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SOME LEGAL AND ECONOMIC IMPLICATIONS OF SEA WATER INTRUSION—A CASE STUDY OF GROUND WATER MANAGEMENT*

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The Salinas Valley, an intensively cultivated coastal valley about 130 miles south of San Francisco, is noted for its summer vegetable production. The moderate climate is ideal for artichoke production near the coast. The irrigation water supply necessary for intensive crop production comes from pumping an underground basin recharged by percolation from the Salinas River which flows through the Valley. Degradation of ground water quality by saltwater intrusion has forced abandonment of wells near the coast.

Two layers of dense heavy clay near the mouth of the Valley separate the ground water basin in that portion of the Valley into three strata. The shallowest of these is a perched water table with a high accumulation of salts from leaching of the surface soil which renders the water unusable for irrigation. The remaining two, the 180-foot aquifer and the deeper 400-foot aquifer, are connected to the river at a point 15 to 20 miles from the coast, and are under artesian pressure. No significant water-bearing strata are apparent below the 400-foot aquifer. Between the area of recharge of these aquifers and the coast lies the city of Salinas (see Fig. 1). Offshore from the Salinas Valley lies one of the largest submarine canyons in the world. A geological survey of Monterey Bay indicates the presence of silt, sand, and gravel. A gravelly out-cropping located in the canyon walls is probably the seaward extension of the 180-foot aquifer; the seaward extension of the 400-foot aquifer has not as yet been found.[1] Both aquifers are, in all probability, exposed to the saline waters of Monterey Bay.

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1. *Sea-water Intrusion in California*, 63 Cal. Dep't of Water Resources Bull. 32 (Nov. 1958).

I
THE PROBLEM

In the late 1930's and early 1940's, water of a high saline content appeared in wells along the coast pumping from the 180-foot pressure aquifer. Since that time, saltwater intrusion has advanced further and further inland. At present the contaminated area underlies about 8,000 acres of vegetable producing land. Until the summer of 1959, the amount of saltwater in the 400-foot aquifer was insignificant. However, since that time, three pockets of saline water have appeared in this aquifer as well (see Fig. 1). This is especially disconcerting since many pumpers, as will be discussed later, have "solved" their saltwater intrusion problem by shifting from the 180-foot aquifer to the 400-foot aquifer.

A brief review of the hydraulics of seawater intrusion will provide a better understanding of the economic problems involved. Before a ground water basin can be intruded by seawater, two basic conditions are necessary. First, the water bearing materials comprising the basin must be in hydraulic continuity with the ocean. Second, the normal seaward gradient of ground water must be reversed, or at least be so flat that the greater density of the seawater cannot be counteracted.[2] The first of these two conditions occurs in the Salinas Valley, at least for the 180-foot aquifer and, in all probability, for the 400-foot aquifer as well.

The second condition is met when the pressure head of seawater exceeds that of the fresh water. This usually results when ground water levels are lowered to or below sea level by excess pumping. In the Salinas Valley, this condition is complicated by the fact that both aquifers are under pressure. To explain the question at hand, it is best to use the analogy of a water pipe. Ground water moving in the two confined aquifers under normal conditions enters the pipe at the landward end and the hydraulic gradient is such that the general movement is toward the sea. As pumping occurs along the pipe, water is extracted reducing the amount of water in the pipe and the hydraulic gradient. If the amount of this pumping is excessive or the pipe is constricted at some point reducing the flow of water, the gradient at the lower end is reduced or even reversed, and the second condition is met.

