops a model of water resource management to examine the socially optimal management of groundwater allocation with a land retirement program. The theoretical model formulates an optimal control problem to determine the socially optimal water use and land allocations among alternative crops. An optimal control problem of a least-cost land retirement program that achieves a given level of groundwater stock is also developed to examine the implications of alternative land retirement programs for achieving the optimal water allocations. The developed model is empirically applied to the ESPA in southern Idaho.

The results show that the alternative land retirement programs have different impacts on the farm income, gross social welfare, and water use. Cost-effectiveness of land retirement programs in meeting water quantity goals can be improved by targeting farmers with the highest benefit (water use) to cost (expected returns from production) ratios. Alternative programs and policies that focus on on-farm water conservations instead of idling croplands can also be developed to achieve water quantity goals. These water conservation programs could focus on changing cropping and rotation practices in the region so that acreage allocated to crops with more intensive water requirements decrease. Environmental and natural resource policies are increasingly relying on the use of land retirement and conversion programs to reduce adverse impacts of agricultural production practices. These results have important implications for the design and implementation of alternative land retirement programs for water resource management. The framework developed in this paper can also be applied to other regions and water conflicts in the United States.

Table 1. Base Model of Optimal Allocation of Cropping Practices in Southern Idaho (Acres)

	Irrigated Crops								Non-irrigated Crops			
County	**Barley**	**Potatoes**	**Wheat**	**Alfalfa**	**Sugar Beets**	**Corn Silage**	**Beans**	**Corn**	**Barley**	**Wheat**	**Alfalfa**	***TOTAL***
Bingham		39405	39405	94572	52540	36778			4450	4450		*271600*
Blaine	12975	5456	10872	1497					2103		1197	*34100*
Bonneville	808	29216	50392	38407		15377			24054	11769	12577	*182600*
Butte	17923	7087	17923	1640								*44573*
Cassia	63036	37600	31222	55229	31560		5853		10182		10182	*244863*
Clark	6900		6900	20700					1187	1187		*36874*
Fremont		24080	36992	39128					23683	13308	13308	*150500*
Gooding	10760	11639	14912	21443	11946	5800						*76500*
Jefferson		29785	47006	73103		41259				5747		*196900*
Jerome	27669	20872	19494	41865	23843	2857			650		650	*137900*
Lincoln	12714	6671	6276	4617	2572	1614	2103	5932				*42500*
Madison		20912	30061	49666					30061			*130700*
Minidoka	40710	27409	15604	52595	30054		5829		4250		4250	*180700*
Power		23998	29001	33093	16850	11795		2764		16363	21389	*155252*
Bannock		8688	13900	9912					6000	7900	7900	*54300*
Twin Falls	45399	31146	21516	62927	35958		2854		3050		3050	*205900*
TOTAL	238893	323965	391474	600394	205322	115481	16639	8696	109669	60725	74503	2145762

Table 2. Alternative Land Retirement Programs

County	Uniform Strategy	Land Restriction Model	Reduce Water Use by 10%
Bingham			
Blaine	8032	8032	8690
Bonneville			
Butte	26925	26925	44341
Cassia			13648
Clark	30051	30051	34500
Fremont			
Gooding	24097	24097	24097
Jefferson			1943
Jerome			13317
Lincoln	10896	10896	11864
Madison			4126
Minidoka			41536
Power			
Bannock			
Twin Falls			14078
Total Land Enrolled	100000	100000	212142
Total Rental Payment (Million $)	14.710	8.809	30.290
Average Rental Payment ($)	147.100	88.092	142.782

Table 3. Optimal Allocation of Cropping Practices that Achieve the Same Water Reduction with the Land Restriction Model

	Irrigated Crops								Non-irrigated Crops			
County	**Barley**	**Potatoes**	**Wheat**	**Alfalfa**	**Sugar Beets**	**Corn Silage**	**Beans**	**Corn**	**Barley**	**Wheat**	**Alfalfa**	**TOTAL**
Bingham		39405	39405	94572	52540	36778			4450	4450		271600
Blaine	12580	5456	10134	2630					2446		854	34100
Bonneville	3088	29216	51724	22104		28068			14187	12557	21656	182600
Butte	17923	7087	17923	1640								44573
Cassia	74723	38131	17637	36636	20935		36438		10182		10182	244863
Clark	4422		4422	13266					7382	7382		36874
Fremont		24080	38677	26319					15930	22747	22747	150500
Gooding	10873	11644	15076	21263	11843	5800						76500
Jefferson		30976	45815	74294		12684				33132		196900
Jerome	29134	20938	17403	39534	22511	2857	4222		650		650	137900
Lincoln	16617	6773	665	965	537	492	3902	12549				42500
Madison		20912	30061	49666					30061			130700
Minidoka	47261	27707	12626	42172	24098		18336		4250		4250	180700
Power		25246	31841	30991	15682	10977		2764		16363	21389	155252
Bannock		8688	13900	9912					6000	7900	7900	54300
Twin Falls	48597	31291	20062	57839	33051		8959		3050		3050	205900
TOTAL	265217	327551	367371	523804	181197	97657	71857	15313	98586	104532	92678	2145762
Change Compared to Base Model (%)	9.93	1.09	-6.56	-14.62	-13.31	-18.25	76.84	43.21	-11.24	41.91	19.61	

Table 4. Comparison of Alternative Land Retirement Policies with the Optimal Policy

	Base Model	Uniform Strategy	Land Restriction Model	Reduce Water Use by 10%	Optimal Policy
Total Water Use (Million Acre/Feet)	5.049	4.814	4.814	4.591	4.814
Reduction in Water Use (Million Acre/Feet)	-	0.235	0.235	0.458	0.235
Reduction in Water Use (%)	-	4.88	4.88	10.00	4.88
Farm Income (Million $)	657.498	663.399	657.498	657.498	653.138
Reduction in Farm Income (Million $)		-5.901	0	0	4.36
Reduction in Farm Income (%)		-0.90	0	0	0.66
Gross Social Welfare (Million $)	657.498	648.689	648.689	627.208	653.138
Reduction in Gross Social Welfare (Million $)	-	8.809	8.809	30.290	4.360
Reduction in Gross Social Welfare (%)	-	1.34	1.34	4.61	0.66

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