An Analysis of Water Resource Productivity and Efficiency of Use in Pacific Northwest Agriculture

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AN ANALYSIS OF WATER RESOURCE PRODUCTIVITY AND EFFICIENCY OF USE IN PACIFIC NORTHWEST AGRICULTURE

by

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SUMMARY AND CONCLUSIONS

An aggregate production function analysis of water resource productivity in Pacific Northwest agriculture was conducted to: (1) evaluate the economic efficiency of the water allocation that existed in 1964, and (2) make inferences about the social desirability of future development of agricultural water resources. An attempt was made to isolate the productivity of different forms of water resource investment, including irrigation, drainage, and water conservation practices. Estimates of irrigation productivity on a per acre-foot basis were obtained for five subareas within the region; independent estimates of the productivity of drainage and water conservation practices were not possible.

Production functions were estimated for five areas within the Pacific Northwest (Idaho, Washington, and Oregon); each area consisted of counties with similar patterns of production. The Census of Agriculture was the primary data source, supplemented by related U.S. Department of Agriculture publications and various state publications.

Ordinary least-squares regression techniques were employed to derive estimates of the parameters of the production function models. The parameter for the irrigation variable in each area provided an estimate of the marginal value product (MVP) of irrigation water in agricultural production. Statistical tests provided estimates of the reliability of the parameter estimates; they also provided a basis for (1) comparing MVP values with private and social marginal costs of supplying the water, and (2) comparing MVP values between areas.

The analysis indicated that significant differences existed in 1964 between some types of farming areas with respect to the MVP per acre-foot of irrigation water. Returns were significantly higher in a field crop area ($10.59) than in a livestock and livestock products area ($4.93) or a livestock and dairy products area ($3.40). The areas in which water had the highest MVP were also the areas which had the greatest physical potential for future irrigation development. These areas included Southwest Washington, Southern Idaho, Central and Northeast Oregon, and the Willamette-Puget Trough.

Estimates of the MVP of irrigation water were compared with limited data on private marginal costs (water prices to farmers) and social marginal costs (public investments in water projects). These comparisons indicated that farmers (in the aggregate) were receiving returns sufficient to cover private marginal costs. The excess of social marginal costs over the MVP of water, however, was at least $5 to $10 per acre-foot and can be expected to increase for future public development projects.

The need for revision of public policy with respect to the pricing of irrigation water is identified as a value judgment which has to be resolved through the political process. Continuance of current policies implies a continued sacrifice of other goods and services to attain regional development objectives. The present value of this opportunity cost is estimated to be at least $66 million for a hypothetical 100,000-acre project in one of the areas with highest irrigation potential.

INTRODUCTION

A significant portion of the water resource investments in the Pacific Northwest has been allocated to water resource use and development in agriculture. These investments have occurred in a variety of forms, including the building of dams and the promotion of various cost-sharing arrangements with individual farmers, and have been administered by a variety of governmental agencies. Decisions to invest have historically been based on a project-by-project or program-by-program evaluation. Various decision-making units have been involved in these decisions and include individual farmers, farm groups (irrigation and drainage districts), municipalities, and state and federal agencies. Recent planning efforts in the Pacific Northwest have been designed to coordinate many of these activities. An example is comprehensive river basin planning in which federal, state, and local groups have the opportunity to participate in the planning process. A purpose of this effort is to remove some of the piece-meal, sometimes contradictory, decisions.

The piece-meal public decision process and its related impact on private decision-making point out the need for coordinated public water management policy. Growing demands (relative to supply) for water and water-related capital increase both the competition for water and the importance of making informed decisions regarding development. The recent awareness of ecological problems associated with misuse of water adds a special note of urgency to the implementation of informed decisions.

Comprehensive planning and the coordination of public and private water development decision-making thus seem imperative in the determination of the best use of our water resources. The success of such an approach depends on a great many factors -- not the least of which is reliable information concerning the productivity and efficiency of water use in the agricultural sector. Information is needed on the productivity of various types of water-related investments and on the returns from both public and private investments in agricultural water resources. That this kind of information is considered important by the United States Water Resources Council is evidenced by the following statement:

> "Federal agricultural water management policy should include consideration of both the policy's overall effect on agricultural production, and the productivity of investment in irrigation relative to alternative investments such as drainage, clearing of land, and other technological developments" [31, p. 4-4-6].

This study was directed toward providing such information for Pacific Northwest agriculture. More specifically, the study was designed to provide information about the productivity and efficiency of water use under 1964 conditions, and thus to provide a basis for making inferences about the efficiency of future development.[1/] It is intended that the information contained here will provide information for federal, regional, and state decision-making with respect to important water resource allocation problems.

Water Resource Development in the Pacific Northwest

Water resource development typically refers to changing the location and/or flow and storage conditions of water, thus making it usable, or more usable, by people. This may, in some cases, require building dams and canal structures, digging irrigation and drainage canals, or dredging harbors. In the opposite vein, it may require building access roads to high mountain lakes, planting trees to protect the soil from rapid runoff and thus protect the quality of downstream water, or simply diverting flash flood runoff in the desert to form livestock watering ponds. A typical classification of water uses includes domestic and municipal, industrial, electrical power, agricultural, navigational, recreational, and fish and wildlife.

[1/] Data from the 1969 Census of Agriculture were not yet available at the time this study was initiated.

The Pacific Northwest has perhaps the broadest range of water resource uses and the most diverse system of development of any other region in the United States. Rivers, streams, and lakes are numerous in western Oregon and Washington where too much water (flooding and slow drainage) is often a problem in winter and where drought consistently occurs in the summer when streamflows are also low. Eastern Oregon and Washington and southern Idaho are semi-arid regions where water shortage is almost always a problem. Major rivers, including the Snake and the Columbia, flow through the area and considerable water diversion is practiced to supplement other sources. Most of the region's electrical power is generated by hydro-electric power units on these two rivers.

Perhaps the most apparent example of development of the water resource in the Pacific Northwest involves streams and rivers. This development began about the turn of the century; the Corps of Engineers completed a navigation project on the Alsea River in western Oregon as early as 1898 [4, p. 3]. Other projects completed by the Corps which are most apparent to the casual observer include The Dalles, McNary, and John Day dams on the Columbia River between Washington and Oregon, and the Chief Joseph Dam on the Columbia near Bridgeport, Washington. Total federal costs of projects completed in the Columbia North Pacific District by the Corps of Engineers up to 1967 were approximately $1.5 billion [4, p. 3]. Non-federal costs of these projects designed for navigation, flood control, power, and recreation, total $10.8 million [4, p. 3]. The Bureau of Reclamation, whose primary function is irrigation development, also has a long record of project construction in the region. Among the first projects completed were the Sunnyside portion of the Yakima project in north central Washington in 1907 and the Umatilla project in north central Oregon in 1908 [29, p. 754]. Net Federal investment in Bureau of Reclamation projects (initial investment minus repayments) in the region up to 1965 totaled $715 million [30, p. 51].

Total private investment in the area is extremely difficult to quantify, but it is also a major source of water resource development. The Census of

Irrigation [28, State Table 1 and 2 for Oregon, Washington, and Idaho] and the U.S. Water Resources Council [31, p. 6-16-5] indicate that at least 54 percent of water use in the period 1959-1965 was from private development sources. These sources include rural, domestic, municipal, and self-supplied industrial systems, individual farmers, and farm organizations in agriculture. Approximately 14.5 percent of the total water used in 1965 was from groundwater sources, less than 1.0 percent was from saline sources, and the remaining 85.5 percent was from surface sources [31, p. 6-16-5].

In general, the water supply of the region is abundant, although the distribution varies widely and seasonal flows are low in many of the smaller streams. The available average annual natural runoff is approximately 289 million acre-feet (maf/yr). Almost 19 percent of this runoff originates in Canada. Total annual withdrawals average 33.3 maf/yr; only 10.5 maf/yr are consumed.

Water Resources for Agriculture in the Pacific Northwest

Irrigation is no doubt the most recognized aspect of water resource development in agriculture and usually the most important. Other aspects usually are present, however, and at times are more important. These other aspects are classified in this study as drainage and water conservation practices. In many areas of western Oregon and Washington, irrigation cannot be developed without also developing a drainage system. Sometimes the soils are such that natural water percolation downward is almost nonexistent and excess water must be removed from the land by surface drainage systems. In other cases, natural water supplies are sufficient and only drainage is necessary. In the semi-arid regions of eastern Oregon and Washington, conservation practices increase the effective water supply by conserving natural precipitation.

Total investment in agricultural water resource development is difficult to assess since a substantial portion comes from private sources. In addition, public investments are often in the form of multiple-purpose projects which serve both agricultural and non-agricultural sectors. Special reports from The Census of Agriculture indicate an average capital investment of $137 per irrigated acre by irrigation organizations in 17 Western states in 1959 [31, p. 4-4-6].

The Agricultural Stabilization and Conservation Service (ASCS) has been instrumental in promoting investment in water resources through the Agricultural Conservation Program. This program is administered with the cooperation of the Soil Conservation Service, Forest Service, Extension Service, Soil and Water Conservation Districts, and other agricultural agencies. Approximately 35 water-related practices are involved, including the establishment and management of drainage systems, irrigation systems, water-conserving agricultural practices, and livestock water facilities. ASCS invested $76.7 million in land and water cost-sharing agreements in Oregon alone between 1936 and 1964 [18, p. 2]. The Soil Conservation Service also conducts the Small Watershed Program for assistance in the construction of small dam projects. This program was authorized under Public Law 83-566 and amended in 1966. Investments in this program to date have been relatively small but the program provides a significant potential source of future investment.

Private farm investments in water resource development and use are partly evidenced by the growth in acres irrigated and drained. The farmers' share of the cost-sharing program of ACP suggests that about $76.7 million was invested by Oregon farmers in land and water conservation programs between 1936 and 1964.2/ Additional investments by farmers have also been made independently of these Federal programs.

Irrigation of agricultural lands accounted for approximately 89 percent of the total regional use of water in 1965 [31, p. 6-16-5]. About 95 percent of the annual consumption from runoff diversions was due to irrigation

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2/ Cost-sharing agreements under ACP are usually one-half the per unit cost.

[31, p. 6-16-1]. An estimated 51 percent of the total agricultural water use for irrigation in 1959 came from private sources, primarily individual systems and farmers' mutuals [28, State Tables 1 and 2 for Oregon, Washington, and Idaho]. Of the total agricultural water use in 1965, about 13 percent came from underground sources. Almost all this development was from private investment [31, p. 6-16-5].

Present Status and Future Development Potential

Decisions regarding future development of water resources should begin by recognizing the location and the extent of present development, as well as any physical limitations to development. Figure 1 shows the location of cropland[3/] in the region, including that portion which is irrigated. Only 11 percent of the total land area in the Pacific Northwest was classified as cropland in the 1964 Census of Agriculture. It has been estimated that the acreage of cropland could potentially be expanded from the present level of 20 million acres to about 50 million acres [12, App. VI, p. 72]. These additional acres which are potentially suitable for cropping consist mostly of land in capability classes III, IV, and VI[4/]; the latter class contains about 15 million acres of desert lands which would be suitable for cropland if irrigated. These lands are distributed throughout the region with major concentrations in eastern Oregon and Washington and east-central Idaho.

