Economics of . . .

Ground Water Allocation

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THE ECONOMICS OF GROUND WATER ALLOCATION WITH PARTICULAR REFERENCE TO THE MILTON-FREEWATER AREA OF OREGON: A METHODOLOGICAL INVESTIGATION 1/

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Introduction

The use of ground water has assumed an important place in the industrial and agricultural development of the West. In some areas the water table has been lowered to the point that means of rationing water among uses and users have become necessary. The problem is not one of legality alone but involves physical as well as economic factors. Economic analysis of ground water problems lies between physical investigation on the one hand and legal studies on the other. In view of the growing economic importance of water it is appropriate that studies be made of the economic problems which arise.

The purpose of this study was to:

1. Illustrate possible application of economic reasoning to problems arising within a particular ground water doctrine.

2. Illustrate an empirical method of relating relevant variables in a water allocation problem.

3. Discuss implications of the study to the design, development, and modification of the institutional framework within which water is allocated.

The study area comprised the Walla Walla River basin on the Oregon side

1/ This study is primarily methodological in nature. A particular geographic area was selected to provide a realistic setting for the exploration of certain problems. The numerical results must be applied, if at all, to the area studied with caution. The study is a part of a regional research project on the economics of ground water allocation and use.

2/ Agricultural Economist and former Graduate Research Assistant, Oregon Agricultural Experiment Station, respectively. The authors are indebted to Chris L. Wheeler, Engineer, State Engineer's Office, Salem, Oregon, for constructive criticism. Mr. Wheeler, of course, is in no way responsible for the material in this publication.

side of the border. This area was selected in consultation with the State Engineer's Office as being one where ground water is likely to become a limiting factor in agricultural production. Data pertaining to water rights on each stream are available.[1/] Water rights are classified by adjudicated rights issued before 1909 and rights issued after 1909.[2/]

All the water from the Walla Walla River and the adjacent small streams has been appropriated during the summer months and additional surface water is not likely to be available in the foreseeable future. Any expansion in the use of irrigation water probably will have to be based on ground water sources or involve greater efficiency in the use of existing water.

At the present time the water table is not being lowered, but additional

1/ The State Engineer maintains an official record of all water rights that have been determined, both surface and ground water.

2/ An adjudicated right is one that has been determined by the State Engineer and modified or confirmed by the courts. These rights exist by virtue of being initiated prior to the effective date of the law governing the appropriation of that class of water for the area. In Oregon the effective dates are: February 24, ,1909, surface waters, May 28, 1927, that part of Oregon east of the summit of the Cascade Mountains for ground water for certain purposes and August 3, 1955, for ground water throughout the state.

Under a statutory procedure the State Engineer makes detailed investigation, holds hearings and determines the priority and the extent of the development to which the water has been put to beneficial use.

The determination of the State Engineer is filed with the circuit court which enters the decree confirming the findings or hears appeals.

Adjudication in the general sense is used to differentiate this type of right from one that is acquired through a permit issued by the State Engineer. Subsequent to the effective dates the only way rights can be acquired is through permits issued by the State Engineer or licenses issued by the Hydroelectric Commission for generation of hydroelectric power by persons or corporations, other than a municipality.

well drilling could create overdraft. 1/ In such a situation the State Engineer's Office would be forced to take action. This office could prevent the development of additional ground water, and under existing law cannot condemn existing rights; yet, if a water shortage develops, what rationing procedure should be used? Should economics play a role in the rationing process? If so, what role should it play?

In Oregon, the doctrine of prior appropriation applies to the ground water of the state. 2/ Beneficial use without waste is the basis, measure and extent of the right to appropriate ground water. Preference is given to domestic and livestock purposes. Other uses such as agricultural, industrial, municipal other than domestic, and recreational, are recognized as beneficial; but no priority is assigned, leaving the determination in specific cases to administrative agencies. 3/

Rather broad powers have been given to administrative groups. In 1955, a State Water Resources Board was created with broad policy powers over the unappropriated water of the state. The State Engineer's Office, on the other hand, is viewed as an action agency. The Engineer's major responsibility is to carry out the policy of the legislature and the State Water Resources Board. Yet the Ground Water Law, which was also passed by the 1955 legislature, gives the Engineer considerable authority in certain matters. Of relevance here is his authority to institute a number of control measures in the event he believes a ground water area should be

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1/ "Overdraft" is defined as the volume of ground water removed in excess of recharge from aquifers within a particular geographic area and for a specified period of time. See Snyder, Herbert J. "Ground Water in California. The experience of Antelope Valley" Giannini Foundation Ground-Water Studies No. 2.

2/ Oregon Revised Statutes, Chapter 537.

3/ In the case of a critical ground water area, the State Engineer has the authority to institute control provisions including the power to accord preferences without regard to priority among uses.

designated as critical.

Description of Area

Location

The Walla Walla Valley is situated in the northern part of Umatilla County. This study is concerned only with that part of the area situated in the state of Oregon. It comprises about 35,000 acres of land lying between the state line and the Blue Mountains.

The main stream is the Walla Walla River which is a nonnavigable, natural water course emptying into the Columbia River. Its principal tributaries are Yellowhawk Creek and Mill Creek which are situated almost wholly within the state of Washington; Birch Creek, Pine Creek, Couse Creek, South Fork and North Fork which are all mostly located within Oregon in the vicinity of the city of Milton-Freewater.

Type of Farming

The valley is characterized by two distinct types of farming. In the area around the Walla Walla River bed the dominant crop is fruit which is irrigated primarily from surface water from the river early in the season and supplemented by pumping from shallow wells during the latter part of the summer. This area will hereafter be referred to as the Milton-Freewater Area or Area I. In the area west of the city of Milton-Freewater the major crops are grain, alfalfa hay and sugar beets. The principal source of water here is ground water as the few natural streams become dry in the early spring. This area will hereafter be referred to as the Umapine Area or Area II. This characteristic division in the agricultural pattern makes the valley suitable for an economic analysis of ground water allocation problems.

Table 1 is presented to give a picture of land use in the basin.