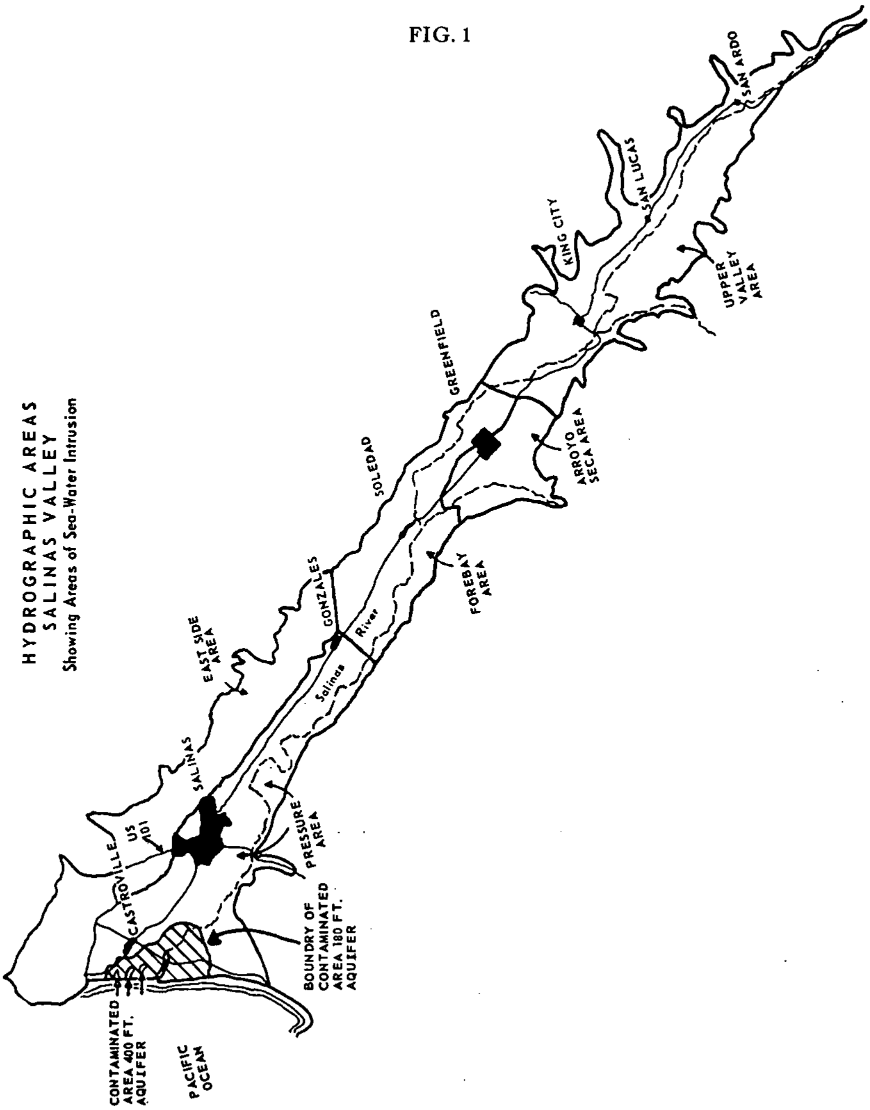
Fresh water is lighter than seawater. Therefore, when the two come in contact within a permeable formation—an aquifer—the tendency is for the fresh water to float to the top. The restrictions of the permeable formation impede the mixing and diffusion of the

2. *Id.* at 15.

two liquids. Following Archimedes law, the seawater forms a wedge moving through the aquifer—our pipe—with the point of the wedge at the bottom pointing landward. This latter condition will become very important when we examine possible cropping adjustments under these conditions.

In 1945, California conducted an investigation of the ground water basin of the Salinas Valley.[3] At that time it was estimated that

FIG. 1



3. *Salinas Basin Investigation,* 52 Cal. Dep't of Pub. Works Bull. (1946).

the average annual inflow of saltwater during the previous 15 years approximated 6,000 acre-feet, all of this intrusion occurring in the 180-foot aquifer. A second investigation by the state in 1954 set the seasonal overdraft of the 81,000-acre pressure area at 20,000 acre-feet. This included 12,000 acre-feet of seawater intrusion and 8,000 acre-feet of induced flow from the recharge area.[4]

A dam was built in 1957 on one of the tributaries of the Salinas River to store winter runoff for summer recharge of the ground water basin. This dam, located above the recharge point of the pressure area, helps to keep the fresh water gradient in our pipe analogy high by maintaining the underground water table high in the recharge area. This structure, built by local funds, has helped minimize the seasonal and secular changes in the free ground water table in the Valley, although the saltwater contaminated area has continued to increase.

A second dam on another tributary has now been constructed also for the purpose of regulating winter runoff for summer recharge of the ground water basin. Since the second dam commenced operations the rainfall and runoff have been about normal, and it is perhaps significant that during the 1965-1966 water year no further increase was found in the area contaminated by seawater.[5]

The existence of the 400-foot aquifer provided pumpers with at least a short-run alternative source of water, since draft on the 400-foot aquifer was substituted for draft on the 180-foot aquifer with no significant increase in the pumping lift. This has also aided in reducing the rate of intrusion in the 180-foot aquifer. However, in the summer of 1959, saltwater was found in a well near the coast tapping the 400-foot aquifer. At present the area of contamination of the deep aquifer underlies approximately 500 acres. A "blind alley" solution is now appearing for some pumpers since the area of contamination of the two aquifers coincides in the vertical plane and no direct alternative source of ground water exists for the area where the 400-foot aquifer is contaminated.

Cropping adjustments to saltwater intrusion are not practicable. As indicated earlier, saltwater moves in the aquifer in the form of a wedge with little mixing and diffusion of the two bodies of water. Since the buildup of salt water in the aquifer at the site of pumping is not gradual, no adjustment can be made in the cropping pattern to minimize the impact of seawater intrusion. Once the seawater wedge

4. D. Ditwiler, The Political Economy of Water Use Transfer and Integrated Water Resource Management in the Salinas Valley, California 93 (1966). (unpublished Ph.D. thesis, University of California).

5. On the other hand, however, we should note that individual pumpers have experienced degradation during 1967.

hits the well casing the salt content of the water rises rapidly, often within a period of a few weeks or even days. Well tests have been observed that show the chloride content in parts per million jumping from a normal for the area of about 100 ppm to over 1,000 ppm within a growing season.[6] Intrusion becomes a discrete variable in the planning of individual farm production.

