ECONOMICS OF WATER ALLOCATION

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Thus far in the conference, we have heard excellent reports on recreation, irrigation, municipal water use, and pollution as specific water uses or problems that require serious evaluation as New Mexico charts its future years of Statehood. The main avenues of improvement in achieving an efficient yet equitable future allocation of the State's water resources have been outlined in these discussions. Additional contributions have been made by Mr. Irby on legal aspects of water use, Mr. Meyers on water conservation opportunities and Dr. Stucky on the economics of beneficial uses. Consequently, I approach the subject of water allocation with considerable trepidation, realizing that most of what I say has already been said by other economists at other times and places, may have questionable relevance to the most pressing water resource problems of this State and, even if this is not the case, is already implicit in the contributions of my program predecessors.

Considering these factors and the Conference theme of looking to the future as well as at the past and present, I concluded that the most fruitful way to discuss the economics of water allocation was to review the development of allocation principles and techniques against the background of historic, current, and future water allocation problems of the country and this region; and further, to perhaps show what economists mean when they say that limited water should be allocated among uses so as to maximize the overall economic values of water use. But there is another difficulty here, involving recognition that some very important alternative water uses such as recreation seem to defy complete monetary evaluation. Recourse to allocation principles not dependent on complete monetary evaluation seems logical in these situations, and I hope to illustrate one variant of this approach as having some potential for resolving future water allocation questions.

The discussions of economic techniques for water allocation will be introduced by: Suggestions on how economists might view allocation problems from a physical as well as an economic angle; a review of current and estimated future water use and water allocation in the United States and New Mexico (29)[2/] and an all-too-brief commentary on the recently

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2/ Underscored numbers in parentheses refer to Literature Cited.

published San Juan-Rio Grande research study of the University of New Mexico and Resources for the Future. The latter study will introduce the two examples of techniques for optimum water allocation, one to fit situations where benefits are measurable and the other to fit situations where they may or may not be completely measurable.

Physical-Economic Considerations

In general, any water allocation problem has four dimensions: the total quantity of water to be allocated; the use to which the supply might be allocated; substitution possibilities between uses; and the criteria that are to govern the allocation decision. Total allocable quantities can be specified with respect to any phase of the hydrologic cycle and any natural or artificial sources of supply subject to management, as pointed out by hydrologists (2). Relevant uses are any that can feasibly draw on the physically defined supply. Substitution possibilities are given by quantities of water required for varying quantities of products associated with each use relative to other uses. Finally, allocation criteria may give preference to uses with lower water requirements per unit of product simply on the basis of physical efficiency, may consider substitution possibilities in relation to comparative economic values of products, or may simply grant preference on the basis of established legal doctrines grounded in such concepts as time priority, beneficial use, and adverse possession.

Despite the overriding importance of legal criteria for allocation in the arid West, various applications of criteria based on economic value are applicable where substantial supplies are unappropriated, are under the direct control of public agencies, or where legal criteria are flexible enough to allow market-type reallocations. Thus we see that the problem of allocating water between uses cannot be stated in general terms even within a State with a uniform set of water statutes and comparable economic conditions. Variations in available ground and surface supplies, if nothing else, dictate unique water allocation situations and possibilities that can be analyzed most meaningfully on a watershed basis.

Considering specific situations, problems of water allocation between uses can be roughly divided for discussion purposes into those concerned with rainfall, runoff, and ground water as the basic resource quantities available for allocation or re-allocation. Of course there may be no ground water to exploit. Also, local runoff may be a trivial factor in the water supply situation and, because of excessive rates of evapotranspiration, would remain so even if rainfall were to be substantially increased by artificial means. This "on-site evaportranspiration," as it is often called, must be recognized as a primary use of water with considerable economic significance.3/

The frequent neglect or assumed constancy of evapotranspiration in economic studies of water development is rather surprising. Opportunities for economic allocation of rainfall exist where its division into evapotranspiration and 'water yield' can be controlled to an appreciable degree by modifying vegetation, harvesting timber on a hydrologic pattern, complete stripping of vegetation, and regulation of snowmelt. The Department of Agriculture estimates, for example, that opportunities for increasing water yield through watershed or vegetation management appear favorable on about 15 percent of the area of the Western States (23). Potential increases over present yields range from one-fourth inch or less in areas dominated by pinyon-juniper as in much of New Mexico, to nearly one inch in the ponderosa pine and douglas-fir stands of northern New Mexico, and up to 6 inches in the true-fir areas of California.