Table 1. Land use in the three enumeration districts, South Umapine, North Umapine, and Crocket, Umatilla County, 1954. 1/

Land Use	Enumeration districts			Total for whole area	Percent of total
	15	16	17		
Number of farms	350	2	152	504	
TOTAL ACRES	15,734	4,850	15,342	35,926	100
1. Acres of cropland	12,375	258	12,858	25,491	71
a. Cropland harvested	9,820	258	9,512	19,590	
Hay	2,439	118	501	3,058	
Grain	2,785	65	4,673	7,523	
Grass seed	10	0	0	10	
Vegetable	746	0	2,975	3,721	
Sugar beets	1,671	75	278	2,024	
Irish potatoes	22	0	30	52	
Orchard	2,024	0	933	2,957	
Other	123	0	122	245	
b. Cropland pastured	1,699	0	309	2,008	
c. Cropland summer fallow	304	0	2,488	2,792	
d. Cropland (other cultiv.)	552	0	549	1,101	
2. Wood land	782	10	529	1,321	4
3. Other land (including pasture)	2,577	4,582	1,955	9,114	25
TOTAL ACRES IRRIGATED	11,263	348	3,876	15,487	43 2/
Cropland	9,252	258	3,442	12,952	51
Pasture	2,011	90	434	2,535	34

1/ Source: United States Department of Commerce, Bureau of the Census, Census of Agriculture: 1954. Through courtesy of the Portland Branch of the Bureau of the Census, it has been possible to break down data into enumeration districts.

2/ Forty-three percent of total acreage is irrigated. Fifty-one percent of total cropland is irrigated.

The difference in land use in the two areas can best be obtained by comparing enumeration districts 15 and 17. District 16 includes parts of both the Umapine and the Milton-Freewater Area.

Seventy-one percent of the total acreage is in cropland of which 51 percent is irrigated. One reason for the low irrigation percentage is that the hills surrounding the valley are included in the total area. The irrigation percentage would increase to about 75 percent if only the valley floor is considered.

Orchards constitute about 15 percent of the cropland harvested while vegetable crops make up about 19 percent. These are the two major crops in the Milton-Freewater Area where the irrigated land amounts to about 85 percent of the total area.

Type of Soil

The Yakima soil series predominate in the fruit growing area. These soils range from cobbly loam to silt loam and are open, porous, excessively drained and occur in the delta of the former flood plain of the Walla Walla River. The soils are variable in depth, in content of gravel and stone, in surface texture and color of the finer soil material. The color of the surface soil ranges from pale brown or light brownish gray to a weak brown when dry, and from weak brown to dark brown or dusky brown when moist. The surface soil is nearly neutral in reaction, though some spots in the series are impregnated with alkali.

The soils in the Umapine Area consist predominantly of the Ritzville soil series which occupies a wide belt of the smooth to rolling uplands extending west from the Walla Walla River. Those soils are for the most part fine and silty and have a floury consistency, although the Ritzville series has fine sandy loam members. All are light in color and low in content of organic matter, and the subsoils have a heavy concentration of lime.

They also are impregnated with alkali deposits which in some places have seeped to the surface. The vegetation on these spots is restricted to salt-grass and sagebrush.

Geologic Structure of Ground Water Reservoir

The most compact and most intensively cultivated body of land irrigated in the area is largely planted to fruit crops and lies between Milton and the state line. The Walla Walla River divides here into several natural branches which are used and controlled as ditches. The water in these branches is used intensively for irrigation which causes it to be distributed over a wide area. As a consequence of this and the nature of the soil, it seeps into the ground and is, to all appearances, lost for surface use. However, part of the water is collected in a groundwater reservoir and is returned to the surface for further use by means of natural springs and artificial wells.

The shallow wells in the area of Milton-Freewater receive their water from the water-bearing layers above a hard subsoil formation which consists of a conglomerate of stone and clay cemented together. The ground water in this zone is recharged from irrigation water percolating through the soil, sub-surface discharge from the Walla Walla River and by precipitation. Any marked expansion in irrigation in the Milton-Freewater Area probably will come from wells in excess of 200 feet which penetrate the basalt.

Most of the wells in the Umapine Area are deeper than 200 feet and fall into two general classifications: those penetrating water bearing zones in the basalt which are located on the slopes south of Umapine and those in the valley floor which penetrate the gravels and average about 400 feet deep. Relatively small amounts of water have been obtained in the Umapine Area at the shallow depths prevailing for the gravel wells of the Milton-Freewater Area. The gravel formations are found as tongues or lenses in the silt and clay formation of the Umapine Area. The interrelationships of ground water between the areas is such that either or both might receive water from the basalt. Adequate information to determine the effect of pumpage from one area to another is not yet available. To some extent the supply in the gravel wells and the spring branches may be dependent on the extent and time of irrigation in the Milton-Freewater Area.

In the Milton-Freewater Area, wells are furnishing about half of the water used for irrigation purposes. The Umapine Area depends much more on ground water as the natural streams become dry before the end of the irrigation season.

According to a geological survey conducted in 1951 by the United States Department of Interior, the amount of ground water tapped annually was estimated to be about 39,200 acre-feet. Of this amount 36,000 acre-feet are supplied by aquifers in old gravel deposits and 3,200 acre-feet from the deep stratum of the Columbia River basalt. The 39,200 acre-feet were distributed among uses such as irrigation, domestic, public, and industrial of which irrigation accounted for about 85 percent of total usage.

Most of the potential ground water in the gravel formations of the valley are beneficially used and only a minor amount are in storage available for use from existing wells. On the other hand, large quantities of water are in storage in the basalt strata.

Climate

The climate of the Walla Walla basin is temperate and semiarid, although some differences in temperature and precipitation occur between the higher and lower parts of the valley. The annual mean temperature lies between 50 and 53 degrees Fahrenheit with the highest annual temperature usually below 100 degrees Fahrenheit and the lowest annual temperature commonly above zero degrees Fahrenheit. The last killing frost in spring usually occurs in April and the first killing frost in autumn normally occurs during October.

The annual precipitation of 14 inches comes mainly as rain in the valley floor and in the higher parts as rain and snow. The months of November through April have the most precipitation with 66 percent falling during this period.

Methodology

The Analytical Framework

In theory, it is possible to define a social optimum in the use of water. 1/ This involves a surface which would define the "product" forthcoming from all possible allocations of water among all possible uses. The "product" would need to be valued by means of a utility function. Such a theoretical model is not operational for the practical problem at hand. Numerous modifications must be made in order to establish a useful economic framework.