Agriculture is the major water user in the Valley and in the pressure area. The estimated consumptive use for irrigation in the confined area in 1963 was 139,240 acre-feet.[7] Most of this water is pumped during the summer months, causing the reverse hydraulic gradient to be greatest in the month of August. As the pumping exceeds the recharge, a depression is formed with an axis parallel to the coast. During the summer months, the axis of this trough deepens and moves landward increasing the reverse gradient from the sea. Urban and industrial use is also concentrated primarily in the confined area. Ditwiler estimated that 70 percent of the Valley's urban population lives in this area. The major center of urban water use is in the city of Salinas, with an estimated withdrawal of 12,500 acre-feet.[8] Urban and industrial users withdraw water from both the 180- and 400-foot aquifers.

The two storage dams on the Salinas River have added "new" water to the Valley's water balance sheet and in the aggregate there is an adequate amount of water to supply the needs for many years in the future. However, this does not reflect locational imbalances of the various subareas of the Valley. The 1955 state investigation indicated a safe yield for the pressure area of only 78,400 acre-feet, whereas the estimated withdrawals are 141,740 acre-feet. The balance then must come from artificial recharge of stored water being percolated into the upper end of our pipe.

Lateral water movement through a permeable material is very slow. Although no investigation has ever been conducted to estimate the transmissibility of this particular aquifer, on the basis of investigations in other areas, it would not be unreasonable to assume that two to three years would be required for a particle of water to move from the recharge area to the area along the coast.[9]

6. Chloride ion concentrations of less than 175 ppm are considered good quality, 175-350 ppm is class II, and above 350 is injurious and unsatisfactory for irrigation according to the California Department of Water Resources.

7. Based on data from H. Blaney & P. Ewing, *Irrigation Practices and Consumptive Use in Salinas Valley*, USDA, SCS (1946). Adjusted for increase in developed land.

8. Ditwiler, *supra* note 4, at 137.

9. V. Chow, Handbook of Applied Hydrology, ch. 13 (1946).

II

ECONOMIC ASPECTS

Kneese defines technological external diseconomies as such, "that the costs of a particular course of action, which may be in the form of an actual outlay, a reduction in income or satisfaction, or even completely foregone opportunities, are born by an economic decision unit which is managerially independent from the one pursuing the course of action."[10]

In the Salinas Valley situation, a large number of independent units, including agricultural, municipal, and industrial use groups, follow independent courses of action regarding pumping water from the confined area. Although managerially independent, they are linked technologically because the underground basin links their physical production units. Thus, while the individual decision to pump water by one unit does not have a profound effect on other units, collectively there is an effect.

In terms of private costs and benefits as opposed to the benefits and costs to society (in this instance, defined as that part of society composed of all pumpers in the confined area) the private cost to the individual does not reflect the additional cost in terms of alternative sources of water or income of pumpers foregone in the salt-water intrusion area. Thus, we contend that costs to those pumpers in the uncontaminated area are actually understated and, therefore, implies an excess use of the water resource by them. By the same token, the pumpers in the contaminated area have an excessively high cost to bear implying, prima facie, a less than optimal allocation of production for the area.

III

LEGAL ASPECTS

Traditionally, residents of the study area refer to the underground water in the Valley as a flowing underground stream. The California Water Code states that a subterranean watercourse must be flowing through a known and defined channel.[11] It further goes on to say that if the channel through which ground water is moving is not defined and known, the presumption is that the water is percolating, and finally, the burden of proof is placed upon the plaintiff.[12]

10. A. Kneese, *The Economics of Regional Water Quality Management,* in Resources for the Future 41 (1964).
11. Cal. Water Code §§ 1200, 2500 (West 1956).
12. W. Hutchins, The California Law of Water Rights 419 (1956).

Up to the present time, the question of whether the underground water in the Salinas Valley is or is not a subterranean watercourse has never been tested in a court of law. Further, the difficulties of trying to prove that water moving along a five-mile-wide valley floor is, in fact, a definite stream appear to be almost insurmountable. Therefore, we must assume that the laws governing percolating waters in an underground basin will apply here.

The doctrine of correlative rights of use in percolating waters, which has been in effect in California since early in the present century, accords to each owner of land overlying a common water supply, a right to the reasonable beneficial use of the water of that supply on or in connection with his underlying land, such right of use of each such land owner being correlative with the similar rights of all other land owners overlying the same ground water supply. In the event of insufficiency of the supply for the requirements of the overlying land owners, the water may be apportioned by court decree.[13] Further, the owner of overlying land who first begins to use the percolating water gains no priority in the use of the water.[14]

The California courts have been reluctant to grant relief when the damage to the injured party is not substantial. In *Peabody v. Vallejo,* the court held that the mere inconvenience, or even the matter of extra expense, within limits which are not unreasonable, will not avail to prevent a subsequent appropriator from utilizing his rights.[15] It would appear that pumpers in the area of contamination of the 180-foot aquifer would not find relief in the courts for the additional cost of drilling deeper wells into the 400-foot aquifer for irrigation water. However, legal redress for the land owners overlying the area where both the 180-foot and 400-foot aquifers are contaminated appears possible.