The economic nature of water allocation problems involving rainfall as the basic supply and on-site evapotranspiration and off-site water yield as alternative water uses can be illustrated by commonplace examples. At one extreme, foresters or grazing interests might prefer that evaportranspiration be maximized, realizing that soil moisture conditions improve as a smaller portion of rainfall is permitted to reach streams, and would approve watershed management practices appropriate to this end. The other extreme of minimizing evapotranspiration use is illustrated by municipalities or irrigation farmers preferring that rainfall in upland areas appear as water yield, especially where they do not have recourse to ground water for supplying their needs. Economic data could likely be developed that would support arguments for both of these groups, but the basic question of allocation is broader than this. It requires identification of some intermediate or compromise solution that would be in the best interests of the groups combined. This involves determining what would be the optimum or ideal amount of evaportranspiration to permit (and thus an ideal water yield to obtain) for a particular basin for a given period of time, either by altering the extent and type of vegetation or otherwise modifying the water regimen of the area. The detailed

3/ The importance of evapotranspiration for U. S. agriculture is indicated by the fact that only about 20 percent of the value of all crop production, 6 percent of the value of pasture production, and 19 percent of crop and pasture values combined is due to irrigation (24). In the Rio Grande Basin of New Mexico and Texas, comparable figures range near 95 percent for crop production but down to 5 percent for pasture production.

research necessary to adequately resolve this allocation question amounts to a comprehensive analysis of water use and development for entire basins, since all upstream as well as downstream water uses would require thorough evaluation in a benefit-cost framework. This in turn implies that any plan for water resources development that does not examine watershed management possibilities in relation to downstream water yield has not fully considered the question of allocating water among alternative uses.

This leads to consideration of streamflow and ground water as supplies available for distribution among uses. For streamflow, economists must first note the variations in allocable supply made possible through watershed management as just described, and then storage possibilities. Reservoirs are creators of water supply in an economic as well as an engineering sense by serving to reallocate natural streamflow both geographically and over time. In effect they convert water from an intermittent 'flow' resource into a 'stock' resource usable for irrigation, municipal-industrial, and other withdrawal purposes, or perhaps for recreation as a nonwithdrawal use. In hydropower generation and flood control, emphasis is on conversion from intermittent to regular flows, either to harness or dissipate energy at a controlled rate. In most of the West the problem of allocating surface water among alternative uses reduces to the question of allocating storage capacity among uses, uses that may be competitive (flood control versus irrigation), or largely complementary (recreation with power generation). These interrelations dictate multipurpose planning of reservoirs and water resource projects. To be applicable to current planning, economic principles and techniques for water allocation must therefore draw heavily from the economic theory of joint production. An example will be given later.

Analytically, ground water poses allocation problems similar to those for surface supplies, in that given quantities must be distributed in some optimum fashion among alternative uses. The most important difference is that ground water is truly a stock resource (or stored) in its natural state. Also, the stock supply usually can be allocated or used over an extended period, although storage carry-over permits intertemporal allocation of reservoir water also, at least on a short-term basis. For ground water, the allocation problem must be stated in terms not only of how the given stock should be allocated among uses, but also of how pumping for each use should be regulated, either to not exceed recharge or to exploit aquifers at an optimum rate, considering both the immediate and future values of the withdrawn water, pumpin technology, costs, and physical characteristics of different aquifers. Both the physical and economic aspects of ground water allocation have received increased attention in recent years.[4] Notable empirical economic studies are those of Hughes, Magee, and Cole in the High Plains (5) (7), Kelso (8) in Arizona, and Snyder (17) in the Antelope Valley of California.

This sketchy physical-economic view of ground water underlines the earlier statement that water allocation in its most relevant sense must often deal simultaneously with a multiplicity of alternative uses, users, and sources of supply--on an intrabasin, interbasin, or interstate basis as dictated by physical economic and institutional factors peculiar to given areas.

Macroeconomic Approaches to Water Allocation

In view of the need for evaluating water resource planning in a physical-economic-institutional setting, how can water allocation as such be discussed in purely economic terms? More particularly, can the economics of water allocation be discussed in an historical yet problem-oriented context? Both approaches are possible but the second is taken here as being more consistent with the Conference theme of reviewing the past for the purpose of focusing on future problems.