Central to the framework of the model is the underlying assumption that market institutions generally serve the needs of the society, and its citizens are themselves best qualified to determine their needs and desires. Under these conditions, the pricing mechanism reflects the wishes of the consumers so any changes in consumer preferences for any product will be indicated by the derived demand for that particular product at the producer's plant. If the above is accepted, the pricing mechanism

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1/ Heady, E. O. and Timmons, John F. Economic Framework for Planning Efficient Use of Water Resources. Chapter 7 in Iowa's Water Resources, Iowa State College Press. Ames, Iowa. 1956.

can be used as the choice indicator to find the optimum or socially desirable point on the production surface.

Ideally, one would need to know the individual production functions for water in each area; however, a survey of water use in the areas will reveal only one point on each production function. This point will reflect the combination of water, land and other inputs that farmers have arrived at in practice. This combination reflects the cost of obtaining and applying water and the value of the product received as well as the cost of the other inputs. If it can be shown that farmers would use any additional water made available to them by combining this water with other inputs in the same proportion as they are now using those inputs, the problem can be more easily managed. This would mean that if it required three acre-feet of water to irrigate an acre and if an additional 300 acre-feet of water are made available, an additional 100 acres of land will be irrigated. The result of this would be that a water transformation curve between the areas would be of the nature of EE_1 in Figure 1. Output in Area II, the Umapine Area, is measured on the horizontal axis and output of Area I--the Milton-Freewater Area, is measured on the vertical axis. The reason the limitation lines of Land I and Land II are perpendicular to the Y and X axes, respectively, is that the area of Milton-Freewater is not adapted to the production of the crops being grown in the Umapine Area; and the area of Umapine is not adapted to the production of fruit.

The limiting factors are land when all the available water is applied to either one of the uses. However, when the two uses are competing for the water, water becomes the limiting factor and the production possibility function becomes ABCD. This function shows all the possible combinations of the two uses which can be attained from the given supply of water. If all of Land I were irrigated, there would still be water left over for Land II. The combination of products in this case would be OA units of Output I and OQ units of Output II. If all of Land II were irrigated, the combination of products would be ON units of Output I and OD units of Output II.

There is no way of establishing the exact nature of this function short of a controlled experiment. However, the hypothesis that the transformation function is linear between the areas appears to be consistent with farmers' decisions and practices in the area. In effect, this assumes that farmers will organize their inputs in the future in approximately the same way as they are at present. If it is accepted that the determinants of the way in which these inputs are organized are the prices of the commodities produced and the cost and productivity of the inputs, the assumption appears reasonable for the problem at hand. These items are not within the control of an administrative water agency, nor are they likely to be. The linear transformation function would not hold for certain other areas with which the authors are familiar but appears to be the most reasonable assumption for the case study area.

Sampling Procedure

The Agricultural Census of 1954 reports that 504 farms are being operated on the Oregon side of the state line of the Walla Walla basin. Of this total, 288 farms are reported as being orchards and the remaining 216 farms are as being farms growing grain, alfalfa, pasture, sugar beets and other crops of lesser importance. The farms in each area were stratified according to total acreage in the farms. In

Area I a sample of 47 farms was drawn from the population of 288 farms. In Area II a sample of 43 farms was drawn.

The primary data were collected in the summer of 1957. Each farmer in the sample was interviewed and detailed information on his farm organization and production practices were obtained. The secondary data were obtained from several governmental agencies and from official reports. The hydrological data of the basin were obtained from a geological report by R. C. Newcomb of the United States Geological Survey and were supplemented by information obtained from the State Engineer's Office in Salem.

Empirical Analysis

The costs of input factors were calculated for each of the enterprises on each farm. Machinery costs were calculated from the data obtained from farmers. These machinery costs were applied to the operations reported by farmers on each crop enterprise. In this manner it was possible to calculate machinery cost for each enterprise on each farm.

The cost of labor was obtained by multiplying the hours the farmers reported as having spent on each operation by the wage per hour which was most common in that particular area. This rate was applied to both hired labor and the operator's own labor. Where custom work was involved the rate per hour actually paid for the work was used. Such items as seed, fertilizer, spray materials and other materials were treated as variable costs and were allocated to each enterprise.

All the costs of production were not included in the individual calculation of each enterprise on each farm because the information