Ever since the famous Raymond Basin case,[16] there has been no question as to the right of the courts to apportion an insufficient water supply for the purpose of protecting the supply and preventing a permanent undue lowering of the water table. In the Salinas Valley, undue lowering of the water table is not the problem. The problem is protection of a water supply. One possible solution to the seawater contamination problem is to request the courts to apportion ground water pumping in the confined area to maintain a fresh

13. *Id.* at 431.
14. *Id.* at 438.
15. 2 Cal. 2d 351, 376, 40 P.2d 486, 496 (1935).
16. Pasadena v. Alhambra, 33 Cal. 2d 908, 207 P.2d 46 (1949). *See also* Snyder, *The California Court Reference Procedure—Economics and Law in the Allocation of Ground Water,* 32 Land Economics 286 (Nov. 1957).

water gradient sufficient to repulse the saltwater in one or both of the aquifers.

Several problems inherent in this course of action should be considered before initiating a legal solution. First, it will be difficult to define the ground water basin accurately. The impervious clay strata are not uniform in thickness or location, and there would be a great deal of difficulty in defining precise boundaries. The cost of solving this problem would be formidable. Secondly, the plaintiffs in such a case would have to prove that both aquifers had a direct connection to the sea and that contamination of the 400-foot aquifer did not come from improperly drilled wells allowing saline water to enter from either the 180-foot aquifer or the perched water table near the surface. Thirdly, there are the practical difficulties of getting joint action by the several affected land owners. Finally, the great cost of a long, drawn-out court case cannot be ignored. In the last instance, the mere threat of legal action may in fact be sufficient to make an alternative solution more attractive.

IV

INSTITUTIONAL SETTING

Kneese has succinctly pointed out the analytical advantages of viewing the technological interrelationships of users within the context of a river basin decision-making unit rather than attempting to allocate joint costs and benefits between individual decision-making units.[17] In an operational sense, this internalization is not easily accomplished. Fortunately, both for analytical and operational convenience, there exists in the Salinas Valley an institution that serves this purpose well. The Monterey County Flood Control and Water Conservation District is an institution which is capable at least in a *limited way* of internalizing these externalities through its taxing power and water management program.[18] This does not imply equivalence to a monopoly firm in control of all the Valley's resources, but rather an intermediate stage institution with a large degree of control of the water supply.

The District was formed in 1947 for the stated purpose of flood control, water conservation (by spreading, storing, or causing waters to percolate into the soil), prevention of waste, and protection of the water supply. Specific zones of benefit for purposes of collecting reimbursement of costs of various localized projects have been formed in the County and Valley. Projects undertaken for the bene-

17. Kneese, *supra* note 10, at 48.
18. Ditwiler, *supra* note 4, at ch. 7.

fit of the entire County are financed by *ad valorem* assessments on all property. Projects undertaken for one of the special benefit zones are financed by *ad valorem* assessments on either all property or all real property in the zone.

Comprehensive water management is possible and probably encouraged under such an institutional arrangement. To a limited extent, external technical diseconomies in the district or within a prior established zone can be internalized. However, this cannot be done merely by administrative decree. Prior to 1963 a two-thirds majority of the registered voters was required in the district or a zone to authorize issuance of general obligation bonds and since that time a simple majority is needed for this purpose.

There is at least the implied obligation of the District (as managed by the County Board of Supervisors) to propose projects and set a water management policy which, within the limits of its enabling legislation, *ceteris paribus,* maximizes the economic product to the County with respect to water use.

V

ALTERNATIVE SOLUTIONS

Detailed analysis of all the possible alternative solutions to the saltwater intrusion problem is not an objective of this paper. This is not out of lack of interest but because detailed engineering and cost estimates are not available. A partial listing, however, is illuminating as it provides some perspective to the analytical framework developed later.

The first alternative is the one alluded to earlier, namely an overall reduction of pumping in the confined area. Although this remedy has the advantage of simplicity of concept, the problems of implementation loom rather large.

It can be argued that if pumping in the area along the coast did not cause a saltwater intrusion problem prior to 1940, then an overall reduction in withdrawals back to the annual rates of the 1920's and 30's should reduce the summer reverse gradient to a point where the intrusion would be stopped or even reversed. If there was no alternative source of irrigation water for the area or if the voters of the district or zone were unwilling to incur the bonded indebtedness to bring in additional water, then this alternative could become the actual situation. The legal problems mentioned earlier would still have to be surmounted.