Figure 1 also shows the 5.5 million acres of croplands which were irrigated in 1964. The major concentration of these lands occurs east of the

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[3/] Cropland is defined as cropland harvested, cropland used only for pasture, and cropland not harvested and not pastured.

[4/] Capability classes III, IV, and VI are defined generally as follows:
Class III: soils in class III have severe limitations that reduce the choice of plants or require special conservation practices, or both.
Class IV: soils in class IV have very severe limitations that restrict the choice of plants, require very careful management, or both.
Class VI: soils in class VI have severe limitations that make them generally unsuitable for cultivation and limit their use largely to pasture or range, woodland, or wildlife food and cover [15, p. 75-77].

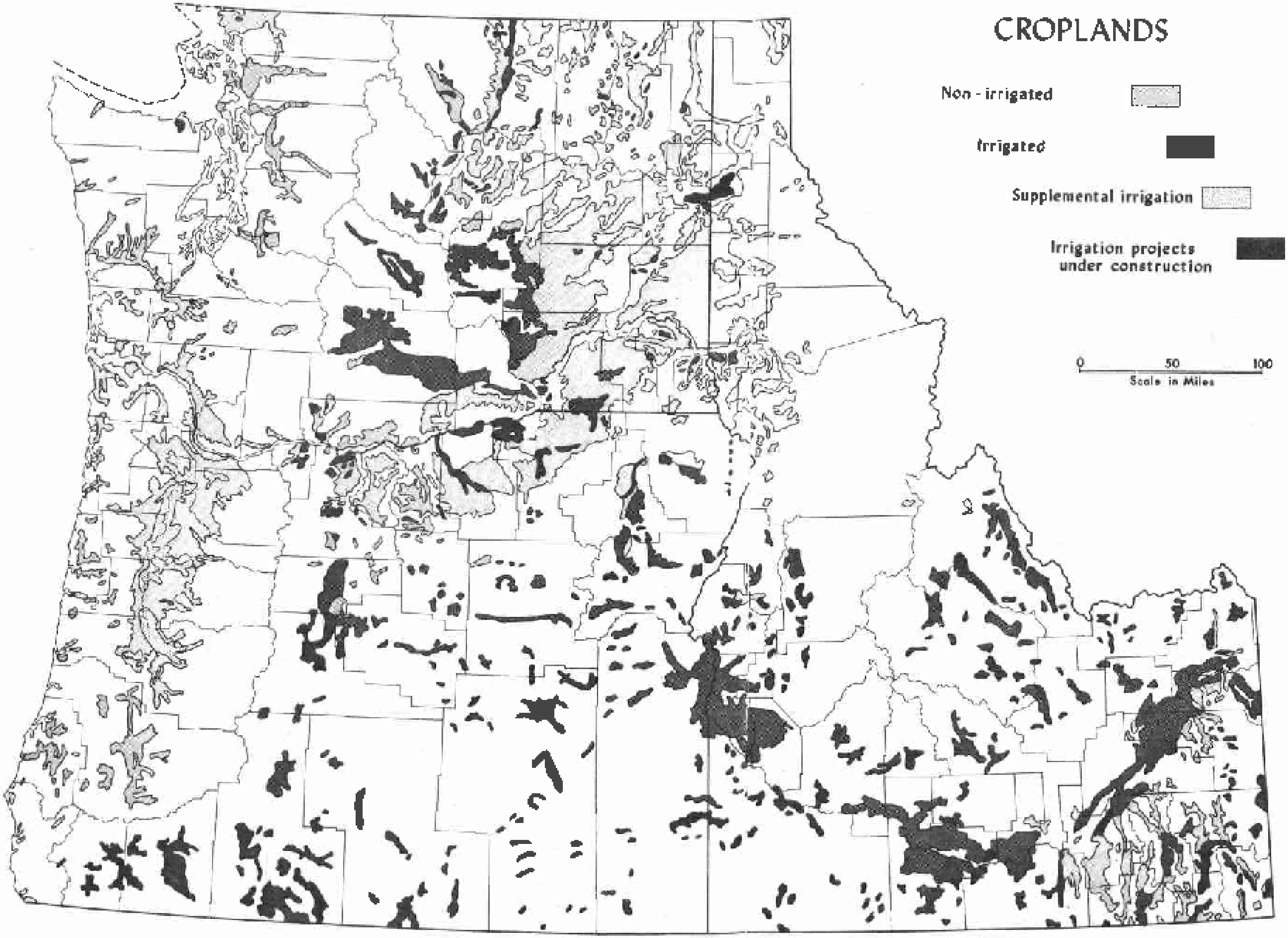

Figure 1. Distribution of Irrigated and Non-Irrigated Croplands (map compiled by R. M. Highsmith, Jr. and R. C. Brown, <u>Atlas of the Pacific Northwest</u>, fourth edition)

Cascade Mountain Range. According to the 1964 Census of Agriculture, only 28.9 percent of the total cropland in the Pacific Northwest was irrigated (Table 1). Approximately 51 percent of the region's irrigated acreage in 1964 was from projects developed by the Bureau of Reclamation. By state, this percentage was estimated as 55, 29, and 68 percent for Idaho, Oregon, and Washington, respectively [25, 26, 27, and 30].

Figure 2 shows the distribution of 30.8 million additional acres which have been classified by the Pacific Northwest River Basins Commission as "potentially irrigable" [12, 72, App. IX]. As defined by the Commission [12, App IX, p. 37]:

> "Potentially irrigable lands have favorable soil, topography, and drainage characteristics which make them suitable for irrigation. Lands have not been excluded because of climatic limitations except in high, mountainous areas. Potentially irrigable lands are neither presently irrigated nor has it been determined that they can be provided with a water supply economically. Included as potentially irrigable are lands now dry farmed as well as forest and rangelands that could, with irrigation, produce higher yields or provide a wider range of crop use. Although these lands were evaluated on the basis of their suitability for irrigated cropland, some may be better adapted for wildlife habitats, range forage production, and recreation or scenic areas."

These potentially irrigable lands are shown by land classes in Table 2.

According to 1966 estimates by the Soil Conservation Service, about 2.8 million acres[5/] (14 percent) of the cropland in the Pacific Northwest have a wetness or drainage problem [12, App. VIII, p. 81]. About 845,000 of these acres have been drained sufficiently for cropping. Slightly more than 1.5 million acres west of the Cascades have wetness or drainage problems; less than half these acres are drained. The wetness problems on these soils are typically caused from high water tables, ponding of runoff, overflow from streams, tidal waters, seepage from high lands, and irrigation of hardpan soils. The region east of the Cascades contains about 1.2 million acres with wetness or drainage problems, of which less

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[5/] Calculated from tables on "Cropland Acres with a Wetness Problem" from each Subregion Section [12, App. VIII].

Table 1. Farm Land by States in the Pacific Northwest, 1964

Item	Idaho	Oregon	Washington	Total	Percent of Land in Farms
	- - - - - 1,000 acres - - - - -				
Cropland harvested	3,935	3,050	4,423	11,408	20.8
Cropland only pastured	696	926	784	2,406	4.4
Cultivated summer-fallow	895	953	2,351	4,199	7.7
Other cropland	352	352	503	1,207	2.2
Total cropland	5,878	5,281	8,061	19,220	35.0
Woodland in farms	1,393	3,194	3,750	8,337	15.2
Other pasture	7,434	11,577	6,741	25,752	46.9
Other land in farms	596	456	500	1,552	2.8
Total land in farms	15,301	20,508	19,052	54,861	100.0
Percentage of farmland in cropland	38.4%	25.8%	42.3%	35.0%	
Irrigated land in farms	2,802	1,607	1,150	5,559	10.1
Percentage of cropland irrigated	47.7%	30.4%	14.3%	28.9%	

Source of data: 1964 Census of Agriculture

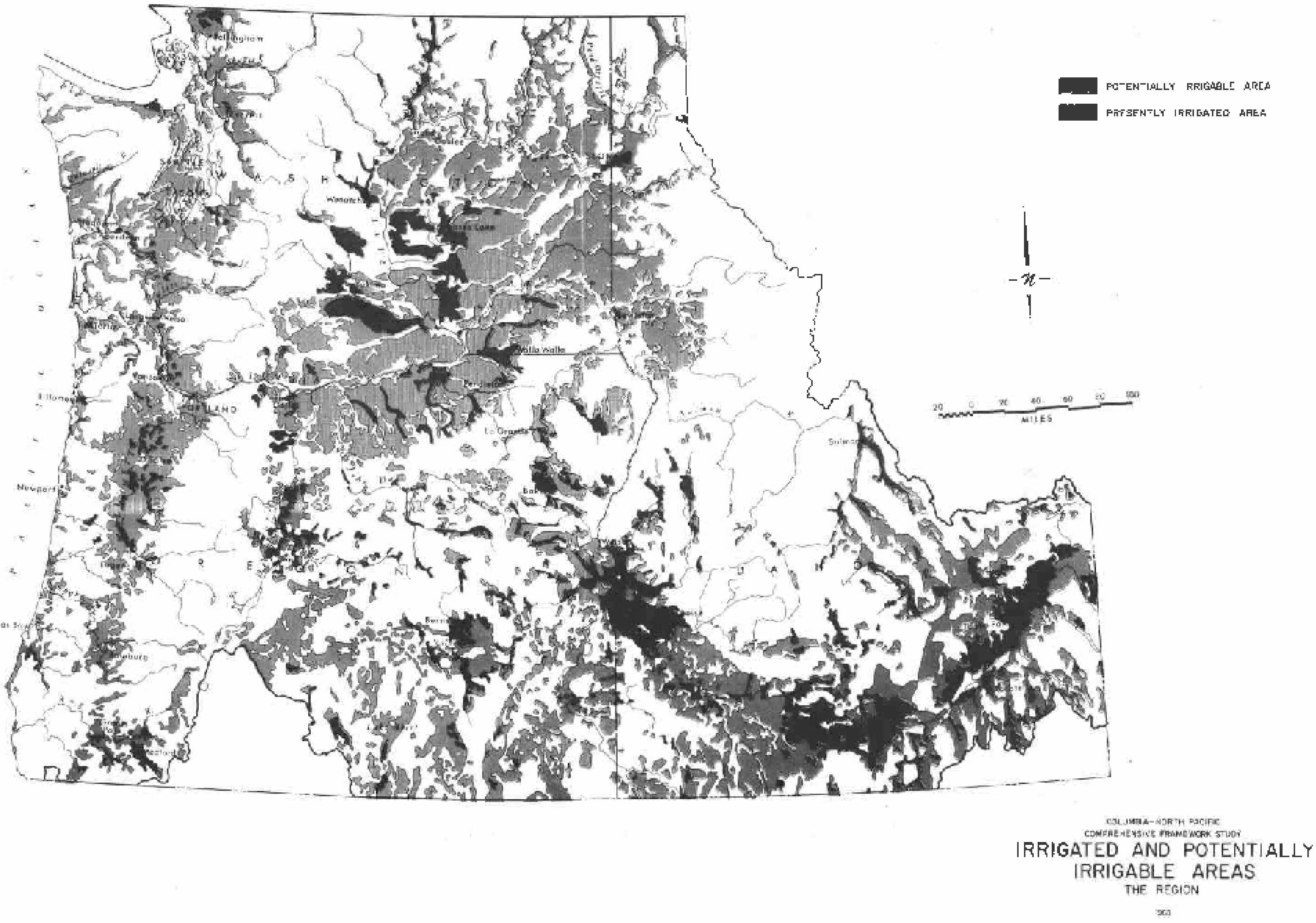

Figure 2. Irrigated and Potentially Irrigable Areas

Table 2. Potentially Irrigable Land by States, Pacific Northwest, 1966

State	Class 1[a]	Class 2[a]	Class 3[b]	Subtotal	Other[b]	Potentially Irrigable
	- - - - - - - - - - -	- - - - - - - - - - -	- - - - - - Acres	- - - - - - - - - - -	- - - - - - - - - - -	- - - - - - - - - - -
Idaho	1,152,900	3,306,300	3,454,700	7,913,900	683,800	8,597,700
Oregon	1,014,200	3,979,600	6,362,700	11,356,500	448,000	11,804,500
Washington	1,145,300	3,126,700	6,160,300	10,432,300	---	10,432,300