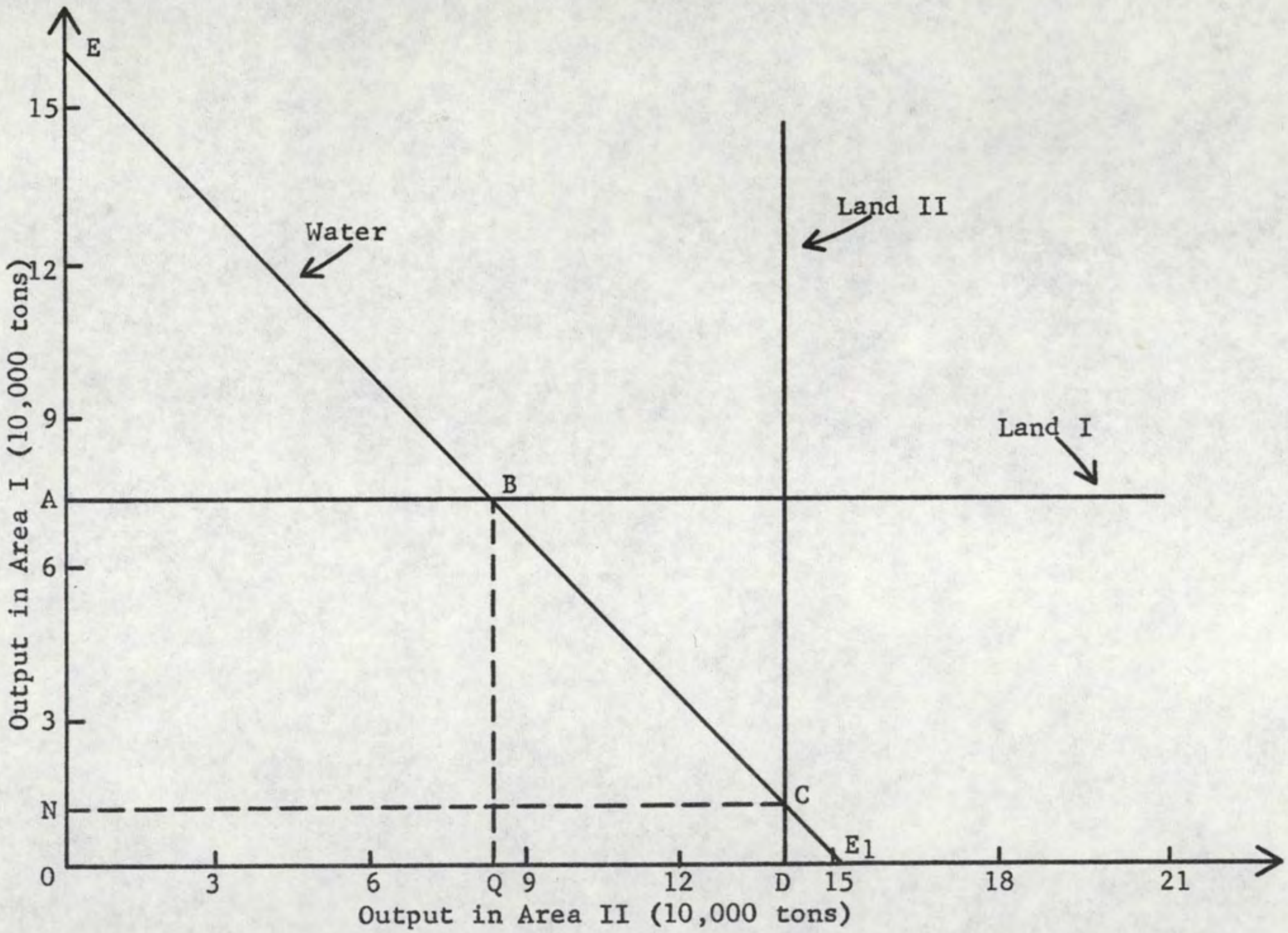

Figure 1. Diagram of Alternative Water Uses

was difficult to obtain. Therefore, such expenses as irrigation equipment, electricity for irrigation pumps, insurance on crops, payroll insurance and telephone and office costs were calculated on basis of the "representative enterprise" using the farmer's own estimates. The costs were then allocated to the relevant enterprises on a per acre basis. Irrigation expenses were calculated from the requirements of pipelines, pumps and motors and wells necessary to irrigate a given area.

The yields used were based on the farm survey whenever possible. When such information was not available, the 1954 Census of Agriculture was used.

Fruit, vegetable, wheat, oats, barley and alfalfa prices were based on state and national price reports. The value of pasture was calculated on basis of the feed equivalent of alfalfa hay.

The enterprises were combined into four composite enterprises assuming "irrigation" and "nonirrigation" for the two areas. The method employed in arriving at the unit profitability of one acre of a composite enterprise was as follows: the net return per acre was computed for each enterprise and a weighted average was calculated in which total acreage was used as the weight. The total acreage was set to equal 100 percent and the acreage of each enterprise determined the weight which the net returns of each enterprise would have.

The results of budgeting of the individual enterprise in the two areas are summarized in Table 2 - 4. The linear programming model used was based upon the input-output coefficients computed from the four budgets. Table 5

Table 2. Summary of budget for irrigated crops in the Umapine Area, 1956. 1/

	Yield per acre	Price per unit 2/	Total return per acre	Total cost per acre	Net return per acre	Unit profit-ability 3/	Total acreage 4/	Yield in tons weighted 5/
Wheat	44 bu.	$ 2.00	$ 88.00	$ 39.75	$ 48.21	$ 7.24	1711	0.20
Oats	60 bu.	0.81	48.60	38.31	10.29	0.17	185	0.02
Barley	40 bu.	1.19	47.60	41.52	6.08	0.19	360	0.03
Sugar beets	20 tons	11.14	222.80	171.93	50.87	8.08	1810	3.18
Green peas	1.2 tons	85.40	102.48	59.88	42.60	1.51	404	0.04
Lima beans	0.75 tons	170.00	127.50	118.63	8.87	0.10	127	0.01
Alfalfa	4.7 tons	20.00	94.00	46.41	47.59	19.62	4698	1.93
Pasture	1.93 tons	20.00	38.56	33.65	4.91	0.90	2101	0.36
TOTAL	-	-	769.54	550.12	219.42	37.81	11,396	5.77

1/ 2.92 acre-feet per acre

2/ Prices of wheat, oats, barley and alfalfa were taken from Oregon Commodity Data Sheet, Oregon State College Extension Service. Prices of sugar beets and green peas were obtained from Table 28, Table 16 of Oregon Farm Product Prices. Prices of lima beans were obtained from the survey data. Prices of pasture were calculated on basis of alfalfa hay equivalent.

3/ Instead of using a simple average the acre unit profitability is weighted by acreage so the unit profitability of one acre becomes $37.81.

4/ Total acreage was obtained from the Census of Agriculture of 1954 and indicates land use in 1954.

5/ Weighted with total acreage.

Table 3. Summary of budget for irrigated crops in the Milton-Freewater Area, 1956. 1/

Name of enterprise	Yield per acre	Price per unit 2/	Total return per acre	Total cost per acre	Net return per acre	Unit profit-ability 3/	Total acreage	Yield in tons weighted 4/
Apples	248.36 bu.	$ 2.68	$ 665.60	$366.07	$299.53	$109.02	1097	2.26
Prunes	8.19 tons	65.82	539.07	404.28	134.79	64.44	1441	3.92
Cherries	3.57 tons	242.20	864.65	406.27	458.38	33.76	222	0.26
Tomatoes	394.5 bu.	3.05	1,203.23	443.78	759.45	54.93	218	0.65
Asparagus	1.75 tons	198.20	346.85	273.44	73.41	0.88	36	0.03
TOTAL	-	-	$3,619.40	$1,893.84	$1,725.56	$263.03	3014	7.12

1/ 3.16 acre-feet per acre.

2/ Prices per unit were obtained from Oregon Farm Product Prices. Prices of apples, prunes and cherries were taken from Table 17 of that publication and Prices of tomatoes and asparagus were taken from Table 15 and Table 16 respectively.

3/ Weighted with acreage so the unit profitability of one acre becomes $263.03.

4/ Weighted with acreage.

Table 4. Summary of budgets for nonirrigated crops in the Umapine Area and the Milton-Freewater Area, 1956.