A second alternative, and one very similar to the first, is to reduce pumping only in the area where the 180-foot aquifer is contaminated. Since all irrigation wells in this area are now tapping the 400-foot aquifer, a reduction in withdrawals to the safe yield level from this aquifer would protect it from any further contamination. Because this area is much smaller than the one contemplated in the first alternative, a voluntary agreement among the relatively small number of land owners affected may be possible. If a voluntary agreement could not be reached, resort to the courts could be had. However, the legal problems applicable to alternative number one would also apply to this proposed solution.

A third possibiity would be a radical departure from tradition in solving saltwater intrusion problems. This solution involves sinking a series of wells at the margin of the coastline that would pump from the contaminated aquifer. Pumping would create a cone of depression causing the hydraulic gradient to the aquifer to reverse. Lowering the pressure gradient at the coast line would change the gradient so that even if the fresh water level was below sea level, the gradient under the cultivated area would always be toward the ocean. This would allow fresh water to continue to move to seaward and, in time, hopefully the salt in the aquifer would be flushed out and again the aquifer would become productive.

Although relatively simple in concept, the physical problems inherent in this solution may present formidable obstacles. The most serious problem is associated with the size of the Valley mouth where the aquifers come in contact with the ocean. Typical of all alluvial valley fills, the Salinas Valley is much wider at the mouth than at any other place. In this instance, the potential interface between the ocean and the aquifer extends across the entire mouth of the Valley. Although the aquifers have not been contaminated across the entire mouth of the Valley, the confined area does include about 12 miles of coast line. To reverse the direction of flow at the coast line would require a sufficient number of wells and pumps to create a zone of depressions some 12 miles in length. Because of this, the reverse pressure solution was rejected as infeasible in an earlier state study of the problem.[19] However, based on the results of a small pilot study in southern California, the State Department of Water Resources is again seriously looking at this alternative.

A fourth alternative would add water to the contaminated area and thus is in essence the exact opposite of the last alternative discussed. This alternative calls for injection wells sunk along the coast line to pump fresh water into the aquifer at this point. This would build a mound of pressure between the cultivated area and the sea,

19. *Seawater Intrusion, supra* note 1, at 81.

using fresh water. By building up the fresh water hydraulic pressure at the seacoast, further intrusion could be stopped.

This alternative would not only require a large number of pumps along the coast line but would also require a sizeable amount of fresh water delivered to these wells for injection purposes. Further, there has been some difficulty encountered (with injection wells) in other areas with the problem of sediment and algae in the fresh water, building up and partially closing the perforations in the injection well casings. Therefore, this alternative requires an effective and expensive filtering process for the fresh water before it can be injected into the aquifer. A further problem is that a large amount of salt water may become trapped between the fresh water barrier and the fresh water moving down the aquifer leaving a large area still contaminated.

A fifth possible solution to the problem calls for a fresh water canal to the area of contamination. Controlled releases into the river from the two storage dams would provide a flow of water which would in turn be lifted into a canal several miles above the service area creating sufficient head for gravity flow to the service area. A storage reservoir would be constructed in the foothills near the service area to maintain the flow during the peak summer irrigation season. Assuming that contamination will continue to increase in the 400-foot aquifer, this system will have to be capable of providing a full irrigation supply to the area rather than a smaller capacity supplemental supply system. Some preliminary designs and cost estimates have been made for this alternative which could provide water to farm headgates at about $8.00 per acre-foot. These estimates are based on a service area somewhat larger than the area where the 180-foot aquifer is presently contaminated thus bringing in the additional problem of economies of scale in project designs.

A purely economic solution to the problem is presented as the sixth possibility. Compensation might be paid to the damaged or injured land owners by pumpers outside the contaminated area. Since a solution within this framework involves all of the practical and legal problems discussed in the first five alternatives, they will not be repeated here.

The possibility of doing nothing to repel the saltwater intrusion is a seventh alternative. The best alternative may be that of allowing the saltwater wedge to continue its advance and allow the land overlying both contaminated aquifers to go idle. In other words, is the problem so small that it is not worth solving? If the answer to the last question is yes, then analyses of the previous six alternatives would merely be an interesting academic exercise. Therefore, let us look at the relative magnitudes involved.

The gross area of the contaminated 180-foot aquifer is about 8,000 acres of land or 7,350 acres of cropland (4.9 percent of the Valley's total). The area covered by contamination of the 400-foot aquifer is only about 500 acres, centered in the artichoke-producing area. That is, at present only 500 acres have no underlying fresh water supply.

To evaluate this problem, two questions must be asked. First, what would be the impact on the economy of the Valley if the intrusion problem is not solved; and second, what is the average annual cost of solving the problem? One estimate of the latter is available although it may not prove to be the most efficient solution. The Flood Control District has estimated the cost of a fresh water canal at about $128,000 per year (16,000 acre-feet of water at an average cost of $8.00 per acre-foot). The answer to the first question is not so easily attained.

