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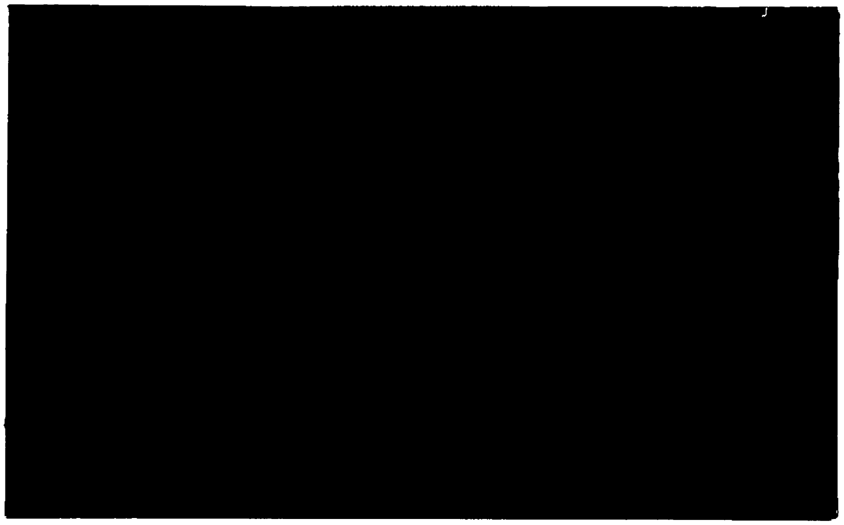

CONSERVATION VERSUS CLEANUP IN
AGRICULTURAL DRAINAGE CONTROL

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CONSERVATION VERSUS CLEANUP IN AGRICULTURAL DRAINAGE CONTROL[1]

Disposal of drainage water is a critical problem of irrigated agriculture in many areas. Because drainage water is very saline and tends to contain substantial nitrogen and phosphorus loads, disposal into surface water sources may cause serious deterioration in water quality. Moreover, in many areas drainage water contains significant concentrations of trace minerals, such as selenium, boron or arsenic, that have been leached from the soil. These minerals may pose a significant threat to human health or to wildlife. For example, selenium in drainage water from the Westlands Water District has been shown to be the source of birth defects and other reproductive problems in wildfowl in the Kesterson Reservoir located in the San Joaquin Valley, California.

To date, policymakers have focused on transport and disposal methods and on decontamination (particularly desalination) technologies as possible solutions. Relatively little attention has been paid to on-farm water conservation as a potential drainage-control mechanism. Yet water conservation may play a key role by reducing drainage volumes (and possibly contamination levels), conceivably to the point where disposal in existing surface waters becomes feasible. Volume reduction can be expected to remain critical even if the remaining drainage water requires treatment because treatment costs will be determined in large measure by treatment volume. The drainage water generated by even a relatively small agricultural area might easily require a processing facility of the same size as a sewage treatment plant servicing a city of hundreds of thousands.

This paper explores the relative roles of water conservation and decontamination in meeting alternative water-quality standards for drainage (or other runoff) water emitted from an agricultural area. We begin by developing a theoretical model of optimal policy for control of stochastic runoff imposed uniformly on a region with heterogeneous production. The model incorporates the key features of agriculture as expounded in the classics of agricultural economics (Schultz (1953), Cochrane (1958), Johnson (1958)), namely asset fixity, competitiveness and rapid technological change. Recognizing the heterogeneity of production conditions common in agriculture, we follow Hochman and Zilberman (1978) in developing aggregate response functions using the procedure developed by Johansen (1972). Particular attention is paid to land retirement under alternative policies. We then apply this model in an empirical analysis of policies aimed at meeting standards for selenium in the San Joaquin River, California. The analysis demonstrates clearly the tremendous potential of on-farm water conservation in mitigating agricultural drainage and runoff problems.

Two innovations of the analysis are worth noting. First, we address the stochastic nature of the pollution problem by considering policies designed to achieve alternative standards with a given margin of safety as required by much of the relevant legislation and by standard approaches to compliance monitoring and enforcement (see, for example, Lichtenberg and Zilberman (1988) and Beavis and Dobbs (1987)). We show empirically that the incremental costs associated with increasing the margin of safety may be substantial. Second, we examine empirically both the long-term economic and the short-run financial consequences of alternative standards using a model of farmers' indebtedness. As one might expect, short-term financial distress exceeds long-run land retirement by a substantial amount.