Name of enterprise	Yield per acre	Price per unit 1/	Total return per acre	Total cost per acre	Net return per acre	Unit profit-ability 2/	Total acreage	Yield in tons weighted
Umapine Area:								
Wheat	25 bu.	$ 2.00	$ 50.00	$ 23.02	$26.98	$ 6.75	1830	0.188
Oats	32 bu.	0.81	25.92	24.52	1.40	0.06	337	0.024
Barley	35 bu.	1.19	41.65	23.02	18.63	0.29	112	0.013
Alfalfa	1.33 ton	20.00	26.60	20.68	5.92	0.51	624	0.113
Pasture	1.133 ton	20.00	22.66	11.10	11.56	6.97	4412	0.683
TOTAL	-	-	$166.83	$102.34	$64.49	$14.58	7315	1.021
Milton-Freewater: Area:								
Apples	125 bu.	$ 2.68	$ 335.00	$237.85	$ 97.15	$31.95	100	1.028
Prunes	4 tons	64.82	263.28	249.11	14.17	5.59	120	1.579
Cherries	1.75 tons	242.20	423.85	258.84	165.01	8.14	15	0.086
Small grain	1.36 tons	20.00	27.20	23.32	3.88	0.24	19	0.085
Alfalfa	1.33 tons	20.00	26.60	20.67	5.93	0.98	50	0.219
TOTAL	-	-	$1,075.93	$789.79	$286.14	$46.90	304	2.997

1/ Source of prices is the same as in Tables 2 and 3.

2/ Unit profitability of one acre is weighted with acreage.

Table 5. Basic Information on Input-Output Quantities and Net Returns for Four Different Production Activities.

Item	Alternative Production Activities 1 Irrigated Crops in Area I	2 Nonirrigated Crops in Area I	3 Irrigated Crops in Area II	4 Nonirrigated Crops in Area II	Quantity of Inputs Available
Yields per acre (tons)	7.122	2.997	5.786	1.021	
Per acre requirement of:					
Net returns ($)	263.03	46.91	37.81	14.58	
Water (acre-feet)	3.160	0	2.919	0	
Per ton requirement of: 1/					
Land in Area I (acre)	0.1404	0.3337	0	0	10,240
Land in Area II (acre)	0	0	0.1734	0.9795	24,365
Water (acre-feet)	0.4438	0	0.5061	0	69,200
Net return per ton ($)	36.93	15.65	6.56	14.28	

1/ Per ton requirement of the limited factors was obtained by dividing "per acre requirement" by the corresponding yield per acre.

sets forth the situation for both areas with its four activities which are called: (1) irrigated crops in Area I, (2) nonirrigated crops in Area I, (3) irrigated crops in Area II, (4) nonirrigated crops in Area II. The requirements of producing one ton of "Irrigated Crops in Area I" are 0.1404 acre of Land I and zero acre of Land II (since Land II is not adapted for that "enterprise") and 0.4438 acre-feet of irrigation water. It will yield a final net return of $36.93. The requirements of producing one ton of "Nonirrigated Crops in Area I" are 0.3337 acres of Land I and zero acre of Land II and zero acre-feet of irrigation water. This will yield a net return of $15.65. The next two columns are interpreted similarly.

The production possibilities are limited by the total number of acres in each area and by the availability of water which is assumed to be 69,200 acre-feet for the growing season. Consider the activity, "Irrigated Crops in Area II." If it is operated at the level of 0.5061 acre-feet per ton of yield, it will absorb 71,125 (0.5061 x 5.768 x 24,365 = 71,125) acre-feet of water which is more than the quantity available. The total net return will amount to $896,955 for this activity. The problem is to select that combination of activities that would yield the highest net return to the limiting land and water resources.

The Results

In Table 6, Plan 4, the results of the simultaneous solution of the equations are shown. This is the optimum solution of the four enterprises under the limitational conditions of the resources. The optimal levels of the variables are those given in the x_0 column, and the maximum attainable yearly net return is $3,342,117 for the two areas combined. It will be noted that the irrigated crops in Area I are allocated all the water

Table 6. Linear Programming Solution with Water Supply at 69,200 Acre-Feet.

Resource	Unit	X_0	0 X_5	0 X_6	0 X_7	\$36.93 X_1	\$15.65 X_2	\$6.56 X_3	\$14.28 X_4	Ratio
Plan 1										
X_5	Acre	10,240	1	0	0	0.1404	0.3337	0	0	72,934.5
X_6	Acre	24,365	0	1	0	0	0	0.1734	0.9795	unlimited
X_7	Acre-feet	69,200	0	0	1	0.4438	0	0.5061	0	155,926.1
Z	\$	0	0	0	0	0	0	0	0	
Z-C	\$	0	0	0	0	-36.93	-15.65	-6.56	-14.28	
Plan 4										
X_1	Tons	72,934	7.1225	0	0	1.0000	2.3768	0	0	
X_4	Tons	11,992	1.1057	1.0210	-0.3498	0	0.3690	0	1.0000	
X_3	Tons	72,775	-6.2458	0	1.9759	0	-2.0842	1.0000	0	
Z	\$		15.7893	14.5785	-4.9949	0	5.2693	0	14.28	
Z-C	\$	3,342,117	237.8507	14.5785	7.9670	0	63.7222	0	0	

X_0 = Supply remainder or output
X_1 = Irrigated Crops Area I
X_2 = Nonirrigated Crops Area I
X_3 = Irrigated Crops Area II
X_4 = Nonirrigated Crops Area II
X_5 = Land I
X_6 = Land II
X_7 = Water

that is needed for irrigation at the established rate.

The marginal value product of the available resources is a by-product of the linear programming solution. Thus, the marginal value product of Land I is $237.85, which means that one additional acre of Land I would be worth $237.85 less land charges. Land charges would have to be deducted from the marginal value product figure because taxes and other land charges were not included in the costs used in the computation. The MVP of Land II is $14.58 and the MVP of water is $7.97. This means, in the case of Land II, that an additional acre of Land II would be worth $14.58, less land charges.

The example in Table 6 gives the MVP's of the limiting resources under the assumption that 69,200 acre-feet of water are available. Table 7 gives a solution assuming 20,000 acre-feet of water is available in the area. Under these circumstances the MVP of Land I is $36.90. The MVP of Land II is the same as before because all of Land II is in "non-irrigated crops." The MVP of water is $68.38.

The MVP's of water change with quantity of water available. In linear programming these changes are of a discrete nature because of the linear nature of the analysis. Thus, the MVP will remain constant over some range even if the input of water is changed. The range for which the MVP remains the same is useful information since the quantity of ground water in a basin is seldom known with great precision.