Source: Columbia-North Pacific Region Comprehensive Framework Study, App. IX, Table 11.

[a] These lands would be suited for a wide variety of crops under irrigation and modern methods. Irrigation may be by gravity methods.

[b] These lands are limited as to crop productivity and must be irrigated by sprinkler systems in many cases.

than half are now drained. The drainage problems in the region result almost entirely from irrigation management practices.

The physical potential for increased drainage of agricultural lands is quite large in both regions. The extent of drainage practices may be expected to increase proportionately to increases in irrigated acres west of the Cascades; however, the same may not be true east of the Cascades.

Water-related conservation practices (including flood control measures, but excluding drainage and irrigation practices) vary considerably across the region, both in terms of present levels of development and potential future development. The major practices include subsoiling, deep plowing, contour farming, and stripcropping. The primary practices include ponds and reservoirs for livestock water in areas where livestock are important. The practices which are most important west of the Cascades include permanent and temporary cover for erosion control, tree planting, stream or shore protection, sod waterways to dispose of excess water, and diversion terraces.

ECONOMIC ANALYSIS OF PRESENT LEVELS OF WATER RESOURCE USE

The estimation of agricultural production functions was selected as the basic technique for analysis of water resource productivity and returns to public and private water resource investment in Pacific Northwest agriculture. The analysis was accomplished by explicitly specifying important types of water resource investment as variables in the production functions. Information regarding the contribution of water resource investment to the value of farm production and the relationship to the other production inputs was obtained through statistical estimates of the parameters of these functions.

The Production Function Concept

The concept of a production function is essentially a physical or biological science concept of the relationships between inputs and outputs in a production process. The production function concept has also been extended to include the production responses of an aggregate of firms, of industries, and of regions. Many empirical studies have estimated production responses at this level of aggregation rather than at the disaggregated level of individual firms.

Extension of the production function concept beyond the firm level of aggregation emanates from the need for answers to a class of questions which transcend those of farm firms. Questions of inter-regional allocation of resources in agriculture, for example, are concerned with aggregate effects. Policy issues of farm organizations, counties, states, regions, and nations are necessarily concerned with the performance of groups of people, groups of firms, and even groups of industries. Policy implementation usually requires control or influence on a system at the aggregate level. This is not to say that individuals within the group are unimportant, only that it is usually an unworkable proposition to direct policies toward each individual in isolation from others in the target population.

The aggregate approach is an obvious alternative to the analysis of individual firm relationships, provided it can be accomplished without ambiguity. To insure the absence of ambiguous answers from the aggregates, the relationship between the individuals and the aggregate must be unique and identifiable. If this condition is met, and if complete and accurate data on input and output prices and quantities are available, one can determine, ex post, whether firms (in the aggregate) used an efficient level and combination of inputs.

The most appropriate level of aggregation for any particular case depends on the kind of research question being asked. If one is interested in results at a high level of aggregation, there is perhaps a tradeoff between probable inaccuracy due to aggregation bias and the cost of doing the analysis at a lower level of aggregation. Limited research time and funds often prevent the latter type of analysis.[6/]

From an empirical point of view, it is noteworthy that there is no guarantee of greater accuracy in obtaining aggregate results if firm functions were estimated and then aggregated. Firm level estimation is subject to the same kind (if not the same potential magnitude) of error as the industry function. These errors are from estimation, equation formulation, and inappropriate aggregation (errors associated with the use of inappropriate weighting procedures for the data). The firm approach is, of course, much more costly in time and research expenditures when the study involves large numbers of firms.

A number of agricultural production functions have been estimated in recent years from county data as opposed to firm data. The essential difference between the two formulations is simply that the former is based on an aggregate (simple sums) of the firm input-output records, whereas the latter method is based on firm level data. A major data source for the aggregate

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[6/] For a review of the historical development of production function analysis, see Holloway [8, p. 19].

functions has been the Census of Agriculture. Recent studies based on county data include attempts by Griliches [5] to isolate the effects of labor quality differentials (measured by level of education) on agricultural production. Headley [7] attempted to measure the effects of agricultural pesticides and Ruttan [14] estimated regional agricultural production functions and the demand for irrigated acreage. These studies all have used cross-sectional rather than time-series data.

Interpretation of the Agricultural Production Function Estimated from County Data

While many levels of data aggregation exist, the two basic forms of data from which production functions can be estimated are cross-sectional and time-series. It is important that the interpretation of functions estimated from these two types of data be understood. A cross-sectional approach using county data is taken in this study. The underlying assumptions required to make "economic sense" of such aggregate functions are related to the use of replications in experimental design. A simple example will help convey the idea.

Assume that a production function for fertilizer in the production of corn on a particular farm is to be estimated. Two possibilities exist for obtaining observations from which inferences can be made. The first is to generate time-series data. A sequence of corn crops could be produced on the same acreage under controlled greenhouse conditions, varying the levels of fertilizer over time. The second approach would generate cross-sectional data. Several "identical" one-acre tracts of land could be isolated to provide observations by varying the level of fertilizer among tracts. To the extent that all other factors are invariant among tracts, the difference in yields would measure the fertilizer response. The basic assumption required is that everything not explicitly accounted for in the functional relationship is quantitatively fixed or unimportant. Units of fertilizer are also assumed to be homogeneous in quality.

Using the cross-sectional approach, it should be clear that the primary intent is not to estimate an aggregate function for ten acres of corn in the sense of estimating total corn production from ten acres, but rather to estimate total corn production from one acre of corn through the application of various levels of fertilizer to ten tracts of land which are otherwise identical. From this example, it should be clear that the production functions estimated in this study are county production functions. They are aggregate functions in that they represent input-output relationships for an aggregate of firm level input-output records. It is assumed that counties are homogeneous units[7/] and that different levels of aggregate output are associated with correspondingly different levels of aggregate input. It is further assumed that each county has the same production function and is operating at a unique position on it. The "homogeneous" county units thus provide cross-sectional observations from which to estimate a county production function.

Given this level of aggregation, functional results cannot be applied to individual firms, individual development projects, or other combinations of firms at a lower level of aggregation. It is also essential that all important inputs in the production process are included when estimating the production function. For example, the functional relationship between irrigation water and the value of farm production cannot be considered irrespective of the levels of other inputs, since other inputs also have positive contributions.

The Economic Usefulness and Estimation Techniques for Agricultural Production Functions

The primary usefulness of a production function is that one can estimate the output response with respect to a unit change in a particular input when all other inputs are held constant at some fixed level. This

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[7/] Considering counties as homogeneous units simply implies that output would be the same for any two counties having the same quantity of homogeneous inputs (labor, machinery, cropland, etc.).

estimate is the first partial derivative or the slope of the production function, and is termed the "marginal physical product" (MPP) in economics. When multiplied by the market price of the output, the MPP is called the "marginal value product" (MVP).[8] For purposes of this study, the primary interpretation is as follows; if the level of irrigation water could be changed by one unit while all other inputs were held constant at some fixed level (e.g., at the mean values), the MVP estimate would express the resulting change in the value of farm output. By comparing MVP estimates with the cost of irrigation water and by comparing MVP estimates among different regions, statements can be made about economic efficiency of water use in each region.

Multiple regression analysis was selected as the statistical tool for identifying the functions which best describe the data. This technique helps determine which general algebraic function is most appropriate, and determines the particular function which best "fits" the data. The technique also helps identify, according to the data, which variables are important in explaining county farm output in each subregion of the Pacific Northwest.

Units of Observation and Description of the Study Area

The choice of the units of observation depended partially upon geographic, hydrologic, and climatic characteristics of the study area. The following description is given to enhance the reader's understanding of the area characteristics. The Pacific Northwest study area consists of Oregon, Washington, and Idaho. The region includes most of the drainage area of the Columbia River basin within the United States, that portion of the Great Basin which lies within Oregon, and the coastal areas of Oregon and Washington. Western Oregon and Washington are characterized by two parallel mountain ranges which extend from north to

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[8] Factor productivities estimated below are in value terms (i.e., MVP's) since output was defined as the value of farm products sold plus home consumption.

south through the two states. The coastal range parallels the ocean a few miles inland from shore; the Cascade range is 100 miles further inland. The Willamette-Puget Trough lies between the two ranges. East of the Cascades lies the basin and range area, including parts of the Columbia Basin, the Snake River Plains, and numerous intermountain valleys of the Rocky Mountain system.

The mountain ranges greatly influence the region's climate. The winters are wet and mild west of the Cascades and summers are typically very dry. Annual rainfall varies from about 30 inches in the valleys to as high as 100 inches in areas along the coast. East of the Cascades, temperature extremes are greater and rainfall less. Although precipitation varies with elevation, annual averages are as low as eight inches in the central plains.

The average annual water runoff of the region is in excess of 200 million acre-feet [31, p. 6-16-3]. About one-fourth of this total originates in Canada. Major groundwater aquifers capable of providing supplies for irrigation, municipal, and industrial uses underlie about one-fourth of the region. Total irrigated land in farms in the region was estimated to be about 5.5 million acres in 1964. Approximately 1.6 million acres were irrigated in Oregon, with 1.1 million and 2.8 million acres irrigated in Washington and Idaho, respectively. Both groundwater and surface sources are important, but the major supply of irrigation water comes from surface sources. An average annual 5.4 million acre-feet of streamflow depletion is estimated for Washington and Oregon. An additional 0.5 million acre-feet are depleted from groundwater sources in the two states. Approximately 8.5 million acre-feet of stream and groundwater depletion is expected in a typical year in Idaho.