Optimal Management of Stochastic Runoff

Consider a situation where effluent from an industry (agricultural drainage or runoff) enters a body of water and thereby creates hazards threatening public health (e.g., contamination of drinking water, accumulation of toxins in edible fish or other wildlife) or the environment (e.g., birth defects or tumors in fish or waterfowl, fish kills). Suppose that these hazards can be expressed as an increasing function of the concentration of pollutants in the body of water. Suppose, also, that the amount of water in that body is subject to random fluctuations due to weather conditions or other stochastic factors. For example, river flow tends to be stochastic because of variations in precipitation and snowmelt. The level of environmental hazard will, therefore, be random as well.

Lichtenberg and Zilberman (1988) have argued that safety rules provide a tractable method for incorporating this randomness into environmental policy decisions. Following their approach, the appropriate planning problem would be to minimize social welfare costs subject to the constraint that environmental risk exceed a maximum allowable level no more than a given fraction of the time, that is, that policy be designed to achieve a given risk standard (maximum allowable risk) with a given margin of safety (fraction of the time the standard is violated). This approach corresponds quite closely to the terms of much of the relevant legislation, which requires regulators to provide adequate protection for public health or the environment within a sufficient margin of safety. It also corresponds to a "disaster avoidance" approach to decision-making which is widespread among the public and the regulatory community. Thus, it can be said to describe the preference structures of decision-makers in many instances.

One can derive from this approach an uncertainty-adjusted cost curve for risk reduction that expresses minimum social cost as a function of the risk standard and the margin of safety. This cost curve can then be used to determine optimal policy according to cost-benefit or other criteria.

As long as (1) environmental risk is a monotonically increasing function of the contamination level and (2) contamination is the sole factor affecting risk that is subject to stochastic influence, the decision problem can be focused on achieving contamination standards rather than risk standards. In addition, it will be assumed that the region supplies only a small fraction of total industry output so that the output price effects of contamination reduction policies are negligible.

Assume that water management practices are dictated on a region-wide basis by a central authority such as a water district.[2] For analytical convenience (and with no loss of generality), assume that this authority can choose between two irrigation technologies: a traditional technology such as a gravity-based delivery system (denoted by the subscript 0) and a modern technology characterized by pressurized, low-volume delivery (denoted by the subscript 1). The key characteristics of the two technologies are: irrigation efficiency, h_i (measured by the fraction of the water applied that is actually used by the crop); deep percolation, b_i (the fraction of the water applied that contributes to drainage or runoff); per-acre water application, a_i; per-acre production cost, c_i; and yield per acre, y_i. The modern technology is assumed to have greater irrigation efficiency ($h_1 > h_0$), lower runoff ($b_1 < b_0$), higher per-acre production cost ($c_1 > c_0$) and yield ($y_1 > y_0$), and lower water application ($a_1 < a_0$) (see Caswell and Zilberman (1986)). We assume fixed proportions technology under both irrigation methods. Yields are assumed to be increasing in land quality, q. Profit per acre under the i^{th} technology on land of quality q is thus

(1) $$v_i = py_i(q) - wa_i - c_i$$

where p represents output price and w represents the price of water.

Assume that land quality can be measured by a scalar such that the worst quality land has a value $q = 0$ and the highest quality has a value of $q = 1$. Let $g(q)$ represent total acreage of quality q. Let $x_i(q)$ be the proportion of land of quality q remaining in production under technology i. Aggregate regional profit from agricultural production under the i^{th} irrigation technology is

(2) $$V_i = \int_0^1 x_i(q)[py_i(q) - wa_i - c_i]g(q)dq.$$

Under the ith technology, effluent per acre is assumed to be proportional to water applied, that is $b_i\ a_i$. Total effluent in the region is thus

(3) $$E_i = \int_0^1 b_i\ a_i\ x_i(q)g(q)dq.$$

Letting k_i denote the fraction of effluent receiving decontamination treatment, the volume of effluent treated is $k_i\ E_i$. The total cost of decontamination is assumed to be a function of volume treated, $K(k_i\ E_i)$. We will assume that it is independent of concentration as is typical of many sewage treatment and related processes.

Let s_1, s_2, and s_3 represent the respective concentrations of the contaminant in treated effluent, untreated effluent, and the body of water receiving the effluent. One would expect $s_2 > s_1$ and $s_2 > s_3$. Let R(P) represent the minimum volume of water present in that body 100P percent of the time (in other words, there is less water present only 100(1 - P) percent of the time). The concentration level achieved under technology i with probability P is

$$(4) \qquad s_i(P) = \frac{[k_i s_1 + (1 - k_i)s_2]E_i + s_3 R(P)}{E_i + R(P)}$$

and the appropriate constraint on contamination is

$$(5) \qquad s_i(P) \le s_0, \qquad i = 0, 1$$

where s_0 represents maximum allowable contamination.[3] One would expect $s_3 < s_0 < s_2$.