Historical aspects of water allocation

Considering the fact that "regulation" is implicit in the term "allocation," historical data on water use are appropriate to allocation economics to the extent they reflect past regulation or indicate needs for greater future regulation of limited supplies. Consider figure 1, which illustrates U. S. trends since 1940 in agricultural as well as nonagricultural water withdrawals and consumption. It is mainly based on Geological Survey data (11). In an essentially free enterprise economy such as ours, one might infer that the greater increases over time in nonagricultural than in agricultural water use have been due to greater increases in demands for industrial products and municipal water services than in demands for agricultural products, particularly the products of irrigated agriculture. Irrigation alone accounted for 115 million acre feet (38 percent) of the 303 million acre feet of water withdrawn, and 54 million acre feet (80 percent) of the 68 million acre feet of water consumed in the United States for all productive purposes in 1960. The inference is correct for the country as

4/ See especially the proceedings of the 1961 New Mexico Water Conference (13) and the 1960 Western Resources Conference (6), both of which were devoted to ground water.

a whole, the East as a whole, and with respect to general nonagricultural versus agricultural demands, but it is much less true considering western irrigation. Most of the increases in nonagricultural uses since 1940 have occurred in the water-surplus East; most agricultural increases are due to irrigation development in the West, where water is in short supply and subject to relatively strict institutional allocation. The importance of institutional limitations on increased water use in the West assumes even greater significance when we consider that crops in surplus were grown on about 43 percent of the 33.2 million acres of U. S. irrigated land in 1959.[5/] If water-supply and institutional factors were less limiting, irrigated acreages of nonsurplus crops, hay and pasture would likely be adjusted more rapidly to market forces, with corresponding changes in water use. Hay and pasture alone accounted in 1959 for nearly 38 percent of the U. S. irrigated acreage.

Moving from historical regulation as deducted from historical use to the question of further allocation of limited supplies, the 303 million acre feet of water withdrawals shown for 1960 in figure 1 (also table 1) amount to 22 percent of the Nation's annual renewable runoff supply of 1.3 billion acre feet, and even only 85 percent of the present dependable renewable supply of somewhat over 350 million acre feet.[6/] The situation in the West is much less favorable and underlies increasing controversies over the role of water rights legislation in reallocating supplies as well as supply-increasing projects. This is true for ground water stocks as well as renewable surface supplies. The limiting nature of ground water resources is indicated by increasing reliance of further irrigation on ground water despite declining water tables in many areas. About 45 percent of the irrigated acreage in the West is now dependent on ground water, with the proportion running as high as 89 percent in Kansas, 82 percent in Texas, 61 percent in New Mexico and down to 2 percent in Montana and Wyoming as the only two Western States with more than 85 percent of their irrigated acreage still supplied from surface sources (31). The rapid increase since 1939 in ground water use for irrigation in the United States is illustrated in figure 2.

A sharper historical perspective of agricultural and nonagricultural water use, considering sources of supply and contrasting geographic factors, can be obtained by comparing

5/ Estimates from Census of Agriculture. Except for rice and perhaps potatoes this does not mean that surplus production is due to irrigation.

6/ After Woodward (30), dependable supply is defined as aggregated maximum monthly streamflow at major points of use under present conditions of development.