If the contaminated area in both aquifers went idle, much of this production would certainly shift to other lands in the Valley replacing lower-value crops already being grown. Resources invested in the contaminated area such as labor and capital would find employment elsewhere although there would be a time lag and an opportunity cost attached. Aggregate purchases of labor, fertilizer, electricity, seed, pesticides, etc., would probably be diminished.

Some estimate of the magnitude can be made by utilizing the results of a California interindustry analysis. Martin and Carter report the following technical coefficients for the northern California vegetable industry (Table 1).[20] These data indicate the direct purchases, ignoring interdependencies, of the northern California vegetable industry from other sectors.

These technical coefficients can be interpreted as the proportion of each dollar of gross income received by a vegetable grower that is paid to other sectors of the economy. Most of the definitions are self-explanatory. However, the household sector warrants some explanation. Household includes wages, salaries, proprietor's income, depreciation on capital inputs, and interest charges. This is by far the largest item, indicating that $0.7449 out of every dollar of producers' income was allocated to this sector.

The absolute expenditure by producers to each sector can be estimated by multiplying the data in column 1 of Table 1 times the

20. W. Martin & H. Carter, A California Interindustry Analysis Emphasizing Agriculture 250 (Gianinni Foundation Research Report, University of California, Feb. 1962).

TABLE 1
SELECTED TECHNICAL COEFFICIENTS FOR NORTHERN CALIFORNIA VEGETABLE INDUSTRY

1954	*Proportion*	*Artichoke value (500 acres)*
		(dollars)
Sector purchased from:		
Vegetable industry	.0131	3,936
Miscellaneous agriculture	.0332	9,976
Chemicals and fertilizer	.0176	5,289
Petroleum	.0082	2,464
Fabricated metals	.0155	4,658
Utilities	.0029	871
Selected services	.0066	1,983
Trade and transport	.0443	13,312
Maintenance and construction	.0083	2,494
State and local government	.0201	6,040
Households	.7449	223,842

Source: Martin and Carter, Appendix Table II.

gross income to producers. The average gross income per acre of artichokes for 1966 in Monterey County was $601,[21] or $300,500 for the 500 acres without fresh underground water. Lack of data precludes estimating the proportion of purchases from other sectors that would be lost to the economy if this land were to be abandoned. However, if only half of these expenditures were lost, this would still exceed the annual cost of a fresh water canal. The annual fresh water canal cost of $128,000 is 42.5 percent of the payments from the vegetable sector on 500 acres of artichoke land.[22]

We therefore conclude that the impact on the economy of the Salinas Valley would be sufficiently great to warrant a solution of the intrusion problem. Further, as the contamination spreads it will become more difficult to reinvest the idle resources. Time will become increasingly important. Having concluded that at least one of the alternatives appears economically feasible we will move directly into the general economic framework that permits an analysis of the remaining alternatives.

VI

THEORETICAL FRAMEWORK

At least two welfare economics criteria are available which appear to be applicable in this case. The first, and more restrictive, is the

21. Monterey County, California, Agricultural Commissioner's Report, Monterey County Annual Crop Report 2 (1966).

22. For general vegetable land, a comparable figure would be $900 per acre or about $450,000 for 500 acres or less than 30 percent of the payments.

criterion developed by Pareto (as discussed by Little)[23] which simply states that any change which harms no one and which makes some people better off must be considered an improvement. This criterion restricts our evaluation to solutions which are upwards and to the right, *i.e.*, northeast, of the status quo position in a utility space.

The second and somewhat less restrictive criterion is generally referred to as the Kaldor-Hicks criterion.[24] Stated in its simplest terms, this criterion says a change is an improvement if those who gain evaluate their gains at a higher figure than the value which losers set upon their losses. This criterion allows evaluation of changes that fall outside of the area amenable to the Pareto criterion.

For simplicity of presentation, let us assume that for those pumpers in the pressure area but not in the contaminated portion taken as a unit there exists an aggregate profit function which includes the cost and quantity of water used. Let this unit be called Group I. Secondly, the remaining pumpers, *i.e.*, those in the contaminated area, also have a profit function and are called Group II. Further, we can locate the coordinates of these two profit functions in a profit space and show the changes in them due to changes in the cost and supply of water, *ceteris paribus* (Fig. 2).

Assume that point A represents profit level coordinates under water cost and supply conditions as they existed prior to seawater intrusion. Point B would then represent the present situation. This change indicates that the level of aggregate profits of Group I have not diminished due to the intrusion, whereas the profit level of Group II has dropped sharply due to having to drill more expensive wells into the 400-foot aquifer. It should be noted that contamination of the 400-foot aquifer would result in a change to point D. At point D, the profit level of Group I would remain unchanged, while the profit level of Group II would be reduced to zero since the latter's supply of irrigation water would be eliminated. Having assumed that a change from point A to point B is the difference due to pumping from the deeper aquifer, then the distance A-B should correspond to the increase in cost for Group II due to the more expensive wells.