The ranges of constant MVP's of water are illustrated in Figure 2. If the supply of water in the two areas is sufficient to cover the water requirements of only part of Land I, the MVP is $68.37. When Land II is being irrigated, the MVP drops to $7.97. The MVP is constant as long as there are still some acres of Land II to irrigate. When all acres are

Table 7. Linear Programming Solution with Water Supply at 20,000 Acre-Feet.

			0	0	0	$36.93	$15.65	$6.56	$14.28	
Resource	Unit	X_0	X_5	X_6	X_7	X_1	X_2	X_3	X_4	Ratio
Plan 1										
X_5	Acre	10,240	1	0	0	0.1404	0.3337	0	0	72,934.5
X_6	Acre	24,365	0	1	0	0	0	0.1734	0.9795	unlimited
X_7	Acre-feet	20,000	0	0	1	0.4438	0	0.5061	0	45,065.3
Z	$	0	0	0	0	0	0	0	0	
Z-C	$	0	0	0	0	-36.93	-15.65	-6.56	-14.28	
Plan 4										
X_2	Tons	11,725	2.9967	0	-0.9481	0	1.0000	-0.4797	0	2.5689
X_4	Tons	24,875	0	1.02093	0	0	0	0.1770	1.0000	2.1979
X_1	Tons	45,065	0	0	2.2532	1.0000	0	1.1404	0	4.3936
Z	$		0	14.5788	0	0	0	2.5275	0	
Z-C	$	2,202,982	46.8984	14.5788	68.3765	0	0	30.5752	0	160.4286

X_0 = Supply remainder or output

X_1 = Irrigated Crops Area I

X_2 = Nonirrigated Crops Area I

X_3 = Irrigated Crops Area II

X_4 = Nonirrigated Crops Area II

X_5 = Land I

X_6 = Land II

X_7 = Water

irrigated and the water requirements are satisifed, the MVP becomes zero.

Stability of Solution

Table 8 is presented to indicate the stability of the solution of the problem. These data make it clear that prices would have to change a considerable amount before the solution would change. In no year of record would the price ratios have changed a sufficient amount to have changed the allocation. In this particular case, we can be confident that the solution will be a reasonably stable one. If the number of alternative uses were larger, the solution would tend to be less stable.

Table 8. Range in Net Revenue for Which the Optimum Solution Remains Unchanged.

Enterprise	Net Revenue Used in Budgeting the Optimum Per Ton	Range in Net Revenue for Which the Program Remains Optimum	
		Lowest Net Revenue Before Program Would Change	Highest Net Revenue Before Program Would Change
Irr. Crops Land I	$36.93	$10.12	unlimited*
Nonirr. Crops Land I	15.65	unlimited**	$79.37
Irr. Crops Land II	6.56	2.53	37.13
Nonirr. Crops Land II	14.28	0	37.06

* This enterprise is in optimum solution to the limit of the land available. Further increases in net revenue will not affect solution.

** This enterprise is not in the optimum solution and only an increase in net revenue can affect solution. A drop in net revenue has no effect on the optimum solution.

Legal and Institutional Implications 1/

In this section, conclusions will be drawn with respect to possible

1/ At this point it should be emphasized that the study problem is illustrative only of the more fundamental allocation problems of water. The "within use" situation depicted here is less complicated than would be the case than if a "between use" problem were being analyzed. There is no reason, however, why the method could not be applied to a more complex situation.