Under these assumptions, the regional runoff control problem is

$$(6) \qquad \max X_0[V_0 - K(k_0 E_0)] + (1 - X_0)[V_1 - K(k_1 E_1)]$$

subject to the contraint (5), where X_0 is an indicator variable having a value of 1 if the traditional technology is used and 0 otherwise. The necessary conditions are

$$(7a) \qquad X_0\{[V_0 - K(k_0 E_0)] - [V_1 - K(k_1 E_1)]\} \ge 0$$

$$(7b) \qquad V_i - K'k_i b_i a_i + n_i[s_o - k_i s_1 - (1 - k_i)s_2]b_i a_i \ge 0, \quad i = 0, 1$$

$$(7c) \qquad -K' - n_i(s_1 - s_2) \le 0, \qquad i = 0, 1$$

plus the constraint (5).

The maximization problem can be solved via the following two-step procedure: First, determine the optimal amount of land in production (the optimal $x_i^*(q)$ for all (q)) and treatment capacity (k_i^*) simultaneously for each technology; second, select the optimal technology by comparing $V_0^* - K(k_0^* E_0^*)$ and $V_1^* - K(k_1^* E_1^*)$. It can also be seen from equation (7b) that the solution to the land allocation problem for each technology (the choice of $x_i^*(q)$ for all (q)) will be to keep all land of quality greater than or equal to a critical quality q_i^* in production and retire all land of quality less than q_i^*. This land allocation problem can be simplified further by assumimg that the constraint (5) holds with equality, which implies

$$(8) \qquad k_i E_i = \frac{s_2 - s_0}{s_2 - s_1} E_i - \frac{s_0 - s_3}{s_2 - s_1} R(P).$$

The first-stage problem thus becomes to find the critical level of land quality q_i^* that solves

$$(9) \qquad \max \int_{q_i^*}^{1} v_i(q)g(q)dq - K(k_i E_i),$$

where $v_i(q)$ denotes operating profit per acre on land of quality q. Assuming an interior solution, the optimal q_i^* is determined by

$$(10) \qquad v_i(q_i^*) = \frac{K' b_i a_i(s_2 - s_0)}{s_2 - s_1},$$

that is, by the equality of operating profit per acre, v_i, and the additional cost of treating the effluent generated by an additional acre, $K' b_i a_i(s_2 - s_0)/(s_2 - s_1)$.[4] The sufficient condition

$$(11) \qquad Q = -v_i' - K''(b_i a_i)^2 \left(\frac{s_2 - s_0}{s_2 - s_1} \right)^2 \leq 0$$

is satisfied whenever $K'' \geq 0$, that is, whenever marginal treatment cost is nondecreasing, and is satisfied for some $K'' < 0$ as well.

Comparative Statics

Assuming increasing marginal treatment cost ($K'' > 0$), it is straightforward to show that the critical quality of land under any technology, q_i^*, increases as:

1. The margin of safety increases [$dq_i^*/dP = K'' b_i a_i R'(P)AB/Q > 0$, where $A = (s_2 - s_0)/(s_2 - s_1)$ and $B = (s_0 - s_3)/(s_2 - s_1)$].

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1. The margin of safety increases [$dq_i^*/dP = K'' \; b_i \; a_i \; R'(P)AB/Q > 0$, where $A = (s_2 - s_0)/(s_2 - s_1)$ and $B = (s_0 - s_3)/(s_2 - s_1)$].

2. The contamination standard becomes more stringent ($dq^*_i/ds_0 = b_i\ a_i\{K' + K''[E_i + R(P)]A\}/Q(s_2 - s_1) < 0$).

3. The concentration of the contaminant in untreated effluent increases ($dq^*_i/ds_2 = -b_i\ a_i[K'(s_0 - s_1) + K''\ E_i(1 - k_i)]/Q(s_2 - s_1)^2 > 0$ whenever $s_0 < s_1$ as it is necessary for an interior solution, because $s_0 < s_1$ implies that zero effluent is required to meet any standard).

4. The concentration of the contaminant in treated effluent increases [$dq^*_i/ds_1 = -b_i\ a_i(s_2 - s_0)(K' + K''\ q^*_i\ E^*_i)/Q(s_2 - s_1)^2 > 0$].

5. The concentration of the contaminant in the body of water receiving the effluent increases [$dq^*_i/ds_3 = K''\ b_i\ a_i(s_2 - s_0)/Q(s_2 - s_0)^2 > 0$].