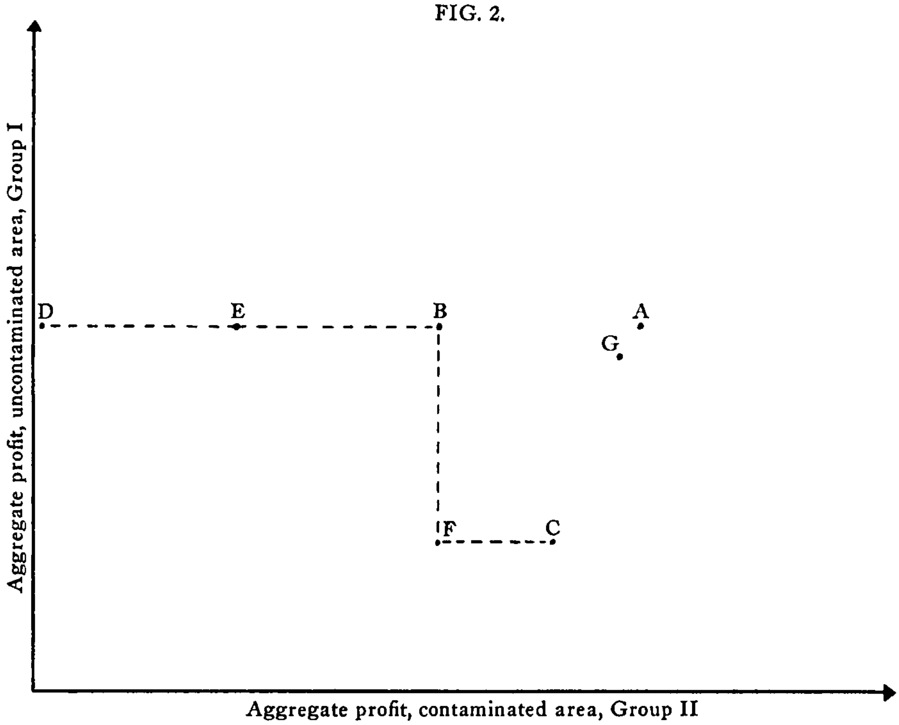
We previously assumed that the profit coordinates prior to contamination were point A which indicates profit levels were highest at that time. However, this point can never be reachieved and, therefore, the logical benchmark becomes point B which represents

23. I. Little, Welfare Economics, ch. VI (1958).
24. *Id.*

the present or status quo position. Any change to the left and below point B reflects a decrease in profit (and supposedly utility as well), for the study area. In analyzing any of the possible alternative solutions described earlier, we would, according to either the Pareto or Kaldor-Hicks criterion, move as far to the northeast from point B as possible. Let us look at the alternative solutions within this framework.

Alternative 1 involved the use of the courts to adjudicate the pumping basin which would force a reduction in the level of withdrawals of all pumpers in the confined area to a level commensurate with the safe yield of the basin. This would reduce the water supply of both groups, causing both to be worse off than they were at point

FIG. 2.



B. The result would be a reduction in utility and a change to some point C. The vertical distance between points B and C (B-F) would represent the decrease in profits (utility) due to a smaller water supply to pumpers in the uncontaminated area (Group I). As indicated earlier, the legal problems of this alternative present a serious and realistic barrier. However, the potential threat of this alternative might be a potent weapon for the land owners in the intrusion area as the subsequent discussion will illustrate.

Alternative 2, which involves Group II pumpers voluntarily reducing their withdrawals to the safe yield of the 400-foot aquifer, would cause a change from the present point B to a point such as point E, which is to the left and in the same horizontal plane as point B. This indicates at least a short-run decrease in profits (utility) for Group II with no change in the level of profits of the pumpers in Group I. Therefore, there would be a short-run decrease in the output and profits in the affected area. Further, there would be no way, under present conditions, in which Group II could prevent members of Group I from tapping the 400-foot aquifer in the future thus nullifying any long-run gains from this action. In terms of the Kaldor-Hicks criterion, this change from B to D would be unacceptable in that one group incurred no gain and the other group was worse off after the change.

Alternatives 3 and 4 can be considered together within our framework since the level of benefits for each should be nearly the same if they are operating properly. The only necessary criterion for choosing between them would be the lowest average annual costs levels.

The physical feasibility of these two alternatives has yet to be shown. However, it can be noted that if, after construction of one of these two barrier systems, it is possible to flush out the saltwater from the two aquifers and they become completely productive again, this would create a change in a northeasterly direction. If it were not possible to flush out that portion of the aquifer now contaminated, the only beneficiaries would be those pumpers in Group I presently in the pathway of the intrusion wedge. By halting the progress of the wedge, these pumpers can maintain their present rate of withdrawals, and the pressure area as a whole could result in a point somewhere to the left and below point B due to the costs of building and operating the barrier. If the 180-foot aquifer could not be cleansed and the barriers did not include the 400-foot aquifer, Group II would not be any better off than they are at present.

It is possible to analyze alternatives 5 and 6 together because there are some preliminary cost estimates available for the fresh water canal system (alternative 5).