The study area includes 157.2 million acres of land [25, 26, 27, State Table 1] of which 79.2 million acres [6, p. 60] are national forest lands. Approximately 19.2 million acres of land are cultivated in crop production [6, p. 70] and the remaining 58.8 million acres of private lands include range, forest, and waste land which are important in livestock production, wildlife habitat, and in providing various forms of recreation. In general, the region has a very diversified output of agricultural products. Agricultural production west of the Cascade Mountain range is predominantly dairy and livestock products. Production is highly diversified (field crops, vegetables, fruits, and nuts) in the Willamette Valley and northward into Washington. Livestock production and field crops are important in eastern Oregon and Washington as well as in most of Idaho.

Delineation of the Study Area by Homogeneous Subregions

The three-state study area was divided into five subregions or county groups. The delineation was based on the type of farm output which was most prevalent. The five subregions were designated Areas A, B, C, D, and E, and were characterized by the Census classification of the dominant types of farm output, as follows:

1. Area A contained 41 counties which typically produce field crops and livestock products;
2. Area B contained 15 counties which produced primarily livestock and livestock products;
3. Area C contained 20 counties which produced mostly field crops;
4. Area D contained 27 counties which produced mostly livestock and dairy and livestock products; and
5. Area E contained 16 counties which were highly diversified in production (see Figure 3).

The procedure for grouping the counties was based on the percentage of total value of farm products sold (TVFPS) from the various Census classifications of farm output. The Census classification included the following farm output categories:

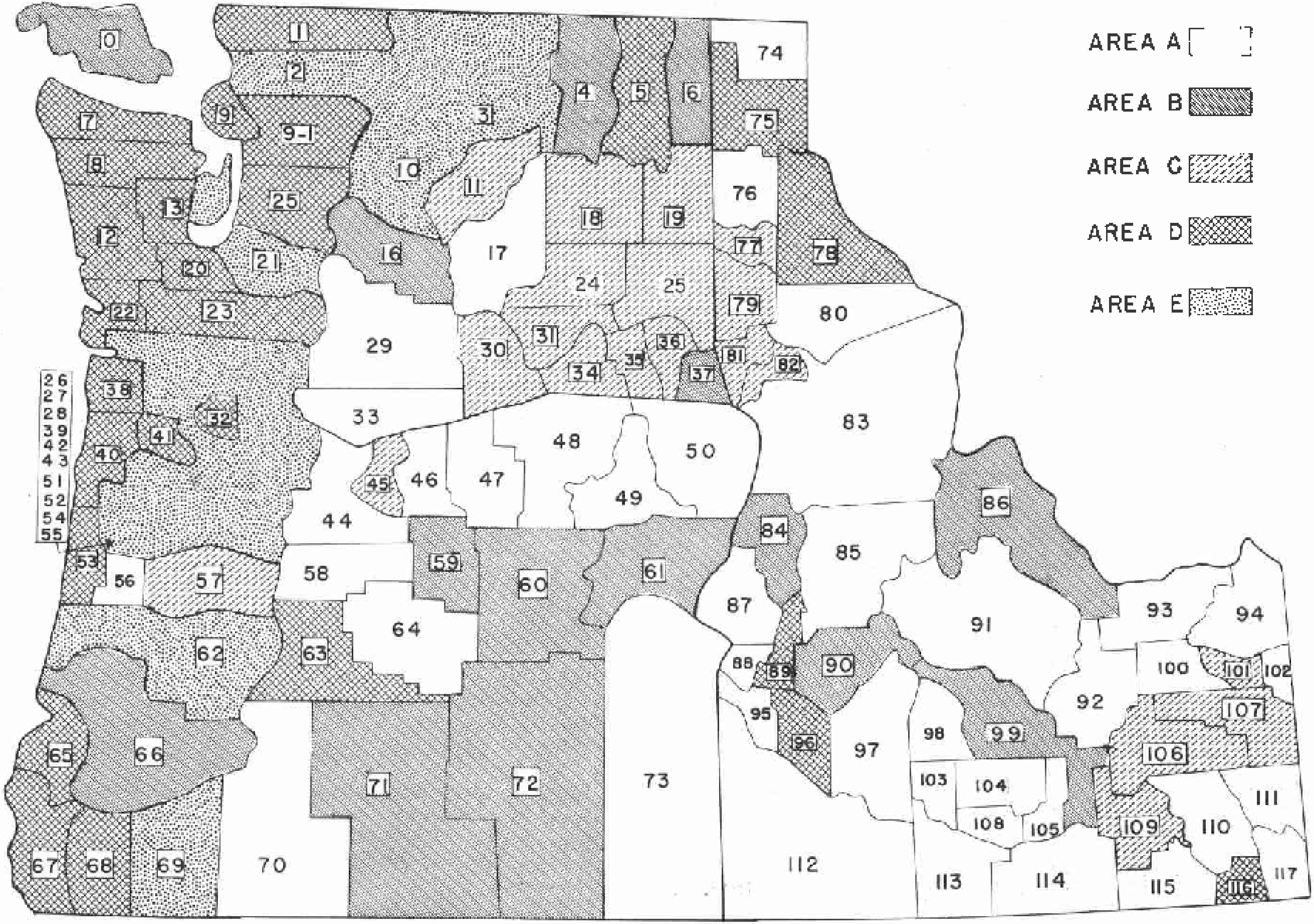


Figure 3. The Pacific Northwest and Five Homogeneous Farming Areas

AREA A

Oregon

Benton	(56)
Crook	(64)
Gilliam	(46)
Jefferson	(58)
Klamath	(70)
Malheur	(73)
Morrow	(47)
Umatilla	(48)
Union	(49)
Wallowa	(50)
Wasco	(44)

Washington

Grant	(17)
Klickitat	(33)
Yakima	(29)

Idaho

Bannock	(110)
Bear Lake	(117)
Boundary	(74)
Butte	(92)
Camas	(98)
Canyon	(95)
Caribou	(111)
Cassia	(114)
Clark	(93)
Clearwater	(80)
Custer	(91)
Elmore	(97)
Fremont	(94)
Gooding	(103)
Idaho	(83)
Jefferson	(100)
Jerome	(108)
Kootenai	(76)
Lincoln	(104)
Minidoka	(105)
Oneida	(115)
Owyhee	(112)
Payette	(88)
Teton	(102)
Twin Falls	(113)
Valley	(85)
Washington	(87)

AREA B

Oregon

Baker	(61)
Douglas	(66)
Grant	(60)
Harney	(72)
Lake	(71)
Wheeler	(59)

Washington

Asotin	(37)
Ferry	(4)
Kittitas	(16)
Pend Oreille	(6)
San Juan	(0)

Idaho

Adams	(84)
Blaine	(99)
Boise	(90)
Lemhi	(86)

AREA C

Oregon

Linn	(57)
Sherman	(45)

Washington

Adams	(24)
Benton	(30)
Columbia	(35)
Douglas	(11)
Franklin	(31)
Garfield	(36)
Lincoln	(18)
Spokane	(19)
Walla Walla	(34)
Whitman	(25)

Idaho

Benewah	(77)
Bingham	(106)
Bonneville	(107)
Latah	(79)
Lewis	(82)
Madison	(101)
Nez Perce	(81)
Power	(109)

AREA D

Oregon

Clatsop	(38)
Columbia	(39)
Coos	(65)
Curry	(67)
Deschutes	(63)
Josephine	(68)
Lincoln	(53)
Tillamook	(40)

Washington

Clallam	(7)
Clark	(32)
Grays Harbor	(12)
Island	(9)
Jefferson	(8)
King	(15)
Lewis	(23)
Mason	(13)
Pacific	(22)
Snohomish	(9-1)
Stevens	(5)
Thurston	(20)
Wahkiakum	(26)
Whatcom	(1)

Idaho

Ada	(96)
Bonner	(74)
Franklin	(116)
Gem	(89)
Shoshone	(78)

AREA E

Oregon

Clackamas	(52)
Hood River	(43)
Jackson	(64)
Lane	(62)
Marion	(55)
Multnomah	(42)
Polk	(54)
Washington	(41)
Yamhill	(51)

Washington

Chelan	(10)
Cowlitz	(27)
Kitsap	(14)
Okanogan	(3)
Pierce	(21)
Skagit	(2)
Skamania	(28)

1. All Crops (AC)
    - a. field crops (FC)
    - b. vegetables (V)
    - c. fruits and nuts (FN)
    - d. forest products (FP)
2. All Livestock and Livestock Products (ALLP)
    - a. poultry and poultry products (PPL)
    - b. dairy products (DP)
    - c. livestock and livestock products (LLP)

Area A contained counties with greater than 50 percent of TVFPS from FC and LLP, where the percentage from FC and from LLP was each greater than 20 percent. Area B contained counties with at least 50 percent of TVFPS from LLP and less than 20 percent from any other single source. Area C contained at least 50 percent of TVFPS from FC and less than 20 percent from any other single classification. Area D contained counties with at least 50 percent of TVFPS from ALLP and not less than 10 percent from DP and not less than 10 percent from LLP. Area E contained the remaining counties which exhibited a diversity of TVFPS over the seven classifications.

Ideally, the aggregation of county production units should be such that observed differences between counties reflect different points on the production function and not price differences. By delineating homogeneous farming areas according to type of farm output, the input combinations and prices of inputs and outputs were expected to be somewhat similar, or at least more similar than if the entire Pacific Northwest had been included in one category. Some price differentials no doubt existed in cases where transportation costs for some counties were greater than for others.

Another purpose of the delineation was to hold constant a set of output-oriented agricultural policy variables with which this study was not concerned.

Price supports and allotment programs have considerable impact on the value of certain classes of agricultural production. This study was concerned with the effects of certain subsidized water resource <u>inputs</u> in agriculture; therefore, it was necessary to hold constant the output policy effects.

Variable Measurement

The production function for each of the five farming areas was specified to include eight input variables. This specification allows for the explicit recognition of the water resource inputs -- irrigation, drainage, and water conservation practices -- which are the focal points of the study.

The generalized production function for each of the five homogeneous farming areas was specified as:

$$Y = f(X_1, X_2, \ldots., X_8)$$

where

Y = value of farm products sold plus value of home consumption ($1,000)

X_1 = man years of family, hired, and operator labor

X_2 = value of current operating expenses, including feed for livestock and poultry, seed, bulbs and plants, fertilizer, gas, fuel and oil, machine hire, repairs and maintenance, and pesticides ($1,000)

X_3 = service flow[9/] of capital on farms, including most types of mechanical equipment and farm buildings ($1,000)

X_4 = cropland: quantity adjusted by a quality index (1,000 acres)

[9/] The term "service flow" indicates a measure of the flow of services from a fixed investment (e.g., a farm tractor) as opposed to the "stock" which is a measure of the remaining <u>unused</u> portion of a fixed investment. In this study, the service flow is similar to an annual depreciation charge plus an interest charge on the value of the remaining stock.