6. The per acre water application increases ($dq^*_i/da_i = -b_i\ B[K' + k''\ E^*_i\ A]/Q > 0$).

7. The fraction of water applied that contributes to drainage increases ($dq^*_i/db_i = -Q_i\ B[K' + K''\ E^*_i\ A]/Q > 0$).

The amount of land remaining in production in the region under technology i is

$$L^*_i = \int_{q^*_i}^{1} g(q)dq. \tag{12}$$

It is readily apparent that a change in any parameter will have an effect on L^*_i that is opposite in sign to the effect on q^*_i. Thus, there will be less land remaining in production (and, therefore, lower regional output) under technology i in cases where (1) the margin of safety is greater, (2) the contamination standard is more stringent, (3) there is more contaminant in untreated effluent, (4) the treatment technology is less effective, (5) the body of water receiving the effluent is more polluted, and (6) the technology has higher water application of deep percolation rates.

Because total effluent, E_i^*, is proportional to the amount of land remaining in production, L_i^*, the sign of the effect of a change in any parameter on E_i^* will be the same as on L_i^*. However, impacts on the optimal fraction of effluent treated, k_i^*, may be of either sign so that the effects of parameter changes on total effluent treated, $k_i^* E_i^*$, and, therefore, on optimal treatment plant capacity, cannot be determined a priori.

Finally, consider the selection of the optimal technology. The difference in the profitabilities of the traditional and modern technologies is

(13) $$Z = [V_0^* - K(k_0^* E_0^*)] - [V_1^* - K(k_1^* E_1^*)].$$

The traditional technology will be chosen when $Z > 0$, the modern technology when $Z < 0$. The selection of the modern technology becomes more likely as:

(1) The margin of safety increases ($dZ/dP = BR'(P)[K'(k_0 E_0) - K'(k_1 E_1)] < 0$ whenever $K'' > 0$ because one would expect $k_1 E_1 < k_0 E_0$);

(2) The contamination standard becomes more stringent ($dZ/ds_0 = [K'(k_0 E_0)[E_0 + R(P)] - K'(k_1 E_1)[E_1 + R(P)]]/(s_2 - s_1) > 0$ for $K'' > 0$ because one would expect $E_0 > E_1$, and $K'(k_0 E_0) > K'(k_1 E_1)$);

(3) The treatment technology is less effective ($dZ/ds_1 = [K'(k_0 E_0)k_0 E_0 - K'(k_1 E_1)k_1 E_1]/(s_2 - s_1) < 0$ for $K'' > 0$ because one would expect $k_2 E_0 > k_1 E_1$ and $K'(k_0 E_0) > K'(k_1 E_1)$);

(4) The modern technology affords greater savings in water

application and/or deep percolation rates ($dZ/da_0 = -K'AE_0/A_0 < 0$, $dZ/db_0 = -K'AE_0/b_0 < 0$); and

(5) The body of water receiving the effluent becomes more polluted ($dZ/ds_3 = [K'(k_1 E_1) - K'(k_0 E_0)]R(P)/(s_2 - s_1) < 0$).

Meeting Selenium Standards in the San Joaquin River

In 1983, it was established that selenium in agricultural drainage water was responsible for a variety of reproductive problems in waterfowl and other aquatic fauna in the Kesterson Reservoir, a repository for agricultural drainage flows emanating from the Westlands Water District on the west side of the San Joaquin Valley, California. In 1985, the California State Water Resources Control Board initiated a process of setting standards for selenium and other heavy metals (boron, molybdenum in the San Joaquin River. These standards would affect growers cultivating 94,000 acres in several water districts to the north of Westlands that had been discharging drainage water into the San Joaquin River. In what follows we employ the model presented in the preceding pages to examine the relative contributions of on-farm water conservation and construction of selenium removal facilities in meeting these proposed standards under alternative stochastic riverflow conditions.

The area studied lies in four irrigation districts (Broadview, Panoche, Pacheco and Firebaugh) that differ in terms of the distribution of land quality (and therefore cropping patterns and percolation coefficients) and water charges. Estimates of acreages and yields of crops on different soil types were obtained for each district from Soil Conservation Service soil surveys. Mapped acreages were expanded proportionally to match total crop acreages reported by each irrigation district (see California State Water Resources Control Board (SWRCB), pp. G193-G197). Variable and fixed (per acre) water charges were also obtained for each district (SWRCB, p. G-208).