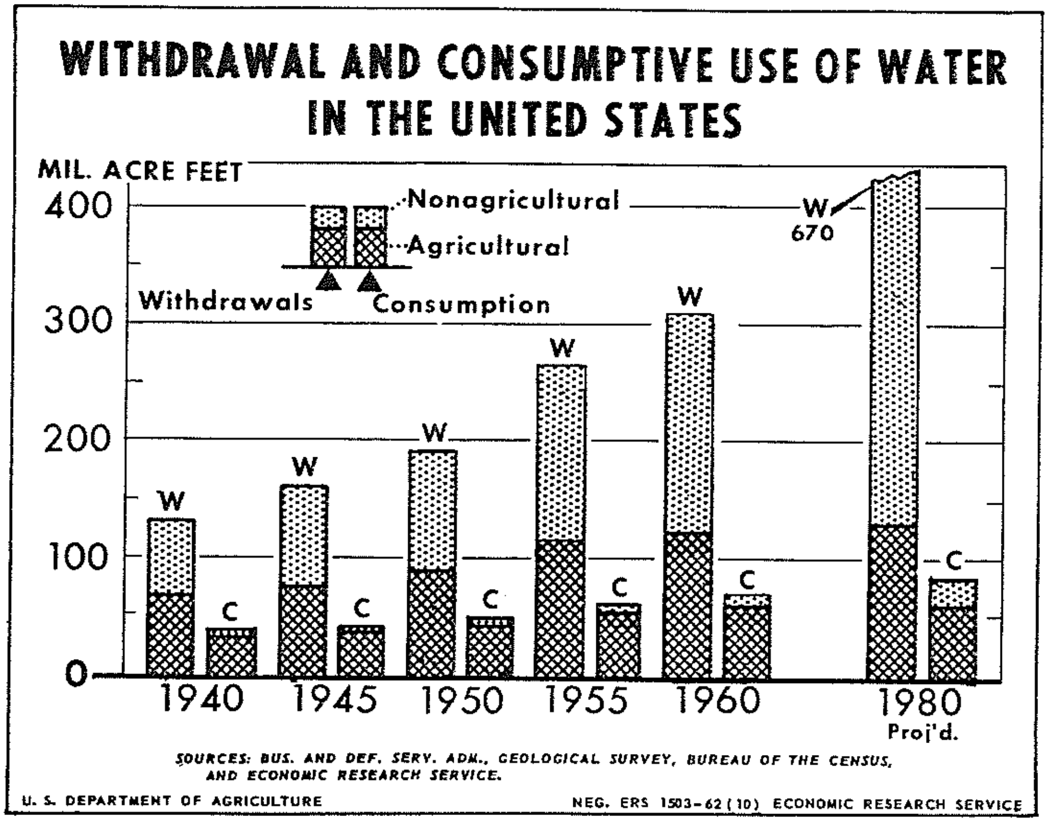

Figure 1

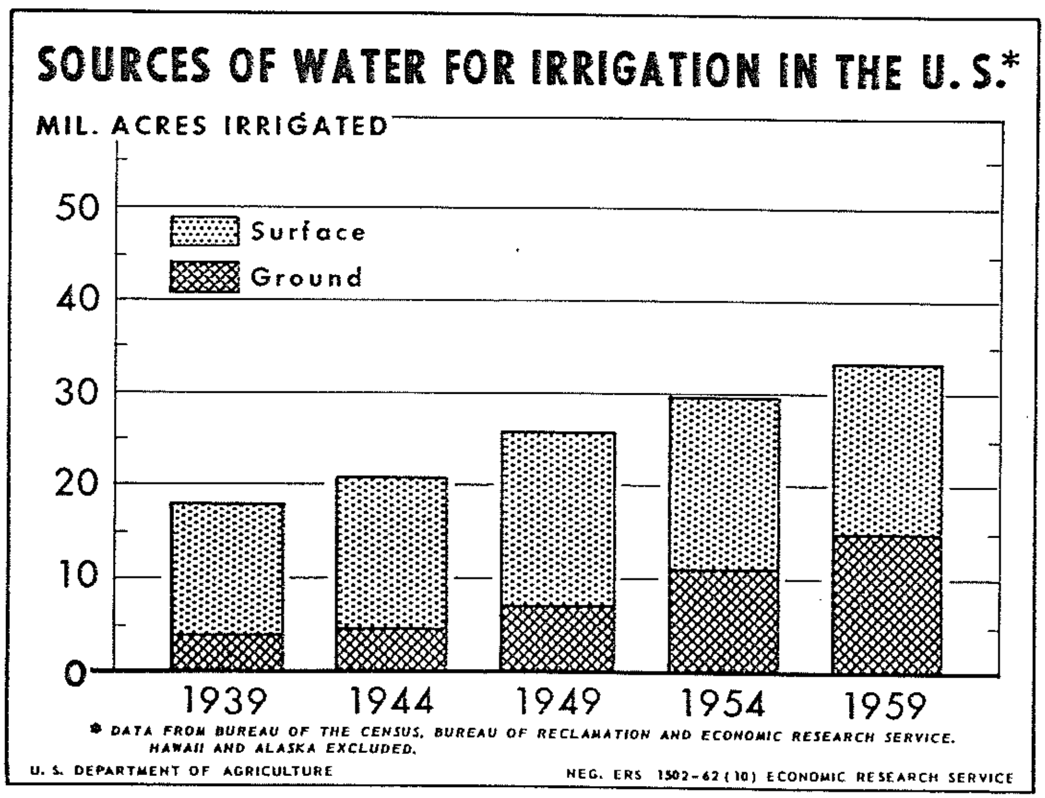

Figure 2

recent (1950-60) trends in the United States and New Mexico. Background data are provided in tables 1 and 2 and graphed in figures 3 and 4. Comparing the charts with respect to agricultural uses in 1960 shows that agriculture (irrigation) in New Mexico is only slightly more dependent on ground water (39 percent of irrigation withdrawals) than U. S. agriculture as a whole (31 percent of withdrawals). However, agricultural ground water withdrawals in the State have almost doubled in the last decade, compared with a 76-percent national increase. Industrial and municipal ground water withdrawals in New Mexico have increased by 82 percent since 1950, compared with a 225-percent increase in surface water use for these purposes. In this respect New Mexico accents a national trend toward greater reliance on surface water development than on ground water pumpage in meeting nonagricultural water requirements. The opposite trend is evident with respect to agriculture, both nationally and in New Mexico. Since 1950, surface withdrawals for agriculture have increased by 19 percent nationally and by 10 percent in New Mexico, compared with respective increases in ground-water withdrawals of 76 and 97 percent.

The data of tables 1 and 2 and the corresponding charts facilitate other interesting comparisons of recent trends in uses and sources of water. But the essential conclusion with respect to ground water allocation in New Mexico is that immediate pressures on ground water supplies as between agricultural and nonagricultural interests will likely be roughly proportional to current ratios of use; that is, 10 percent of the added future demand for ground water in New Mexico will be exerted by the municipal-industrial sector of the State's economy. But this assumes the absence of a ground water allocation policy geared to a program for accelerating industrial development.

For surface water development and allocation we could assume that future municipal-industrial demands in New Mexico will be much more pressing than suggested by current use, and that these demands compete much more effectively with agriculture than in the case of ground water in the absence of revised allocation policies. Additional surface water development holds, as we all know, considerable potential for meeting future supply requirements of all uses including agriculture, industry, municipalities, and recreation. In this respect New Mexico typifies the Southwest at large, which has been characterized by Ackerman (1) and the Senate Select Committee on National Water Resources as a region where comprehensive water development is essential for economic growth.

A further important aspect of surface water use that is importantly related to water development concerns the prodigious quantities of existing supplies depleted by reservoir and pond