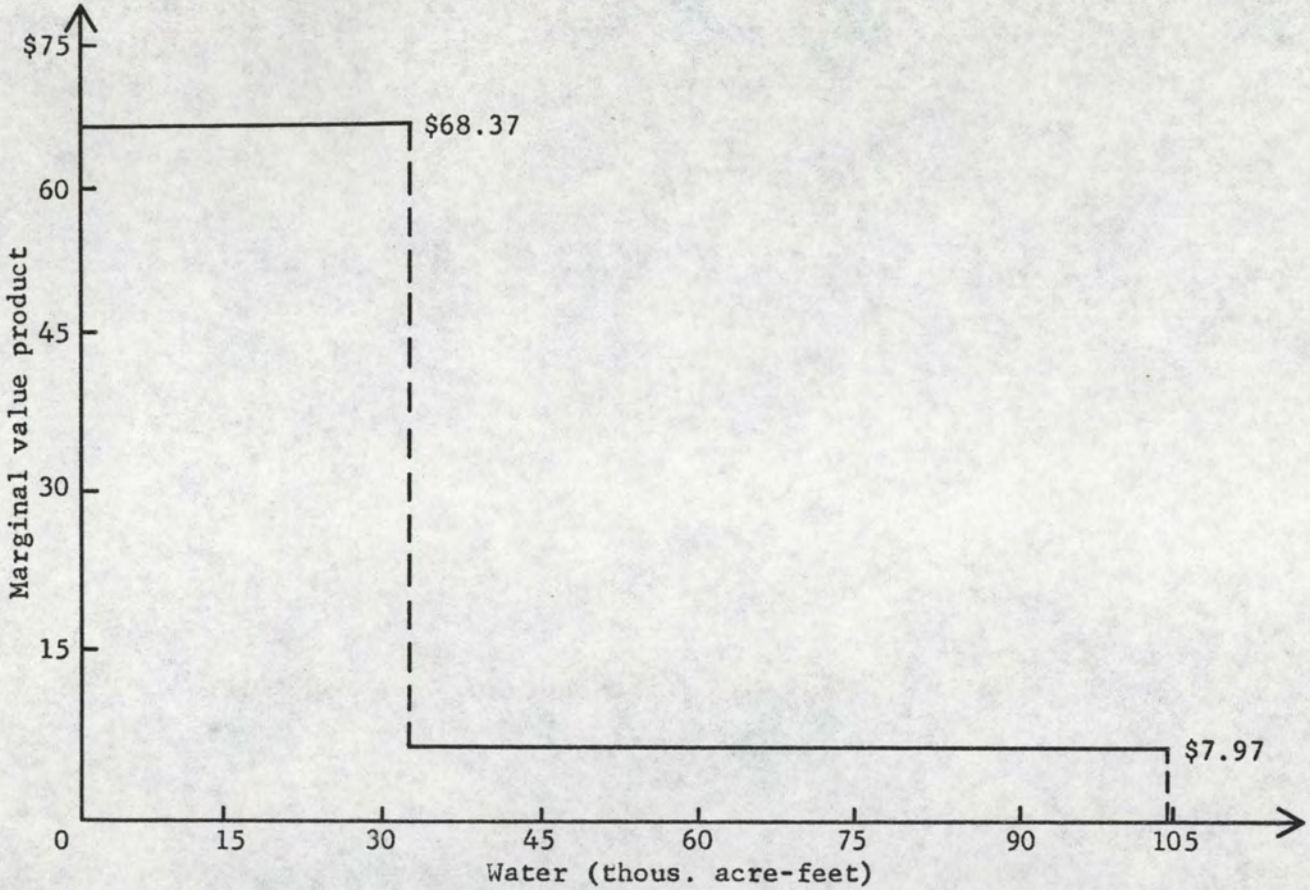

Figure 2. Marginal Value Product Curve of Water

applications within the institutional framework for water allocation. A careful reading of ground-water law indicates that economic considerations are intended to be given weight. Beneficial use is the important concept under the doctrine of prior appropriation. Presumably, in the event of conflict among uses and users, this concept would be crucial in decision making. A clear understanding of this concept as interpreted in the law should provide a basis for determining the extent to which economic criteria are or can be used in defining beneficial use in specific cases. Two articles by attorneys will be relied upon to indicate the legal meaning of the term. 2/

It may appear to one making a review of court cases in which the concept was used that the legal definition is largely devoid of economics. A use is often defined independent of another use. Such singular consideration of uses does not appear to provide expression of the principle of opportunity cost which appears to be the relevant economic concept. Yet court cases involve conflicts between uses. In effect, the arguments pertain to which use was the more beneficial though this is often not the explicit form of the argument.

In one case the judge reasoned precisely according to the principle of opportunity cost. The case involved the use of water on the Deschutes

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2/ These articles were contributed specifically to meet this need for understanding on the part of economists. The articles are:
"The Concept of Reasonable Beneficial Use in the Law on Surface Streams," by Frank J. Trelease.
"The Concept of Reasonable Beneficial Use in the Development of Ground Water Law in the West," by Wells A. Hutchins.
These articles appear in "Ground Water Economics and the Law," Report 5, Conf. Proc. of the Comm. on the Economics of Water Resources Development and Western Regional Research Comm. W-42, at Berkeley, California, December 20 and 21, 1956.

River in Oregon where the use of water to clean debris from a reservoir to prevent the fouling of electric turbines was denied. The court recognized that the use of water for this purpose would prevent the irrigation of 1,600 acres of land, and held that the use of water for cleaning the reservoir was wasteful, stating that the difference between absolute and economic waste was one of degree only. 1/ On the other hand courts have been somewhat slow to exercise leadership in this respect. They have relied upon the legislature to state preference classes. They have also held close to the constitutional policy of protecting property rights. Hutchins makes the following statement:

> Once an appropriative right has been vested, its superior position with respect to later rights is impregnable so long as the right is kept in good standing. That is to say, despite constitutional and legislative declarations that in times of scarcity one use shall be preferred over others, no court decision that has come to the speaker's attention has sanctioned the imposition of such a preference, in disregard of priority of appropriation, without making compensation to the senior appropriator whose water is taken from the preferred use. 2/

Yet the payment of compensation does not violate the principles of efficiency of resource use, unless the gain from diverting to the second use is insufficient for the payment of compensation.

It should be clear from this review of the legal setting that there is sufficient flexibility within the law for economic considerations to be given a place. The law also provides for property rights to be protected by various means. Given this interpretation of the law are studies of the nature reported on here of any value to those in the administrative and judicial branch of Oregon's state government who must interpret and administer the law?

In Oregon the State Water Resources Board has responsibility for un-

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1/ Trelease, Frank J., ibid., pp. 16

2/ Hutchins, Wells A., ibid., pp. 32.

appropriated waters and the board is conducting a basin by basin study of the state. Upon completion of a basin study, the Board specifies what it considers to be the beneficial uses of the basin and formulates broad guides for the development of water. These determinations carry the force of law and guide the State Engineer as he considers applications for water rights. To date the State Water Resources Board has made no reference to ground water in their studies. In view of the authority given the State Engineer, they probably will not concern themselves with ground water unless ground water has a direct measurable effect on surfact water supplies. In those basins where the Board has completed a study and has arrived at its determinations, conflicts are less likely to develop because guidelines have been established. However, it takes a considerable amount of time to complete basin studies for the entire state and conflicts may arise before a basin study is completed. Any citizen has recourse to the courts if he believes the rulings of the State Engineer are unlawful.

In case of the basin studies it does not appear that an investigation such as the one reported on here would have great application. These basin studies are for the purpose of studying the probable economic development of an area and then attempting to establish water use in such a manner as to enhance that development. It is proper that these determinations be broad in nature. By establishing limits within which development can take place, the actual development will be made by individuals working with other agencies of the state and federal government. Unfortunate or undesirable developments may be prevented but the dictation of the precise kind of development is avoided. In the event two or more possible future uses appear to be in conflict precise studies might be desirable.

In case of application for unappropriated waters, a more specific question is raised. A permit may be refused if it has been precluded by a Board order withdrawing the particular source from the proposed beneficial use. In terms of the study situation, possible alternative uses might be compared. Suppose an application for use of water in Area II was received. The following problem would arise: Should the use of water in Area II be denied it might be some time before an applicant from Area I would wish to use the water. An opportunity cost would be suffered by society involving the nonuse of water during the intervening period, but the potential user in Area II will be unwilling to develop the water unless he has security in his water right. If a water right is granted in Area II and this precludes development in Area I, water obviously is not being put to its most economic use. The results of the analysis help to clarify this problem somewhat. The annual economic return to one acre-foot of water in Area II is $7.97. In Area I it is $68.37. If the economic return in Area II is treated as an annuity and accumulated at five percent, and the annual return in Area I is discounted at the same rate of interest, the two become equal during the seventh year. If it is believed an application would be forthcoming within seven years in Area I the water right in Area II should not be granted. With this much differential, the application probably would be forthcoming before seven years had elapsed. There may be instances, however, when future developments can be foreseen and reservation of water would be good policy.