Furrow irrigation with 1/2 mile runs is the standard irrigation technique presently used with all crops in the area. Subsurface drainage per acre per month under this technology was estimated for Broadview and Firebaugh using data from Broadview (see Day and Nelson). Total annual subsurface drainage per acre was 0.61 acre feet. Total annual subsurface drainage per acre for Panoche and Pacheco was estimated at 0.78 acre-feet using data from the California Department of Water Resources (1980-1983). The monthly pattern of subsurface drainage discharges was assumed to be the same as that of Broadview. Surface runoff was estimated by subtracting estimated subsurface drainage discharges from total flows recorded in the drains of each irrigation district (Summers Engineering, Inc.). Water application rates under furrow irrigation were set equal to the average values reported by the California Department of Water Resources (1975).

Crop rotations, rather than individual crops, were the unit of analysis. Cotton, grown in rotation with wheat or barley, is the principal crop in this area; between 1978 and 1984, these crops accounted for an average of 61.0 percent of the area's total crop acreage. Processing tomatoes, sugar beets and alfalfa are the other major crops, accounting for averages of 8.6, 3.2 and 3.1 percent of total crop acreage. The remaining crop land is planted to melons or vegetables. Because grains are typically rotated with cotton every second or third year, a rotation period of 2.5 years was assumed. Cotton, the most profitable alternative, was assumed to be the rotation crop of choice for all other crops. Processing tomatoes and sugar beets must be rotated with other crops every other year. The frequency of rotation of cotton with melons and vegetables was determined empirically as the ratio of acreage of these "other" crops to all cotton acreage not accounted for by the cotton-grains, tomato-cotton and sugar beet-cotton rotations. Alfalfa, a nitrogen-fixing perennial, is not typically rotated with any other crop.

Crop prices were assumed to remain constant at the average prices received by Fresno County growers in 1984. Per acre production costs under furrow irrigation were set equal to the sum of the variable costs estimated by the Fresno County Cooperative Extension Service and the fixed water charges of each irrigation district. Baseline per acre profits for each crop on each quality of land in each irrigation district were calculated as the difference between revenue per acre (crop price times yield per acre on land of quality q) minus water cost in each district (water applied times each district's variable water charge) minus per acre production costs in each district as described above. The profitability of each rotation under furrow irrigation on each quality of land in each district was then calculated as the weighted average of these crop profitabilities, with weights derived from the rotation frequencies (SWRCB, p G203).

The distribution of per acre profits under furrow irrigation in each district was then estimated via linear programming by selecting land allocations to maximize total profits in each district subject to the constraints that (1) total land allocated to each crop equaled the 1984 average level and (2) total land of each quality allocated to all crops equaled the estimated amount. The resulting rotational allocations are reported in SWRCB, p.G-212. These rotations were used to match per acre profitability with acreage. Differences in rotational profitabilities were sufficiently large, and differences in crop water requirements were sufficiently small to rule out shifts in cropping patterns in response to technology changes or cost increases; thus, these rotational allocations provide a stable basis for estimating per acre profitability under all technologies and cost changes.

Assuming that land is retired from production only when profits are nonpositive implies that the inverse of the cumulative distribution of per acre profitability gives the acreage remaining in production after a cost increase of any given size. This inverse distribution is shown in Figure 1.

Land retirement is a long run outcome of increased costs. In the short run, the principal impact of imposing charges to defray drainage control expenses is likely to be increases in financial pressure on farmers. Such short run financial distress is of considerable concern for designing appropriate implementation programs as well as for political-economic reasons. Since data on the indebtedness of the individual farmers in the study area were unavailable, debt-carrying capacity was estimated as follows. Estimates of the proportions of farmers having different debt/asset ratios were obtained from Mr. Mark Herringer of the Sacramento, California Production Credit Association, according to whom about 60 percent of California farmers have an average debt/asset ratio of 0.2, 30 percent have a debt/asset ratio of 0.4 and the remaining 10 percent have a debt/asset ratio of 0.7. It was assumed that debt/asset ratios were distrbuted uniformly within these groups. Land was assumed to be the sole asset and was valued using the estimated per-acre profitability derived above with a capitalization factor of 10 percent. The distributions of financial capacity (debt/asset ratios) and per-acre profitability were assumed to be independent and were combined to yield a distribution of the proportion of land remaining solvent (earning a positive cash flow) after a cost increase of any given size. This distribution is shown in Figure 1.

Four alternative irrigation technologies were selected for analysis: furrow irrigation with runs shortened to 1/4 mile, installation of tailwater recovery systems, spinkler irrigation and drip irrigation. The parameters describing irrigation efficiency h_i, deep percolation b_i and surface runoff were chosen to be broadly representative of the estimates in the literature (see for example California Department of Water Resources (1984) and Boyle Engineering). These parameters are shown in Table 1. They were used to estimate reductions in water application, deep percolation and surface runoff and increases in per acre production costs relative to the baseline estimates under furrow irrigation described above. The increases in annual total production costs due to adoption of these alternative technologies were calculated using estimates made by the University of California Committee of Consultants on Drainage Water Reduction (1988, Table 2 and Appendix). The change in cost from switching to each alternative technology, was estimated as the difference between the estimated total production cost under that technology and the estimated total production cost under furrow irrigation with 1/2 mile runs. These changes in cost, shown in Table 1, were combined with estimates of savings in water purchases in each irrigation district to obtain net changes in per acre production costs relative to the baseline.