To reiterate, we look for a solution that will move the pumpers from point B to some point above and to the right on the diagram. To bring our analysis into proper perspective, we must include the variable of property rights described under alternative number 1 and the cost of making the change. In that discussion, it was indicated that the State Water Code provides for adjudication of ground water basins to protect and preserve the basin. Recourse to this alternative would cause a change to point C and would make

Group I worse off. If it were not for the threat of this alternative, there would be no reason for Group I to have any concern for the welfare of Group II. Recourse to this alternative has Group I as a defendant in the court action and has a bearing on the cost sharing of alternative number 5 or the payers of compensation to Group II in alternative number 6.

The argument goes as follows: If Group II was successful in their court action to reduce the withdrawals of the basin to the safe yield, Group I would be worse off by the amount corresponding to the vertical distance between point B and point F. Therefore, they could afford either to pay as compensation to Group II this amount to maintain their present rate of withdrawals or contribute up to this same amount as their share of the costs of a fresh water canal which would bring the entire study area to a point east of B (let's call this point G), due to an increase in the aggregate supply of water. Since there would be a benefit accrued to Group II by the amount represented by the horizontal distance between B and C, they could contribute the amount represented by the line F-C, in lieu of the costs of the court action previously described. If the costs represented by the length of the two line segments B-F plus F-C are greater than the average total cost of delivering fresh water from a canal to the contaminated area, then the problem arises as to how the costs should be shared.

One way to divide the costs of the supplemental water would be on the basis of the relative lengths of the two line segments. We do not have before us detailed estimates of the aggregate profit levels for each group. The diagram is useful in its explanatory value and not in its quantitative ability; therefore, a more practical approach offers more appeal.

The second approach would be to levy a charge for canal water that did not exceed the average cost per acre-foot in the intrusion area prior to the contamination when Group II was pumping from the 180-foot aquifer. From an earlier cost study in the Valley, an estimate of about $5.00 per acre-foot was made.[25] A charge of $5.00 per acre-foot for canal water delivered to the farm headgates in the service area would make Group II as well off as they were prior to contamination and the balance of $3.00 per acre-foot collected from Group I would make them better off than they would be at point C and almost as well off as they were at point A. Using point F as a benchmark due to the interjection of property rights, the Pareto criterion can be applied because both groups have gained from the

25. Moore & Snyder, *Pump Irrigation Cost Increases in the Salinas Valley*, 19 Cal. Agriculture 14 (Aug. 1965).

change. If point B is used as a benchmark, the Kaldor-Hicks criterion must be applied because point G is below the horizontal plane of point B. In the latter case, the gains of Group II are greater than the losses of Group I at point G even when the net cost of the change is taken into consideration. Therefore, depending upon which point is taken as a benchmark, the change is considered acceptable under both criteria.

The question still arises as to how to collect the compensation or Group I's share of the cost of the fresh water canal. The Flood Control District, described earlier, stands as an excellent mechanism for internalizing these external diseconomies. It would be a relatively simple matter to define a zone of benefit that included only the pressure area. A bond issue floated for the purpose of constructing the fresh water canal could be repaid by a tax on the assessed valuation of the property within the prescribed zone. An amount could be collected that caused Group I to pay about $3.00 per acre-foot for anticipated project deliveries to the project service area. Those pumpers within the canal service area but not in the contaminated area would be no worse off by paying this amount.

Collecting a tax on the Group I pumpers to be used for paying compensation would be much more difficult in that the constitution of the District would have to be changed to allow for a tax that is not collected to repay a bond issue. There would also be the problem of how to divide any taxes collected among the Group II pumpers. If the tax was collected but not paid to the Group II pumpers, there would still be a misallocation of resources as has been shown by Turvey;[26] and the Group II pumpers would be only slightly better off than they are at present, since it is doubtful that a tax of this magnitude would cause pumpers of Group I to reduce their withdrawals to the level of safe yield of the basin. Therefore, the cost-sharing alternative would appear more appealing in that it avoids this complication.

CONCLUSION

This paper has described some of the physical characteristics of saltwater intrusion into a ground water basin. The major focus has been to define and evaluate legal and economic problems that might be encountered in applying any of six major alternative solutions to the intrusion problem considered feasible at this point of development. When these alternatives are analyzed within both the frame-

26. R. Turvey, *On Divergences Between Social Cost and Private Cost,* Economica 309 (Aug. 1963).

work of welfare economics and the legal setting of property rights, the threat of court action by the injured parties causes a change away from the present status quo solution to one where the pumpers in the uncontaminated area would be as well off if they contributed to the cost of a fresh water canal rather than suffer the consequences of having the courts adjudicate the basin. Secondly, the aggregate profit level of the entire pressure area would be maximized under this solution.

A profitable future line of research might be to undertake an empirical estimation of the quantitative magnitudes involved in the aggregate profit levels hypothesized in our welfare economics model including the net cost of the various alternative solutions.