X_5 = AUMs (animal unit months) of available grazing (1,000 units)

X_6 = irrigation water application (1,000 acre-feet)

X_7 = service flow of farm investment in drainage ($1,000)

X_8 = service flow of farm investment in water conservation practices ($1,000) designated ACP.

The variables for the production function models were based primarily on data from the 1964 Census of Agriculture. Other sources were used when Census data were inadequate, but whenever possible the other sources were made consistent with Census data. In the case of drainage (X_7) and ACP (X_8), however, this was not possible. Appendix B contains a complete description of the variables and sources of data.

STATISTICAL RESULTS

The results of the statistical analysis were inconclusive with regard to drainage and water conservation practices, but provided generally stable results concerning returns to irrigation. The attempt to separate drainage and water conservation practices from the more general forms of fixed capital resulted in estimates which were not statistically significant. Such attempts also damaged the reliability and stability of the other variables[10/], including the irrigation variable. The original specification was altered by combining the drainage and water conservation variables with X_3 (machinery capital).[11/] As a result, any information gained from the analysis regarding these two variables was not independently distinguishable from machinery capital.

The regression results are recorded in Appendix A. The variable definitions remain the same as indicated on the previous page, with the exception of X_3 which was changed to include X_7 and X_8. Different functional forms were examined to find the form that best described the data. Linear functions (a plane in three dimensions) and exponential functions (a three dimensional configuration similar to the upper half of an airplane nose)

[10/] In some cases X_7 and X_8 were highly correlated with some of the other variables, resulting in unstable coefficients of the related variables. When this is a serious problem, one has an option of proceeding in several alternative ways -- including discarding the data. For further discussion of these procedures, see Holloway [8, Chapters IV and V].

[11/] The new capital variable (X_3) is the simple sum of the former X_3, X_7, and X_8. This procedure assumes that the three variables are combined in fixed proportions. As a result, the regression coefficients (in the case of linear functions) for the three variables are the same by assumption. With the exception of Area B, the original specification yielded coefficients which were (statistically) not significantly different from zero, even at very low probability levels. The variables could have been discarded in the reformulation without doing damage to the remaining parameter estimates in most cases. Since X_7 and X_8 were actually portions of fixed capital (X_3), however, they were combined with X_3 in the reformulation. This was possible since all three variables were measured in terms of dollars of service flow.

described the data well. The exponential functions[12/] (hereafter referred to as Cobb-Douglas functions) are the most plausible from a theoretical standpoint since they allow for diminishing marginal productivity of the inputs, whereas linear functions do not. Conceptually this is important because the incremental increases in production are expected to diminish with continued increases in a particular input. For example, the second or third hundred-pound increment of fertilizer per acre could be expected to increase production less than the first hundred pounds. As a practical matter, however, this characteristic may not be an overriding factor. The linear forms were selected for further analysis in this study because (1) statistical tests are more precise in the linear form, (2) the linear functions are good approximations of non-linear functions over the range of the data, and (3) MVP estimates from the linear functions (for the irrigation variable) were not significantly different from MVP estimates from the Cobb-Douglas function (evaluated at the means of the inputs) for the same area. Figure 4 presents a graphical representation of the three equation forms for each homogeneous farming area. Table 3 presents a comparison of the MVP estimates from the different functional forms.[13/]

[12/] The exponential functions are referred to in economics literature as Cobb-Douglas functions. The functions were fitted to the data under two assumptions about the error term in the regression. Ordinary least-squares techniques were applied to the log transformation of the data and non-linear regression techniques were used to estimate the parameters with the data in its original form.

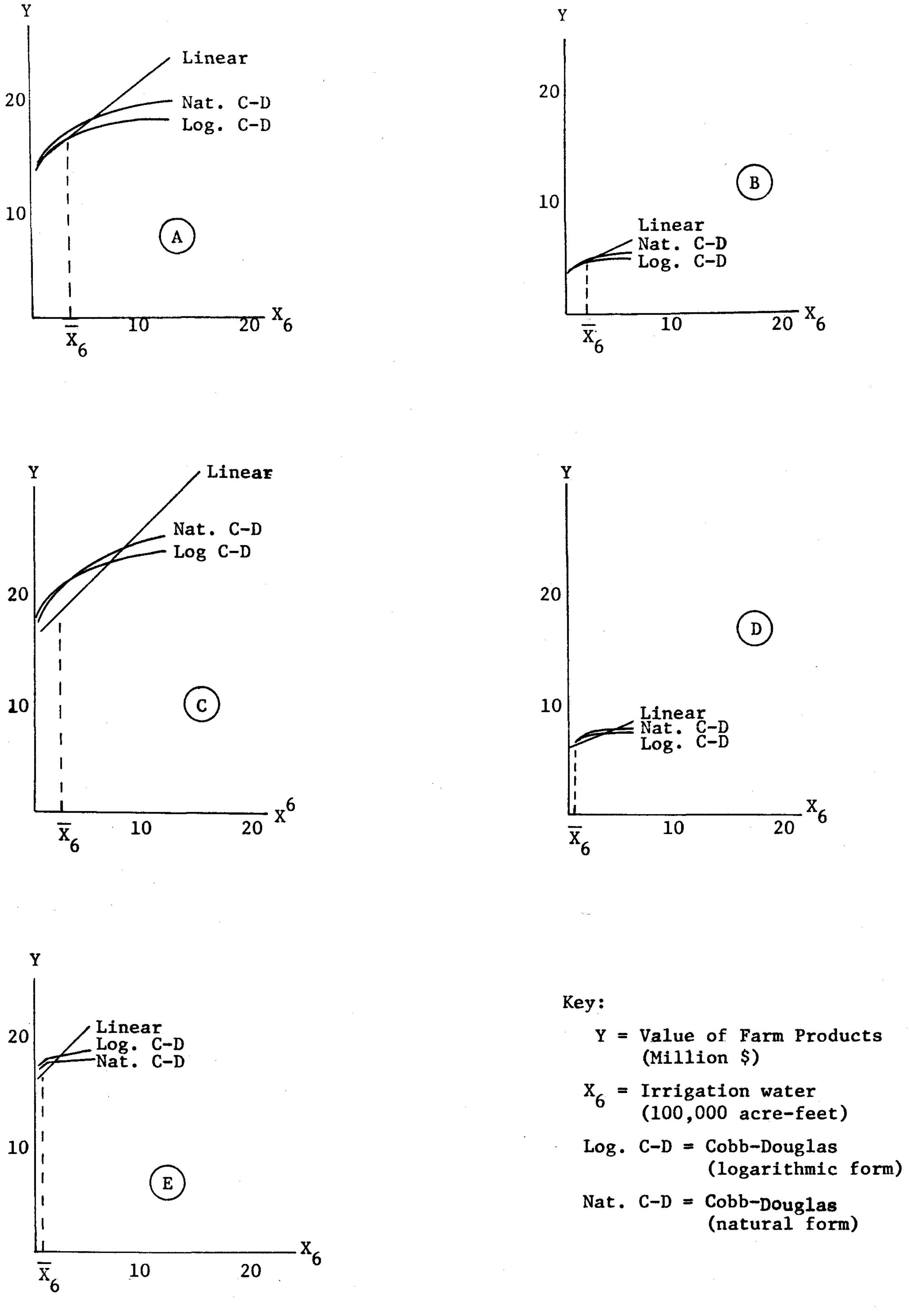
[13/] Exact statistical tests for differences in MVP estimates between equation forms were not possible. Tests were made, however, taking the estimates of MVP from Cobb-Douglas functions as constants to be tested against the parameter estimates from the linear equations for the same homogeneous farming areas; that is, $\hat{\beta}_6$ from the linear equation was tested against the MVP estimates from the Cobb-Douglas functions (e.g., a test was made to see whether $\hat{\beta}_6 = 7.613$ from Area A was significantly different from 4.302--see Table 3). At the 90 percent confidence level, $\hat{\beta}_6$ from Area B was significantly different from the MVP = 1.571 from the log linear function for Area B. No other comparisons were significantly different at 90 percent.

Table 3. Parameter Estimates, MVP Estimates, and Confidence Intervals for the Irrigation Variable, Three Equation Forms, Five Homogeneous Farming Areas, Pacific Northwest, 1964

Equation Form	Area	Point Estimate For β_6	90 Percent Confidence Interval for β_6	MVP[a/] Estimate for Irrigation (X_6) (In Dollars per Acre-Foot Delivered to the Farm)	MVP Interval Implied by the 90 Percent Confidence Interval for β_6 (In Dollars per Acre-Foot of Water Delivered to the Farm)
I. Linear Equations	A	7.613	$3.510 < \beta_6 < 11.716$	$ 7.613	$ 3.510 -- $11.716
	B	4.928	$3.681 < \beta_6 < 6.177$	4.928	3.681 -- 6.177
	C	10.590	$7.316 < \beta_6 < 13.864$	10.590	7.316 -- 13.864
	D	3.403	$.069 < \beta_6 < 6.737$	3.403	.069 -- 6.737
	E	10.688	$-3.754 < \beta_6 < 25.130$	10.688	-3.754 -- 25.130
II. Log-linear Equations (Cobb-Douglas)	A	.0865	$.0500 < \beta_6 < .1230$	4.302	2.480 -- 6.102
	B	.0557	$.0075 < \beta_6 < .1039$	1.571	.210 -- 2.879
	C	.0904	$.0458 < \beta_6 < .1350$	8.404	3.700 -- 10.905
	D	.0390	$-.0152 < \beta_6 < .0932$	5.008	-1.954 -- 11.984
	E	.0310	$-.0638 < \beta_6 < .1258$	9.417	-18.256 -- 35.997
III. Non-linear Equations[b/] (Cobb-Douglas)	A	.1385	$.0710 < \beta_6 < .2060$	7.129	3.522 -- 10.219
	B	.1224	$.0746 < \beta_6 < .1702$	3.546	2.067 -- 4.717
	C	.1217	$.0581 < \beta_6 < .1853$	11.387	4.693 -- 14.968
	D	.0334	$-.0090 < \beta_6 < .0758$	4.410	-1.157 -- 9.747
	E	.0113	$-.0568 < \beta_6 < .0794$	3.423	-16.253 -- 22.720

[a/] MVP estimates are derived from the equations by taking the first partial derivative of the function with respect to X_6. For the linear functions, $MVP_6 = \hat{\beta}_6$. For the Cobb-Douglas functions $MVP_6 = \hat{\beta}_6 \hat{Y}/X_6$ evaluated at the average level of the inputs, where MVP_6 = marginal value product of X_6 (irrigation), $\hat{\beta}_6$ = the regression estimate of the parameter, β_6, and $\hat{Y}$ = the regression estimate of Y (the value of farm output).

[b/] The confidence intervals for this equation form are not exact probability statements, but are close approximations.