These cost increase estimates should be considered conservatively high, especially for drip systems. While they do incorporate reductions in pesticide application costs afforded by chemigation, they ignore the increased yields that typically result from low volume water application as well as lower disease incidences from lower soil moisture, both of which can be quite substantial (see for example Street (1988)). Moreover, there exist alternative low volume and sprinkler delivery systems that are as efficient as the drip and srpinkler systems considered here yet cost less.

The cost function for selenium removal was taken from SWRCB, Appendix I (1986). It consisted of three components: a cost of selenium removal, a cost of removing suspended solids (applicable when combined surface and subsurface drainage flows were treated) and a cost of storing drain water to smooth monthly treatment requirements.

Four year types were used to characterize precipitation, and therefore riverflow, patterns. The years 1978/1979 and 1983/1984 were chosen as representative of normal years, 1984/1985 was selected as representative of a dry year and 1980/1981 was selected as representative of a critical year. The margin of safety associated with setting standards designed to hold in each year was estimated using the historical distribution of river flows reported by the California Department of Water Resources. By this criterion, 1978/79 corresponded to a 43.9 percent margin of safety, 1983/84 to a 53.7 percent margin of safety, 1984/85 to a 76.8 percent margin of safety and 1980/81 to an 81.7 percent margin of safety.

Eight technological alternatives were analyzed: treatment of combined surface and subsurface flows with and without storage under standard furrow irrigation, treatment of subsurface flows only with and without storage under standard furrow irrigation, furrow irrigation with shortened runs with and without storage, sprinkler irrigation and drip irrigation. For each year, the optimal treatment capacity under each technological alternative was chosen by minimizing total treatment cost subject to the constraint of meeting selenium concentration standards of 2, 5 and 10 parts per billion (ppb) in the San Joaquin River during every month. The total cost of treatment plus investment in irrigation technology was then calculated for each technological alternative. Financial distress was estimated under the assumption that the total cost was spread evenly over all current acreage, while land retirement was estimated under the assumption that the total cost was spread evenly over all acreage remaining in production in the long run.

Finally, analysis indicated that the minimum cost strategy always involved delivering drainage water into the San Joaquin River at a point upstream of the Merced River, to take advantage of the additional dilution capacity of the Merced. This approach required construction of a canal at an estimated annual cost of $1.16 million.

Empirical Results

Table 2 shows the capacities of the treatment and storage facilities required to meet each of the proposed standards in each of the different years. It is evident that treatment capacity can be reduced substantially and storage virtually eliminated for every year type and every standard considered by using an alternative irrigation technology. Drip irrigation, in particular, reduces drainage flows so much that treatment is needed only to meet the most stringent standards with very high margins of safety, and storage is never needed.

Table 2(C) shows the total costs required to meet alternative selenium standards in the San Joaquin River. In normal years, a standard of 10 ppb can be met entirely through dilution under the existing irrigation technology. When the margin of safety rises to 76.8 percent, as in the dry year 1984/85, it becomes optimal to construct a small treatment plant for the combined surface and subsurface flows, but remains unnecessary to switch irrigation technologies. As standards become more stringent and the margin of safety increases, though, water conserving technologies become increasingly desirable. It becomes optimal to switch to shortened runs and build small storage and treatment facilities to meet a 10 ppb standard with an 81.7 percent margin of safety or to meet a 5 ppb standard under any of the safety margins considered here, and it becomes optimal to switch to drip irrigation to meet a standard of 2 ppb under any of these safety margins. In each of these cases the adoption of the water conserving irrigation technology reduces drainage flows sufficiently to afford substantial savings in storage and treatment costs.

Table 3 shows the estimated per acre cost of meeting these standards under the margins of safety considered. The cost imposed on growers increases at an increasing rate as the standard becomes more stringent and as the margin of safety increases. The incremental cost of meeting any standard with a higher margin of safety represents a premium paid for reduced uncertainty about the degree of environmental risk. Table 4 shows the average uncertainty premium per 1 percent increase in the margin of safety for the increases in the margin of safety and selenium standards analyzed. It can be seen that the average uncertainty premium increases as the selenium standard becomes more stringent and as the margin of safety increases, both in absolute dollar and percentage cost increase terms, except for an increase in the margin of safety from 53.7 to 76.8 percent under a standard of 2 ppb.