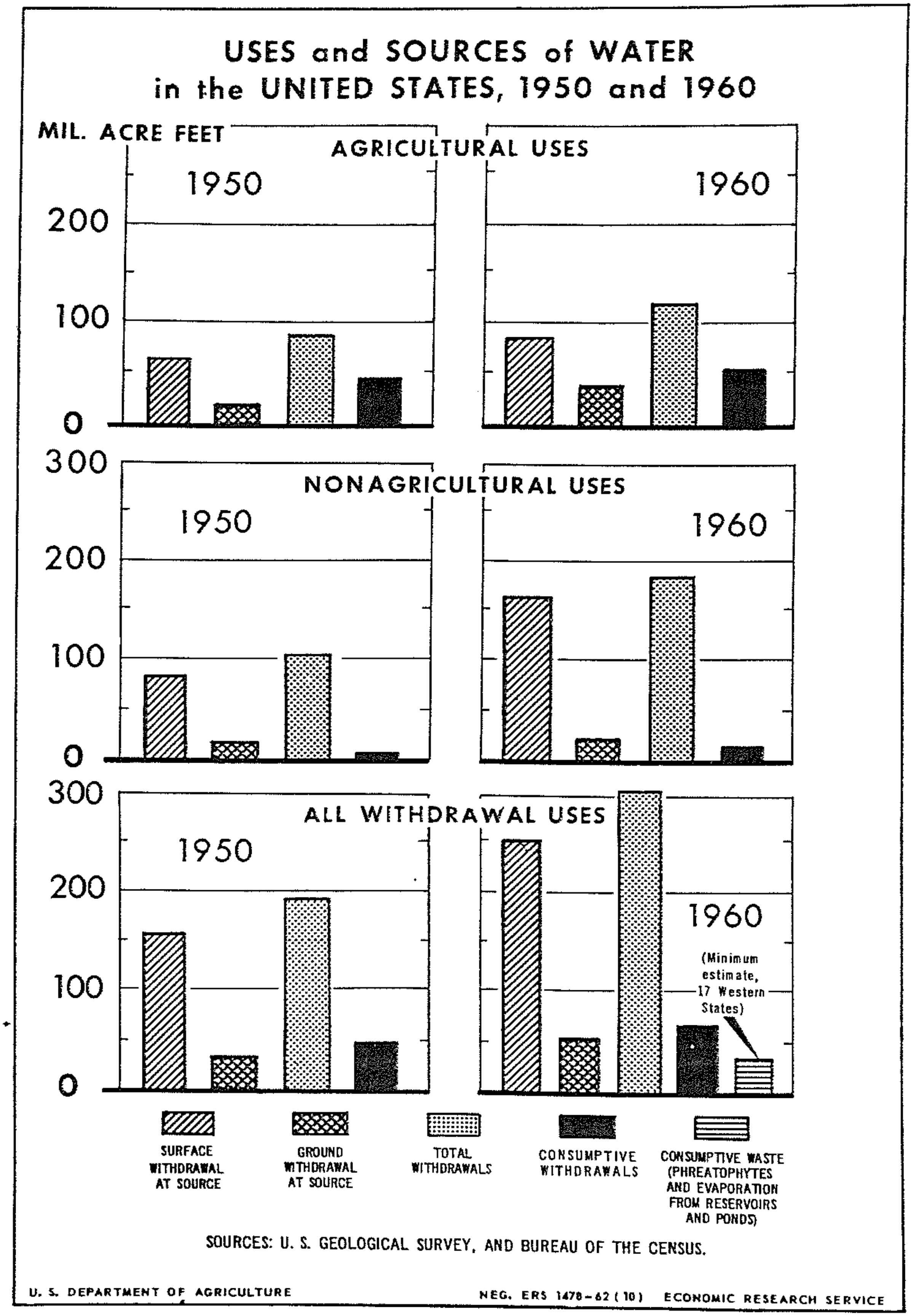
USES and SOURCES of WATER
in the UNITED STATES, 1950 and 1960
MIL. ACRE FEET
AGRICULTURAL USES
1950
1960
200
100
0
300
NONAGRICULTURAL USES
1950
1960
200
100
0
300
ALL WITHDRAWAL USES
1950
200
1960
100
(Minimum estimate, 17 Western States)
0
SURFACE WITHDRAWAL AT SOURCE
GROUND WITHDRAWAL AT SOURCE
TOTAL WITHDRAWALS
CONSUMPTIVE WITHDRAWALS
CONSUMPTIVE WASTE (PHREATOPHYTES AND EVAPORATION FROM RESERVOIRS AND PONDS)
SOURCES: U. S. GEOLOGICAL SURVEY, AND BUREAU OF THE CENSUS.
U. S. DEPARTMENT OF AGRICULTURE
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Figure 3

Table 1. Agricultural and nonagricultural water use in the United States in 1960 and changes from 1950 to 1960, by source of supply[1/]

Uses and items	Surface sources	Ground sources	Total withdrawals	Consumptive withdrawals
All withdrawals: 1960, mil. ac/ft.----------------	249	54	303	2/ 68
Percent of total 1960 withdrawals----------------	82	18	100	22
Percent change, 1950 to 1960--------------------	58	50	58	39
Agricultural withdrawals: 1960, mil. ac/ft.--------	3/ 82	4/37	119	5/ 57
Percent of agricultural withdrawals, 1960--------	69	31	100	6/ 49
Percent change, 1950 to 1960--------------------	19	76	32	30
Percent of all withdrawals, 1960----------------	33	69	39	84
Percent of all changes, 1950 to 1960------------	14	89	26	68
Nonagricultural withdrawals: 1960, mil. ac/ft.-----	167	17	184	11
Percent of nonagricultural withdrawals, 1960-----	91	9	100	6
Percent change, 1950 to 1960--------------------	92	13	80	120
Percent of all withdrawals, 1960----------------	67	31	61	16
Percent of all changes, 1950 to 1960------------	86	11	74	32

1/ Data mainly from U. S. Department of the Interior, Geol. Surv. Circs. 115 and 456, Estimated Use of Water in the United States, 1950 and 1960, by K. A. MacKichan (Circ. 115) and K. A. MacKichan and J. C. Kammerer (Circ. 456). Some estimates from various reports of the Bureau of the Census.

2/ Excludes at least 16 million acre feet of reservoir-pond evaporation and 20 million acre feet of consumptive waste in the 17 Western States.