Key:

Y = Value of Farm Products (Million $)

X_6 = Irrigation water (100,000 acre-feet)

Log. C-D = Cobb-Douglas (logarithmic form)

Nat. C-D = Cobb-Douglas (natural form)

Figure 4. Alternative Production Functions Evaluated at the Means of the Inputs for Each Area

Confidence intervals for the coefficients of irrigation are also presented in Table 3. The interpretation of these confidence intervals should be that the true value of β_6 is in the interval, and that this statement can be made with 90 percent confidence. That is, the true value of β_6 is in the interval unless this particular sample is an unusual one. There is one chance in ten that the sample was unusual enough that β_6 could be outside the intervals.

Statistical tests for significant differences in irrigation coefficients between the areas were conducted for each linear equation (Table 4). Coefficients for areas C and B were significantly different from each other at the 95 percent level of confidence, as were the coefficients for areas C and D.

Table 4. Tests for Significant Difference in Parameter Estimates for Irrigation (β_6) Among the Farming Areas, Linear Equation Forms, Pacific Northwest, 1964

Equation and Area	Value of Student's "t" Statistic				
	AREA				
	A	B	C	D	E
Linear Equation					
Area A		.504	.972	.982	.272
Area B			3.465**	.587	.899
Area C				2.155**	.009
Area D					.888
Area E					

** Indicates that the two estimates are significantly different at the 95 percent confidence level.

EVALUATION OF THE EFFICIENCY OF WATER USE IN PACIFIC NORTHWEST AGRICULTURE

Production functions and statistical results from the study provided information for evaluating the efficiency of irrigation water use in the Pacific Northwest. The basis for evaluation is outlined in the following sections. The results for each homogeneous farming area were examined and comparisons made between areas. The reader is reminded that these evaluations apply only to area aggregates; they cannot be applied with equal precision to individual farms or projects within the areas.

Economic Efficiency as a Criterion for Public Policy

Efficiency of resource use from the private viewpoint is achieved when the owner of a firm employs successive units of a resource in the production process until the use of the last unit adds equally to the total cost and total revenue.[14/] This is the point where the private marginal value product (PMVP) of the resource equals the private marginal cost (PMC) of the resource. The rationale for this equality requirement for efficiency is basically simple. As long as the employment of successive units of a resource adds more to total revenue than to total cost, net revenue can be increased by employing more of the resource.

Efficiency of resource use from the social viewpoint can be characterized in much the same manner as described for the private viewpoint; the social marginal value project (SMVP) of the resource must equal the

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[14/] This statement requires the assumptions of "well behaved" production functions with diminishing marginal productivities of the inputs and no constraints except the production function. If constraints exist, efficiency is obtained when PMVP $\geq$ PMC.

social marginal cost (SMC) of resource use.[15/] If this condition is not satisfied everywhere in the economy, national output (and thus national consumption) can always be (conceptually) increased by altering resource allocation among alternative uses and/or users until SMVP equals SMC for all resources in all uses. If certain highly restrictive assumptions are met, the existence of perfectly competitive markets would insure that the allocation of resources would be efficient from both private and social viewpoints. As a practical matter, many violations of these assumptions occur. The existence of monopolistic power by a firm, for example, may preclude a socially efficient optimum resource allocation; monopolies generally restrict output and set prices above social marginal costs of production. Another example is provided by the existence of "side-effects" which are not priced in the market place. Many of these externalities exist because of the inability to define and control property rights and/or because of the interdependence of production processes between owners of production units. As a consequence, some resource allocations which are economically efficient from a private viewpoint are not economically efficient from a social viewpoint.

Assuming that increased national output and consumption (at zero cost from a given resource base) are desirable, efficiency of resource use from the social viewpoint would seem to be a desirable criterion for public policy. There are, however, other legitimate criteria for public policy. Pricing policies and investment decisions by public water resource agencies have traditionally been designed to promote social goals which are not necessarily limited to, and in fact may conflict with, economic efficiency. Proponents of public irrigation projects, for example, contend that this type of development is desirable

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[15/] It is recognized that these are not complete statements of the requirements for economic efficiency. The interested reader may refer to one of many economic textbooks on welfare economics for a complete explanation, including the usual assumptions under which the above conditions hold.

as a means of developing arid regions and/or maintaining the "family farm." As a result, irrigators do not pay the full social cost of supplying the water on public irrigation projects; power revenues usually subsidize the irrigation function. Other agricultural programs are designed to increase agricultural incomes and conserve natural resources through cost-sharing agreements. Certain types of agricultural inputs have been provided to farmers through the Agricultural Conservation Program at about one-half the market cost. In each of these cases, farmers could be expected to use more resources than would be socially efficient since social marginal costs (SMC) would exceed private marginal costs (PMC). In that a conflict thus exists between economic efficiency and other criteria for public water policy, it would be instructive to determine the extent of this conflict in Pacific Northwest agriculture. In other words, to what extent is society sacrificing other goods and services to pursue objectives other than economic efficiency? The following section is devoted to this topic.

Comparisons Between Marginal Value Productivity and the Private and Social Marginal Costs of Water Supply

The production functions above provided estimates of the marginal value of agricultural production (MVP) from irrigation.[16/] As indicated in the last section, estimates of the social marginal costs (SMC) and private marginal costs (PMC) are necessary to determine whether the efficiency criterion of resource use was satisfied from private and/or social viewpoints. Precise estimates of the SMC and PMC of supplying

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[16/] It is assumed here that MVP values would be the same from both private and social viewpoints. In essence, national secondary benefits from irrigation development are assumed not to exist. To the extent that this assumption can be shown to be inappropriate, this weakens the conclusion that water was not used efficiently from a social viewpoint.

irrigation water to agriculture for each of the areas were not available, but some related data were available from which informed judgments about the effects of current water pricing policy and future development alternatives were made. Inferences about the achievement of efficiency from both private and social viewpoints could thus be made, although it is recognized that the MVP figures have a higher degree of reliability than the PMC or SMC data.

Private Marginal Costs

Estimates of the costs of irrigation water to farmers were available in two different forms. These included (1) water prices at the "farm gate" and (2) water prices at the point of application to the land. The latter includes the cost of distribution on the farm (not including labor costs). To provide MVP estimates which were comparable to the costs at the application point, an adjustment for evaporation and seepage loss through farm distribution systems had to be made. The adjusted MVP estimates thus reflected the value of irrigation water at the application point rather than at the farm gate.[17/] Table 5 summarizes the MVP estimates based on (1) water delivered at the farm gate, (2) water applied with 75 percent irrigation efficiency, and (3) water applied with 50 percent irrigation efficiency.[18/] The two latter sets of estimates were determined by assuming uniform efficiency among counties within each area. This

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[17/] To accurately assess the efficiency of water use from a social viewpoint, one should compare MVP estimates based on the net disappearance of water with the SMC of supplying the water. This would take the return flow and any quality change affecting reuse into account. This detailed information, however, was not available.

[18/] Irrigation efficiency is defined as the quantity of water actually applied compared with the quantity delivered to the farm gate. Irrigation efficiency in the Northwest ranges from 50 to 80 percent. Accurate data on efficiency by county were not available. The 50 and 75 percent efficiency rates were assumed as a means of providing a range of possible MVP estimates at the application point.

Table 5. Comparison of the Marginal Value Products with Estimates of the Private and Social Marginal Costs of Irrigation, Five Homogeneous Farming Areas, Pacific Northwest, 1964

	AREA A	AREA B	AREA C	AREA D	AREA E
Private (and Social) Marginal Value Product					
At Delivery Point ($/Acre-Foot)	7.613	4.928	10.590	3.403	10.688
At Application Point Assuming 75% Irrigation Efficiency[a/] ($/Acre-Foot)	10.150	6.571	14.120	4.537	14.250
At Application Point Assuming 50% Irrigation Efficiency[a/] ($/Acre-Foot)	15.226	9.856	21.180	6.806	21.376
Private Marginal Cost					
At Delivery Point ($/Acre)[b/]	5.07	1.87	2.32	6.26	6.69
At Delivery Point ($/Acre-Foot)[b/]	1.44	.60	.89	1.68	2.14
At Application Point ($/Acre-Foot)[c/]	N/A	N/A	20.00	N/A	23.00
Lower Bound of Social Marginal Cost					
At Delivery Point[d/]	13.72	11.03	19.78	14.78	19.69

[a/] MVP estimates generated by the linear regression equations when the quantity of the irrigation variables (X_6) was divided by the constants .75 and .50, respectively.

[b/] Weighted average assessment per acre (including operation and maintenance costs) by area for 73 irrigation districts in Oregon in 1966 [11]. Weights were irrigable acres in each district. Conversions to a per acre-foot basis were made on the basis of average delivery rates reported by Oregon irrigation organizations in the 1959 Irrigation Census [28]. These rates were 3.52, 3.15, 2.60, 3.72, and 3.13 acre-feet per acre for Areas A through E, respectively. Additional data for three individual Bureau of Reclamation projects in Oregon (Area A) indicated recent prices of $1.50 to $2.00 per acre-foot of water delivered [3]. Prices for the water delivered to farmers in the Columbia Basin project (mostly in Areas A and C) range from $2.50 to $3.00 per acre-foot in recent years [32]. Water prices for an estimated 25 percent of the irrigated acreage in the Snake River Valley of Idaho are usually $2.00 to $2.50 per acre-foot [2].

[c/] Available data for sprinkler irrigation costs per acre-foot in the Willamette Valley in Oregon (primarily Area E [10]) and in the deep well irrigation of eastern Washington (primarily Area C) include pumping and distribution costs. These estimates are not representative of average farmer irrigation costs at the application point, but rather the upper point on a range of costs since other distribution systems are less costly. The average price for water at the application point would likely be considerably below these estimates.

[d/] Estimates based on data from Bureau of Reclamation projects in the region. These estimates include the original investment cost per acre, adjusted to 1964 prices, a one-hundred year life expectancy, and a five percent opportunity cost for undepreciated investment.

assumption may, of course, neglect a significant source of variation (irrigation efficiency); therefore, more reliance should be placed on the estimates at the delivery point.

The data on private costs in Table 5 were not complete since they were not representative of all the irrigation in each area. Lack of complete information was due to the multiplicity of irrigation districts, irrigation companies, and the mixture of both public and private development projects. Data were available, however, on average per acre assessments for water delivered to farms in 73 irrigation districts in Oregon in 1966 [11]. These districts accounted for 13, 13, 0.5, 27, and 42 percent of total irrigated acreage in Areas A through E, respectively. The cost of water delivered to the farm gate ranged from $1.87 to $6.69 per acre. Upon conversion to per acre-foot prices (based on average delivery rates in Oregon), it appears that the cost of water delivered to the farm gate generally did not exceed $2 per acre-foot. Additional data for several public irrigation projects in the Pacific Northwest indicate that the $2 figure is not an unrealistic estimate [2, 3, 32].