The long run impacts of selenium standards in terms of agricultural land retirement were estimated assuming that the total cost of meeting the standards was spread equally across all acreage remaining in production in the area. Land retirement was minimal: As can be seen from Table 3 and Figure 1, meeting a standard of 2 ppb under any margin of safety would force retirement of only about 3.5 percent of the crop land in the area, while with any other standard, production would remain profitable on all land currently cropped.

In contrast, the short run financial effects of imposing selenium standards are quite substantial. Meeting a standard of 10 ppb will induce financial distress on 1 to 2 percent of the crop land in the area, meeting a standard of 5 ppb will induce financial distress on 5 to 7 percent and meeting a standard of 2 ppb will cause financial distress on 17 to 28 percent. The short run effects on growers currently operating in the area will thus be far greater than the long run effects on the area's agricultural economy.

Policy Implications

This analysis demonstrates, first of all, that water conserving irrigation technologies can play an important role in mitigating drainage problems in areas where disposal of drainage has severe negative environmental impacts. Reducing drainage volumes by increasing irrigation efficiency allows for substantial reductions in both storage and treatment capacities and therefore the costs of meeting environmental quality standards. In the case considered here, it proved possible to meet stringent standards with a high margin of safety without constructing huge, expensive treatment facilities. The substitution of drainage reduction for treatment is especially important because treatment technologies are still in their infancy. In the case of selenium removal, all treatment technologies are still experimental and have not yet reached even the prototype testing phase. Over time, the efficiency of treatment is likely to rise, and the cost of treatment to fall, as the industry gains experience with these technologies. The adoption of a drainage reduction strategy essentially buys time for this learning while achieving relatively high environmental quality goals at high margins of safety even in the near term.

A second implication is that environmental quality factors like disposal of toxic drainage water are likely to play a significant role in spurring adoption of water conserving irrigation technologies, thereby fostering more efficient water use. In many areas of California, low water costs have made adoption of water conserving irrigation technologies unattractive. It has proved difficult to increase water costs, even though growers complain of water shortages. Increased water conservation and alleviation of water shortages may ultimately be achieved indirectly, as a side effect of environmental quality concerns, as observers have noted (see for example Claude Phene, quoted in Street (1988)).

Finally, the empirical results demonstrate the importance of separating short run financial effects from long run efficiency effects on agricultural production. In the case considered here, land retirement was negligible under all standards, while a significant fraction of the area's crop land would experience financial hardship, that is, imposing selenium standards had small efficiency effects and large equity effects. Growers, of course, respond to the short run financial effects by opposing environmental standard setting. The small size of the long run impacts, though, suggests that the appropriate policy response is financial assistance for growers in the near term rather than lowering environmental quality goals.

Footnotes

1. This research was supported by the State of California Water Resources Control Board and by the San Joaquin Valley Drainage Program. The views expressed are those of the authors, not of either agency. Research assistance was provided by Lloyd Dixon, Gregory Ellis, and David Chapman.

2. The authority of water management agencies varies according to location and political circumstances. We consider a case with strong central authority because of the empirical problem. Further research is needed for cases in which growers have greater authority.

3. In many instances (for example, when bioaccumulation of toxins poses a problem), the contamination standard may be better expressed in terms of total contaminant loading rather than concentration. The loading achieved with margin safety P under technology i would be $\ell_i(P) = [k_1 s_1 + (1 - k_1)s_2]E_i$ and the relevant constraint would be $\ell_i(P) \leq \ell_0$.

4. The additional cost of treating the effluent from an additional acre in production equals the marginal cost per unit of effluent volume, K', times the amount of effluent generated, $b_i a_i$, times treatment volume per unit of effluent needed to meed the standard $(s_2 - s_0)/(s_2 - s_1)$.

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Table 1

Characteristics of Alternative Irrigation Technologies

Technology	Irrigation Efficiency	Percolation Fraction	Surface Runoff	Increase in Production Cost ($/acre)	Water Savings
Furrow, 1/2-mile runs	0.60	0.1750	0.225	NA	NA
Furrow, 1/4-mile runs	0.70	0.1330	0.167	5.93	14%
Sprinkler	0.80	0.0875	0.1125	52.77	25%
Drip	0.95	0.0400	0.0100	75.66	37%

(Sources: see text)