It might also be possible to grant a water right with the reservation that it could be withdrawn after a certain number of years had elapsed. However, this brings up involved legal and welfare problems. If a water right is to be transferred, wealth is obviously being redistributed. It would be more consistent with ground water doctrine and our ideas of equity to bring about transfer by the payment of compensation. A transfer of income would result if a water right were discontinued in Area II and the water was used in Area I unless compensation was paid. The value of an acre-foot of water in Area II capitalized at five percent would amount to $159.40. The money needed to pay the compensation might be raised by selling water rights to appropriators in Area I. If the figures developed are accurate, an appropriator in Area I would be willing to pay $68.37 annually for an acre-foot of water. At this rate it would take the Area I appropriator 2 1/3 years to recover his original investment. If national riches are to be increased, sufficient gain should result from the transfer to permit compensation to be paid. If the criterion is adopted of making no one "worse off" compensation should, of course, actually be paid. Property rights are usually protected in the law by the compensation provision.

If a market for water rights existed it would be possible for a developer in Area I to buy rights directly from irrigators in Area II. However, in a ground water basin, water is not sufficiently well identified to permit this. In most cases it would be necessary to have an administrative agency regulate the location of wells as well as to select the rights to be withdrawn. There have been arguments that a private, essentially unregulated, market for water rights would lead to a "better" use of water than would excessive administrative regulations. It probably is not necessary to choose between such extremes. It may be possible for an administrative agency to rule with rather loose reins and serve as a broker in water rights. For example, water rights may be granted when and if applications are made so long as the water is to be used without waste for beneficial purposes. In some instances water rights might be reserved in the event administrators were convinced application would soon be made which would lead to a higher and better use. If all water were appropriated and a prospective user proposes to put water to a higher and better use, he might go to the administrative agency with his proposal. If it is truly a higher and better use he should be able to compensate an existing user for his loss of water. Under such a system, water rights could be granted and not be revoked without compensation. In this way the administrative agency could control water use by approving sales. Yet the main burden for water development and the determination of economic feasibility would be placed on the individual. It would appear such a plan would be more consistent with the values of a market economy.

A plan such as the one outlined above would apply well to most private uses. It would encounter difficulties with respect to such public uses as recreation or maintenance of fish and wildlife. Although these uses are not important in ground water management, ground and surface water management must be consistent and integrated. At the present time there appears no substitute for subjective administrative judgment on this point. The sacrifice or the opportunity cost in terms of other uses foregone can be specified for such public uses. A state agency can then decide if the public use represents a higher and better use. It may, however, be possible at some time in the future to make economic evaluations of recreational uses as well as to place economic values on fish and wildlife maintenance. It is doubtful that the decision should ever be based entirely on economic criteria. Yet economics probably should not be ignored to the extent that it is currently with such uses. Such considerations, however, takes us outside the scope of this particular study.

In the event of water shortage or a falling ground water table, stress is placed on a system of ground water rights. Under such circumstances the results of a study, such as the one reported on here, could be of value.

The application of these results would be under that portion of the law that reads as follows:

> A provision according preference without reference to relative priorities to withdrawals of ground water in the critical area for domestic and livestock purposes first, and thereafter, other beneficial purposes, including agricultural, industrial, municipal other than domestic, and recreational purposes in such order as the State Engineer deems advisable under the circumstances. 1/

Although this does not specify that users within a use class might be treated differently, it is believed that provision is sufficiently broad to cover such a contingency. In any case this "within use" study, is illustrative of the possible usefulness of a between use study along the lines outlined here.

If the results of such an analysis were to be used to ration a diminishing stock of ground water among competing uses, great emphasis would be placed on economic efficiency relative to protection of existing rights. The law, as it now stands, permits such an interpretation. 2/ Yet, this would be a substantial departure from practice in other states. If the amount of water to be allocated is fixed or expanding the law has sufficient flexibility to permit water to be put to its most economic use with protection of existing rights. If the amount of water is declining the problem is much more difficult. Under these circumstances it would appear that water probably would be allocated either on a proportionate basis or on the basis of priority in time of the rights, assuming the water is being put to beneficial use. Interpreted in this way, beneficial use would refer to the broad usage rather than in the context of opportunity cost as described earlier.

1/ Oregon Laws, Chapter 700, pp. 12. A competent legal scholar has indicated this provision may be unconstitutional. He also doubts the wisdom of this passage. This is a legal problem and the analysis obviously would not apply if the provision is modified in any way.

2/ The State Engineer would protect domestic and livestock uses regardless of priority.

This may not be a bad state of affairs in most cases. If the ground water level in a basin is declining, eventually there will be some reduction in rate of withdrawal. This will occur as a result of an order by an administrative authority or because the stock is exhausted from an economic point of view. It is perhaps appropriate that economic efficiency not be given undue emphasis under such circumstances. It is important that a method be used that would be accepted as equitable. Within this context economic efficiency can be given emphasis in view of the entire economy of the area.

This type of problem can be illustrated with reference to the basin studied. Suppose, for example, that prior rights were held in Area II but that Area I shows the greatest return to water. Or, conversely, that the study had shown Area II had the greatest return to water while Area I enjoyed prior rights. In the event of a declining ground water table should the prior rights be condemned even though they returned less to the economy than subsequent rights? Or should every right be reduced proportionately either by restricting pumping or defining beneficial use in terms of some quantity?

It might be possible to transfer the rights through the payment of compensation. That is, the prior right holders could perhaps be compensated by the holders of subsequent rights. Yet the holders of subsequent rights would probably object on the basis that this was a violation of their property rights in that it reduced the value of their assets. However, the compensation provisions could be placed on a voluntary basis. The holder of subsequent rights could have the option of paying to hold his rights or to release them to the holders of prior rights. Again, it would appear that efficiency and equity considerations would not necessarily be in conflict.

Administrative Feasibility

We turn now to the practicality of an administrative body making such studies in order to interpret the law in accordance with economic criteria. The problem would be one of rather substantial dimensions in most situations. There would be interrelationships among uses that would need to be taken into account. Detail on every use would need to be obtained comparable to that collected for the "within" use study reported on here. This would necessarily require personnel trained in economic analysis, computational techniques and who would have a rather intimate knowledge of various facets of the economy of an area. Given these resources there appears to be no reason why estimates could not be made of the economy gains and losses of different allocations of water.

It is not anticipated that will happen in the near future. This would require a considerable break with tradition and it would also be expensive. Whether the gains from this would justify the expenditure is not known and perhaps will never be known. It is anticipated, however, that the trend will be in this direction. Water will undoubtedly become more expensive and major decisions regarding its use are not likely to be placed exclusively in private hands. It appears inevitable, therefore, that administrators will turn increasingly to specialists to provide guidance in the making of decisions. Studies of this type may make some decisions appear less arbitrary.