The efficiency criterion for private resource use requires that the marginal costs of water be less than or equal to the marginal value product of that water. Comparison of the MVP and PMC estimates at delivery points (Table 5) suggests that, in general, farmers were using irrigation water in quantities which more than covered the cost of water to them. The MVP values, which ranged from $3.40 to $10.69 per acre-foot, all exceeded $2 per acre-foot. The $2 per acre-foot cost is more accurately regarded as a weighted average cost (rather than a marginal cost) of farm water supply, but because of the water pricing policies of many irrigation districts, these values are probably close to the marginal costs (on these project acres) because water prices are usually constant values per unit up to the maximum quantity available.

An indication of the private marginal costs of irrigation water at the application point was available through cost data on sprinkler systems in the Willamette Valley of Oregon (primarily Area E) and in eastern Washington (primarily Area C). Table 5 indicates that the MVP of water at the point of application (50 percent efficiency) in areas C and E was about equal to the costs of sprinkler irrigation in those areas (Table 5). This reinforces the earlier conclusion that farmers in the Pacific Northwest were generally not inefficient water users in the sense of allowing private costs to exceed private returns. Rather than using too much water, the data suggested that many farmers could have benefited from applying additional water if it could have been purchased for those prices shown in Table 5.[19]

Social Marginal Costs

Estimates of the lower bound on social marginal costs of water supply were limited to data from Bureau of Reclamation projects. These projects, however, were responsible for 66, 19, 67, 49, and 13 percent of total irrigated acreage in Areas A through E, respectively, and accounted for about 13.7 of the 23.1 million acre-feet used on farms in the Pacific Northwest in 1964. The estimates of social cost per acre in Table 5 were based on the original irrigation development investment per acre [30], as adjusted to 1964 prices, a 100-year expected life, and a 5 percent opportunity cost for the undepreciated investment. A weighted average cost per acre-foot was then determined by using 1964 average delivery rates on Bureau of Reclamation projects [30]. The resultant estimates of social cost ranged from $11.03 to $19.78 per acre-foot. These cost estimates are likely to be somewhat low due to the inflated expected life estimate and the relatively low estimate of the opportunity cost of the investment. More importantly, the estimates represent a lower bound on social marginal cost for Bureau projects since the estimates are

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[19] It should be noted that this conclusion would be reversed if farmers are operating with large opportunity costs. As a practical matter any opportunity cost not already accounted for would have to be perhaps as high as $2 to $3 per acre-foot to reverse the conclusion since the above estimates are on the conservative side.

constructed from an average of existing projects. A better estimate of the marginal cost would be the cost of additions to existing projects or the addition of new projects, both of which would be more costly than existing ones.

As contrasted with the efficiency of water use at the farm level, it must be concluded that the social marginal cost of supplying irrigation water was considerably in excess of the marginal value product. Statistically, all of the MVP estimates (at delivery point) were significantly less than the lower bound SMC estimates except in Area E where a large variance was associated with the MVP estimate.

It should be noted, on the other hand, that the MVP estimates in Table 5 reflect the productivity of all irrigation water, whether publicly or privately developed. It is quite likely, for example, that the MVP of water on public projects in Area A exceeded the overall MVP of $7.61 which was estimated for that area. One means of testing the implications of this possibility is to (1) assume that non-federally developed water was used efficiently in each region, and (2) solve for the implicit MVP of water developed by Federal projects.[20] This latter value can then be compared with the SMC of those projects (Table 6).

The equation for solving for the implicit MVP for Area A was:

$$\$7.61 = \frac{9.016\ X + 4.645\ (\$1.44)}{13.661}, \text{ or}$$

$$X = \$10.78$$

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[20] Estimates of MVP on Federal projects should be taken as upper limits to the true values, rather than point estimates. The reason for this is that the estimates of PMC (Table 5) are actually based in large part on prices paid for water which is publicly rather than privately developed. (Recall that the estimates were based on assessments by 73 Oregon irrigation districts, many of which use federally developed water.) The marginal costs of water developed privately ranges upward from $2 per acre-foot to more than $20 for sprinkler systems.

Table 6. Comparison of the Marginal Value Product (MVP) and Social Marginal Cost (SMC) of Federal Project Water Assuming that PMC = PMVP

AREA	Total Irrigation Water Delivered (mil. acre-ft.)	Bureau of Reclamation Projects as Percent of Total Irrigated Acreage	Irrigation Water Delivered by: Public Projects (mil. acre-ft.)	Irrigation Water Delivered by: Private Sources (mil. acre-ft.)	Public Projects: MVP	Public Projects: Lower Bound SMC
A	13.661	66%	9.016	4.645	$10.78	$13.72
B	2.523	19%	.479	2.044	23.35	11.03
C	4.512	67%	3.023	1.489	15.37	19.78
D	1.501	49%	.735	.766	5.19	14.78
E	.921	13%	.120	.801	67.76	19.69
Regional Total	23.118		13.373	9.745	$12.47	$15.10

in other words, if total water used in Area A were 13.661 million acre-feet (9.016 from federal projects, 4.645 from privately developed projects), if the overall MVP of water in that area were $7.61 and if those who used privately developed water equated their MVP with the private marginal cost of $1.44, then the MVP of water on federal projects would have equaled $10.78 per acre-foot. This value was still less than the lower bound of SMC ($13.72). A similar conclusion also holds for Area C, where the estimated public MVP ($15.37) was also less than the lower bound of SMC ($19.78). Together, Areas A and C accounted for 90 percent of the publicly developed water, and thus were the only areas for which such analysis is of consequence in testing the earlier conclusions.

IMPLICATIONS FOR FUTURE WATER RESOURCE DEVELOPMENT

Prior to examining some of the implications of this study, a note of caution is needed with respect to the nature of the methodology. The study was designed to explore policy issues of water resource allocation. With this objective in mind, an aggregate production function approach was chosen as the appropriate analytical concept. Counties were used as units of observation. Thus, the methodology is most accurately characterized as "diagnostic," rather than "prescriptive." In other words, the principal value of the results is the diagnosis of the degree of efficiency with which resources, especially water, were used by the units of observations under study. The results are not necessarily prescriptive in the sense of providing advice on resource allocation to each and every unit of observation (county) in the study. A method of analysis which utilizes data from an aggregation of counties provides results which are applicable only to that level of aggregation. In this case, the estimates of the MVP and efficiency of water use are applicable only to the five areas or broad groupings of counties. The results are not equally applicable to individual counties, public projects, or farms within an area. For example, the MVP of water in an individual county or farm within Area A may be above or below the $7.61 estimate for the area as a whole. Decisions on augmentation of water supplies through a public agency should be made, then, on the basis of an analysis of the individual project in question.

Viewed as a "diagnostic" tool, the production function analysis was useful in identifying some important parameters of irrigation water use in the Pacific Northwest in 1964. One set of parameters relates to the productivity of the water input; another set relates to the overall efficiency of water use. A discussion of these parameters and their implications may be useful in assessing the policy significance of this study.

Productivity of Irrigation Water

1. The MVP per acre-foot of water delivered to the farm ranged from $3.40 in Area D (a livestock and dairy region, primarily in Coastal Oregon and Washington) to slightly more than $10.50 in Area C (a field crops region, primarily in southeast Washington and southeast Idaho) and Area E (a highly diversified region, primarily in the Willamette-Puget Trough). This indicates that the marginal value of additional water in the latter areas is nearly three times as great as in the former area. If future irrigation development costs were about the same in each area, one would expect the greatest additional development to occur in the two latter areas.

2. The two areas in which water was most productive (C and E) were also among the three areas which have the greatest physical potential for future development, measured either in total potentially irrigable land or the concentration of large tracts of irrigable land. The MVP of water in the third area (Area A, a field crop and livestock region in Central and Northeast Oregon and Southern Idaho) was estimated at $7.61 per acre-foot.

3. The county-to-county variation in water MVP's <u>within</u> areas, however, reduces the degree of confidence which can be placed on differences <u>between</u> areas. The statistical tests indicate a significant difference (at the 95 percent level) between area-wide MVP's in only two cases; the productivity of water was greater in Area C than in either Area D or Area B (a livestock region, primarily in Eastern Oregon). It can be said with about 60 percent confidence that the MVP values are different in four of the eight remaining pair-wise comparisons between regions.

4. The productivity of water (in either physical or value terms), taken by itself, is insufficient evidence on which to base future water development decisions. The costs of future development must

also be taken into account. Even with perfect information on future costs and returns from additional water, quite different decisions might be made by private and public decision-makers. It is highly desirable, however, that decision-makers recognize the implications of past decisions, as illustrated in the next section.

Efficiency of Water Use

1. The fragmentary evidence on private marginal costs of past water development indicates that Pacific Northwest farmers have used irrigation water in a reasonably efficient manner. If they erred substantially in any direction, it was in the direction of using too little water, rather than too much. Obviously, there were exceptions to this statement.

2. The conclusion that "farmers use water efficiently" should be qualified to include the phrase "...given the decision rules and social institutions of the larger society in which they operate." Using the terminology of the previous section, irrigation water was apparently used efficiently from a <u>private</u> viewpoint; farmers came reasonably close to equating the marginal (private) returns from water with the marginal (private) cost.

3. The study also indicated that water was not used efficiently from a <u>social</u> viewpoint. The MVP of water was significantly less than the social costs of development in four of the five areas. For Areas A and C, which accounted for 90 percent of the publicly developed water in the region, the excess of social costs over social returns was on the order of \$5 to \$10 per acre-foot per year.

4. In light of the public water institutions that have arisen in the West since the turn of the century, the above conclusion is not

at all surprising. These institutions, particularly the water pricing policies of the Bureau of Reclamation, have been designed to circumvent social economic efficiency in water resource use in favor of regional development objectives. That the MVP of the water was less than the social costs of development simply reflects the fact that these policies have effectively shielded irrigators from full repayment of project costs.

5. The desirability of institutional change in water pricing is a value judgment which must necessarily be resolved through the political process. Continuance of current water pricing policies by public agencies implies a continued sacrifice of other goods and services to attain regional development objectives through provision of irrigation water. The extent and incidence of the sacrifice are thus important policy issues.

6. The social marginal costs of water development can be expected to increase over time as the less costly sources are developed and utilized. The existence of chronic excess capacity of agriculture in the U. S. makes it unlikely that corresponding secular increases in the prices of agricultural commodities (and thus the MVP of water) will occur.21/ The sacrifice of goods and services

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21/ The MVP of water would be expected to increase over time if the marginal physical productivity (MPP) of water were to be increased or if the prices of farm products grown under irrigation were to rise. It is quite likely that technological improvements in plant varieties, fertilizers, and farm equipment will cause a modest secular rise in the MPP of water. Farm product prices, on the other hand, have a substantial cyclical component which must be considered in deriving policy implications from MVP estimates. For example, when the acreages of the major categories of agricultural products associated with irrigation in the Pacific Northwest (e.g., food grains and feed grains) are weighted by the "prices received by farmers" for these categories, the resulting aggregate price index rises from (continued next page) which would be required if current water pricing policies are maintained in the future can be expected to increase, rather than decrease.