Table 2

Requirements for Meeting Alternative Selenium Standards in the San Joaquin River

A. Treatment Plant Capacity (1,000 acre-feet)

	1978/79			1983/84			1984/85			1980/81		
	2 ppb	5 ppb	10 ppb	2 ppb	5 ppb	10 ppb	2 ppb	5 ppb	10 ppb	2 ppb	5 ppb	10 ppb
Treat Combined Flow												
Without Storage	79.9	30.4	0	83.9	36	0	86.3	49.4	0.07	86.8	51.6	14.6
With Storage	38.1	10	0.0002	35	10.6	0	43.9	13.2	0.006	48.7	18.8	2
Separate, Treat Tile Only												
Without Storage	30.7	13.1	0	36.5	16.9	0	38.3	20.6	2.4	32.8	22.8	8.6
With Storage	13.9	4.3	0.00015	13.4	4.2	0	18.4	5.8	0.5	19.7	8.4	1.7
Water Conservation												
Shorten Runs/No Storage	54.4	7.4	0	57.5	13	0	55.6	16	0	64.2	25.6	2.1
Shorten Runs/Storage	21.3	1.9	0.0003	21.2	2	0	26.3	3.6	0.001	30.8	6.7	0.002
Sprinkler	26.2	2.3	0	29.7	0	0	30.2	0	0	38.1	6.1	1.3
Drip	1.6	0	0	4.7	0	0	6.6	2.2	0	12.2	4.9	0

B. Storage Capacity (1,000 acre-feet)

	2 ppb	5 ppb	10 ppb	2 ppb	5 ppb	10 ppb	2 ppb	5 ppb	10 ppb	2 ppb	5 ppb	10 ppb
Treat Combined Flow												
Without Storage	0	0	0	0	0	0	0	0	0	0	0	0
With Storage	13.3	4.5	0	18.4	7.9	0	12.1	9.2	0	12	9.4	1.5
Separate, Treat Tile Only												
Without Storage	0	0	0	0	0	0	0	0	0	0	0	0
With Storage	5	1.7	0	7.4	3	0	4.9	3.6	0.4	4.6	3	1.1
Water Conservation												
Shorten Runs/No Storage	0	0	0	0	0	0	0	0	0	0	0	0
Shorten Runs/Storage	9.94	0.54	0	11.88	1.64	0	9.46	2.78	0	9.5	4.8	0
Sprinkler	0	0	0	0	0	0	0	0	0	0	0	0
Drip	0	0	0	0	0	0	0	0	0	0	0	0

C. Total Treatment and Storage Costs (millions of dollars)

	1978/1979			1983/1984			1984/1985			1980/1981		
	2 ppb	5 ppb	10 ppb	2 ppb	5 ppb	10 ppb	2 ppb	5 ppb	10 ppb	2 ppb	5 ppb	10 ppb
Treat Combined Flow												
Without Storage	13.46	6.46	1.16	14.06	7.26	1.16	14.36	9.26	1.19	14.36	9.56	3.96
With Storage	8.46	3.66	1.165	8.16	3.96	1.16	9.26	4.46	1.193	9.96	5.36	1.96
Separate, Treat Tile Only												
Without Storage	8.24	5.44	2.94	9.14	6.04	2.94	9.34	6.64	3.54	8.54	7.04	4.64
With Storage	6.14	4.24	2.945	6.14	4.34	2.94	6.84	4.64	3.24	7.04	5.04	3.64
Water Conservation												
Shorten Runs/No Storage	10.056	2.756	1.256	10.466	3.736	1.256	10.206	4.256	1.256	11.406	5.766	1.756
Shorten Runs/Storage	5.866	1.926	1.261	5.926	2.066	1.256	6.636	2.486	1.256	7.326	3.196	1.256
Sprinkler	7.963	3.893	3.363	8.513	3.363	3.363	8.593	3.363	3.363	9.773	4.643	3.693
Drip	4.714	4.304	4.304	5.324	4.304	4.304	5.684	4.834	4.304	6.644	5.404	4.304

Table 3

Cost per Acre of Meeting Alternative Selenium Standards

Standard	Margin of Safety			
	43.9%	53.7%	76.8%	81.7%
10 ppb	$12.34	$12.34	$12.66	$13.36
5 ppb	$20.49	$21.98	$26.45	$34.00
2 ppb	$50.15	$56.64	$60.47	$70.68

Table 4

Average Premiums for a One Percent Increase in the Margin of Safety

Margin of Safety	Standard		
	10 ppb	5 ppb	2 ppb
43.9-53.7	0 0	$14,286 (0.74%)	$62,245 (1.32%)
53.7-76.8	$1,299 (0.311)	$18,182 (0.88%)	$15,584 (0.29%)
76.8-81.7	$13,469 (1.13%)	$144,898 (5.83%)	$195,918 (3.45%)