7. The implications of the above arguments can perhaps be captured through the following example:

   (a) Suppose that a proposal is made to bring under irrigation an additional 100,000 acres in one of the three areas with the greatest physical and economic potential for new irrigation (A, C, or E). Assume further that the current average of about three acre-feet per year is applied to each of these acres. This proposal would thus constitute about a 1.3 percent increase in total irrigation water used in the Pacific Northwest.

   (b) The current excess of social development costs over the MVP of water ranges from at least \$6 to \$9 per acre-foot in these areas. Given that future development costs can be expected to increase relative to the MVP of water, an expected deficit of \$12 per acre-foot per year (or \$36 per acre per year) is not at all unreasonable.

   (c) The sacrifice of other goods and services which would be required if this development were to take place would thus amount to about \$3,600,000 per year. Viewed in terms of the present value of all future sacrifices over a 50-year project life, discounted at 5 percent, the total sacrifice is nearly \$66 million. In other words, an "opportunity cost" of about \$660 in foregone goods and services would be incurred for each additional acre brought under irrigation.

21/ (continued) 234 for 1964 to 338 for 1972 (1910 - 1914 = 100). This implies a 44 percent increase in prices received from irrigated crops and associated livestock products, and a similar increase in the MVP of water. Two mitigating points should be noted, however. First, the MVP values estimated here are probably somewhat below "expected" values since farm products prices in 1964 were lower than in any other year between 1958 and 1973. Second, the increase in the aggregate "prices received" index is almost solely attributable to increases in livestock prices. To the extent that this is a cyclical, rather than secular, phenomenon, the implications of this study remain unchanged.

(d) The <u>incidence</u> of sacrifice is yet another matter. The total sacrifice of $66 million would be shared by the U. S. society at large in that this particular use of scarce labor and capital resources would reduce the supply of goods and services which would otherwise have been available. Since the Pacific Northwest accounts for only a small share of the U. S. population, one might argue that this is not an unduly large sacrifice for this region to make, considering the potential gains to the region. The viewpoint of persons living outside the Pacific Northwest might be quite different, since they would bear most of the costs while receiving few benefits.

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Appendix A. Aggregate Agricultural Production Functions for Five Homogeneous Farming Areas, Pacific Northwest, 1964 [a]

Function Form & Homogeneous Farming Area[b]	Parameter Estimates and Standard Errors for							R^2		Critical Values of Student's "t"	
	Constant	X_1 (labor in man years)	X_2 ($1,000 current operating expenditures)	X_3[c] ($1,000 capital service flow)	X_4 (1,000 acres cropland)	X_5 (1,000 AUMs)	X_6 (1,000 acre-feet irrigation water)	Natural	Log	(.90)	(.95)
Area A										(1.697)	(2.042)
Linear	-1259.950	4.917	2.852	-2.217	17.449	4.969	7.613	.9918			
		(.719)	(.331)	(.545)	(3.962)	(1.507)	(2.118)				
Log of C. D.	5.0280	.2122	.7653	-.1065	.1047	-.0035	.0865		.9861		
		(.1528)	(.0936)	(.1408)	(.0411)	(.0300)	(.0215)				
Nat. of C. D.	7.1552	.3361	.7143	-.3346	.1573	.0896	.1385	.9929			
	(2.9046)	(.0606)	(.0914)	(.1163)	(.0306)	(.0304)	(.0400)				
Area B										(1.860)	(2.306)
Linear	-14.325	-.753	3.963	-.531	-4.610	.123	4.928	.9979			
		(.847)	(.149)	(.279)	(2.519)	(.351)	(.671)				
Log of C. D.	4.981	.1356	.9737	-.2207	.0422	.0331	.0557		.9818		
		(.3799)	(.2277)	(.3654)	(.1289)	(.0619)	(.0259)				
Nat. of C. D.	7.0985	.0595	1.0661	-.2576	.0093	-.0431	.1224	.9945			
	(3.9563)	(.1976)	(.1108)	(.1702)	(.0845)	(.0473)	(.0257)				
Area C										(1.771)	(2.160)
Linear	-435.857	-4.324	2.685	.709	10.418	.457	10.590	.9804			
		(3.024)	(.481)	(.619)	(1.855)	(3.591)	(1.849)				
Log of C. D.	6.481	-.4673	.5229	.6553	.1700	-.0061	.0904		.9720		
		(.2816)	(.1747)	(.1824)	(.0648)	(.0509)	(.0252)				
Nat. of C. D.	2.1887	.2208	.5652	.4270	.2331	.0532	.1217	.9619			
	(1.5164)	(.3206)	(.2183)	(.2079)	(.0703)	(.0526)	(.0359)				
Area D										(1.725)	(2.086)
Linear	-344.025	2.768	1.950	-.794	19.602	1.874	3.403	.9853			
		(1.764)	(.262)	(.518)	(10.968)	(1.222)	(1.933)				
Log of C. D.	1.5650	.3121	.5822	.2150	-.0562	-.0002	.0390		.9810		
		(.2206)	(.1471)	(.2638)	(.1046)	(.0515)	(.0314)				
Nat. of C. D.	3.0156	.4648	.7151	-.1925	.0178	.0459	.0334	.9825			
	(1.9779)	(.2176)	(.1461)	(.2386)	(.0812)	(.0411)	(.0246)				
Area E										(1.833)	(2.262)
Linear	-649.98	6.051	1.441	-1.649	18.403	.192	10.688	.9895			
		(.967)	(.381)	(.653)	(10.295)	(.143)	(7.879)				
Log of C. D.	10.0600	.5998	.6448	-.4338	.1553	.0098	.0319		.9899		
		(.2061)	(.2192)	(.2277)	(.0815)	(.0394)	(.0523)				
Nat. of C. D.	12.6593	.7469	.4544	.3460	.0734	.0143	.0113	.9804			
	(12.5384)	(.2154)	(.2080)	(.2369)	(.1006)	(.0385)	(.0376)				

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[a] The basic data for these regressions are available in Holloway [8, Appendix II].

[b] Log of C. D. refers to the log form of the Cobb-Douglas function; Nat. of C. D. refers to the natural form of the Cobb-Douglas function.

[c] This input was calculated using a 0.05 discount rate. Discount rates of 0.075 and 0.10 were also used, but the estimated coefficient did not change significantly. Results from these regressions are available upon request from the author.

Appendix B. Variable Definition and Data Sources

The value of farm products sold (Y) was taken directly from the Census of Agriculture for 1964 [25, 26, 27; Table 6, line 63]. The value of home consumption was estimated by using the state estimates of value of home consumption from Farm Income Situation [21] and allocating this estimate among the counties according to the number of people on farms [25, 26, 27; Table 7, line 2].

Total man-years of labor (X_1) was estimated from the Census of Agriculture in three components: (a) hired labor, (b) family labor, and (c) operator labor. Hired labor was estimated as expenditures for hired labor [25, 26, 27; Table 9, line 92] divided by average monthly farm wage rates for all farm laborers in the state times twelve [22]. Family labor was estimated by counting one man-year of labor for each male person living on farms between the ages of 19 and 65 who was not a farm operator; 40 percent of a man-year for each male person on farms between the ages of 15 and 19; 60 percent of a man-year for each male person on farms over 65 years of age (who was not a farm operator). This figure was then reduced by the man-years of off-farm work by family members (assuming 300 days of off-farm work equal to one man-year). Operator labor was estimated by counting one man-year per operator under 65 plus 60 percent of a man-year for operators over 65.

Current operating expenditures (X_2) included expenditures for feed for livestock and poultry, seed, bulbs and plants, fertilizer, gasoline, fuel and oil, and machine hire. The source for these items was the Census of Agriculture for 1964 [25, 26, 27; Table 9, lines 57, 73, 75, 78, and 89]. Repairs and maintenance (R and M) were estimated using tractor, auto, truck, and machinery repair and maintenance cost per unit by type of farm from a U. S. Department of Agriculture national survey [16; pp. 25, 46, 52, and 76]. A weighted average cost per unit was obtained by taking R and M cost per unit (adjusted to 1964 price levels) times the appropriate percent of the corresponding type of farm in the county.

Pesticide expenditures were estimated using the 1964 Census of Agriculture and the ERS Pesticide Use Survey for 1964 [20]. The latter was used to determine percentage of total acreage treated by crop and by state, and the expenditure per acre treated. The total expenditure (estimated by state and crop) was allocated among the counties by the number of treated acres in each county. Pesticide expenditures on animals were estimated using the Pesticide Use Survey estimates of average cost per farm that treated any livestock, times the number of farms treating any animals [25, 26, 27; Table 8, lines 75 and 77].

The service flow of capital (X_3) included durable machinery items such as tractors, combines, trucks, etc., and was estimated by allocating Farm Income Situation Reports state estimates of 1964 capital consumption [21] among counties by: (1) dividing the state estimate among categories for major machinery items based on ratios of one year's total depreciation for all major machinery items to one year's depreciation for each major item (based on new machinery prices), and (2) calculating the service flows at the state level and allocating them among counties according to the number of machinery items in each county contained in the major item category [25, 26, 27; Table 8, lines 5, 9, 12, 17, 20, 22, 26, 28, and 31].

Acres of cropland (X_4) were taken directly from the 1964 Census of Agriculture [25, 26, 27, Table 1, line 17]. Timber land, range land, and waste land on farms and national or state forest and range lands are excluded. This quantity was adjusted by an index of land quality [8; p. 46].

The number of AUMs per county (X_5) was taken from the Columbia-North Pacific Region Comprehensive Framework Studies [13] compiled under the direction of Economic Research Service, USDA.

Acre feet of irrigation water per county (X_6) was estimated using average application rates from the 1959 Census of Irrigation [28, State

Table 2, Idaho, Oregon, Washington, line 43]. These rates were calculated using river basin irrigation rates. A weighted average irrigation rate per county was estimated using the percentage contribution from each river basin to total irrigated acres in the county. Dot maps showing the location of irrigated acres were used to establish these percentages [28]. Total acre feet per county was estimated by multiplying this weighted average rate by the number of irrigated acres reported in the 1964 Census of Agriculture. This procedure uses 1964 irrigated acres and assumes 1959 application rates. The variable was not measured in value of service flow terms since adequate private investment data were not available.

The <u>service flow of drainage investment</u> (X_7) was based on Agricultural Stabilization and Conservation Service (ASCS) historical records of farmer participation in Agricultural Conservation Program (ACP) cost-sharing arrangements in drainage practices. It was assumed that most drainage investment was made under ACP and that the farmer's investment was equal to the Federal government's share under ACP. (The farmer's share on drainage practices, as well as most other practices, is 50 percent of the total cost). Time series data was obtained from ASCS Annual Reports [18, 19, 20] for each state and the service flow for 1964 was calculated. Life expectancies for all ACP practices were obtained from the Soil Conservation Service [23].

<u>Water conservation practices</u> (X_8) include some 36 different water-related practices under ACP. The service flow was calculated for each practice using the same assumptions and data sources as for the drainage variable.