3/ Includes about 1 million acre feet for livestock and rural domestic use, with the remaining 81 million acre feet for irrigation, 24 million acre feet of which is lost in conveyance.

4/ Includes about 3 million acre feet for livestock and rural domestic use, with the remaining 34 million acre feet for irrigation, of which 2 million acre feet is lost in conveyance.

5/ Includes about 3 million acre feet for livestock and rural domestic use, with the remaining 54 million acre feet for irrigation.

6/ About 60 percent if based on actual farm delivery.

evaporation, phreatophytes, and canal seepage, even discounting the latter in view of recovery possibilities. Meyers' recent report on evaporation in the Western States (12) indicates that major reservoirs and regulated lakes annually evaporate on the order of 13 million acre feet of water; and that small ponds evaporate another 3 million acre feet. He reports evaporation losses in New Mexico of 200 thousand acre feet from the large impoundments and regulated lakes, and 150 thousand acre feet from small ponds and reservoirs. If we add to these evaporation losses the consumptive use of valuable water by phreatophytes and other useless plants, conservatively estimated from Robinson's data (16) at 20 million acre feet in the 17 Western States and from Senate Select Committee data (23) at 200 thousand acre feet for New Mexico alone, we find that "consumptive waste," as it is aptly called, comes to a minimum of 36 million acre feet for the United States, or about half as much water as that consumed beneficially (see figure 3). The total in New Mexico is about 550 thousand acre feet or two-fifths as much water as that consumed beneficially (figure 4).

These gross estimates of consumptive waste suggest dramatic possibilities for effectively increasing water supplies for all beneficial purposes. Their significance in an allocation context can be indicated by examining them on an incremental substitution basis and with respect to alternative beneficial uses of the water conserved. In New Mexico, for example, consumptive use in agriculture averages 49 percent of withdrawals, excluding consumption associated with conveyance, while consumptive use averages 32 percent of withdrawals for nonagricultural uses (table 2).[7] This is to say that, on the average, water goes at least 1.5 times as far in meeting municipal-industrial needs as in meeting irrigation requirements. By inference one could also say that, to justify an added acre-foot diversion for irrigation where nonagricultural water requirements were not being fully supplied, the economic value of an acre-foot of water consumed in irrigation would need to be 1.5 times its productivity in nonagricultural uses.[8]

7/ Nonagricultural withdrawals are only about 6 percent consumptive nationally, due to the preponderance of low-consuming self-supplied industrial uses relative to municipal and other public uses. Over 70 percent of nonagricultural withdrawals in New Mexico in 1960 were from public systems.

8/ For the moment we are ignoring various empirical studies that suggest irrigation values much lower than this. For example, the New Mexico-Resources for the Future study of the San Juan and Rio Grande Basins (29) indicates that industrial water values may range from $3,000 to $4,000 per acre foot, compared with $50 per acre foot for irrigation.

Table 2. Agricultural and nonagricultural water use in New Mexico in 1960 and changes from 1950 to 1960, by source of supply1/

Uses and items	Surface sources	Ground sources	Total withdrawals	Consumptive withdrawals
All withdrawals: 1960, thous. ac/ft.----------------	1,709	1,203	2,912	2/ 1,400
Percent of total 1960 withdrawals----------------	59	41	100	48
Percent change, 1950 to 1960---------------------	13	95	37	37
Agricultural withdrawals: 1960, thous. ac/ft.-------	3/ 1,657	4/ 1,079	2,736	5/ 1,343
Percent of agricultural withdrawals, 1960---------	61	39	100	6/ 49
Percent change, 1950 to 1960---------------------	10	97	34	35
Percent of all withdrawals, 1960-----------------	97	90	94	96
Percent of all changes, 1950 to 1960-------------	82	90	88	92
Nonagricultural withdrawals: 1960, thous. ac/ft.----	52	124	176	57
Percent of nonagricultural withdrawals, 1960------	30	70	100	32
Percent change, 1950 to 1960---------------------	225	82	110	103
Percent of all withdrawals, 1960-----------------	3	10	6	4
Percent of all changes, 1950 to 1960-------------	18	10	12	8

1/ Data mainly from U. S. Department of the Interior, Geol. Surv. Circs. 115 and 456, Estimated Use of Water in the United States, 1950 and 1960, by K. A. MacKichan (Circ. 115) and K. A. MacKichan and J. C. Kammerer (Circ. 456). Some estimates from various reports of the Bureau of the Census.

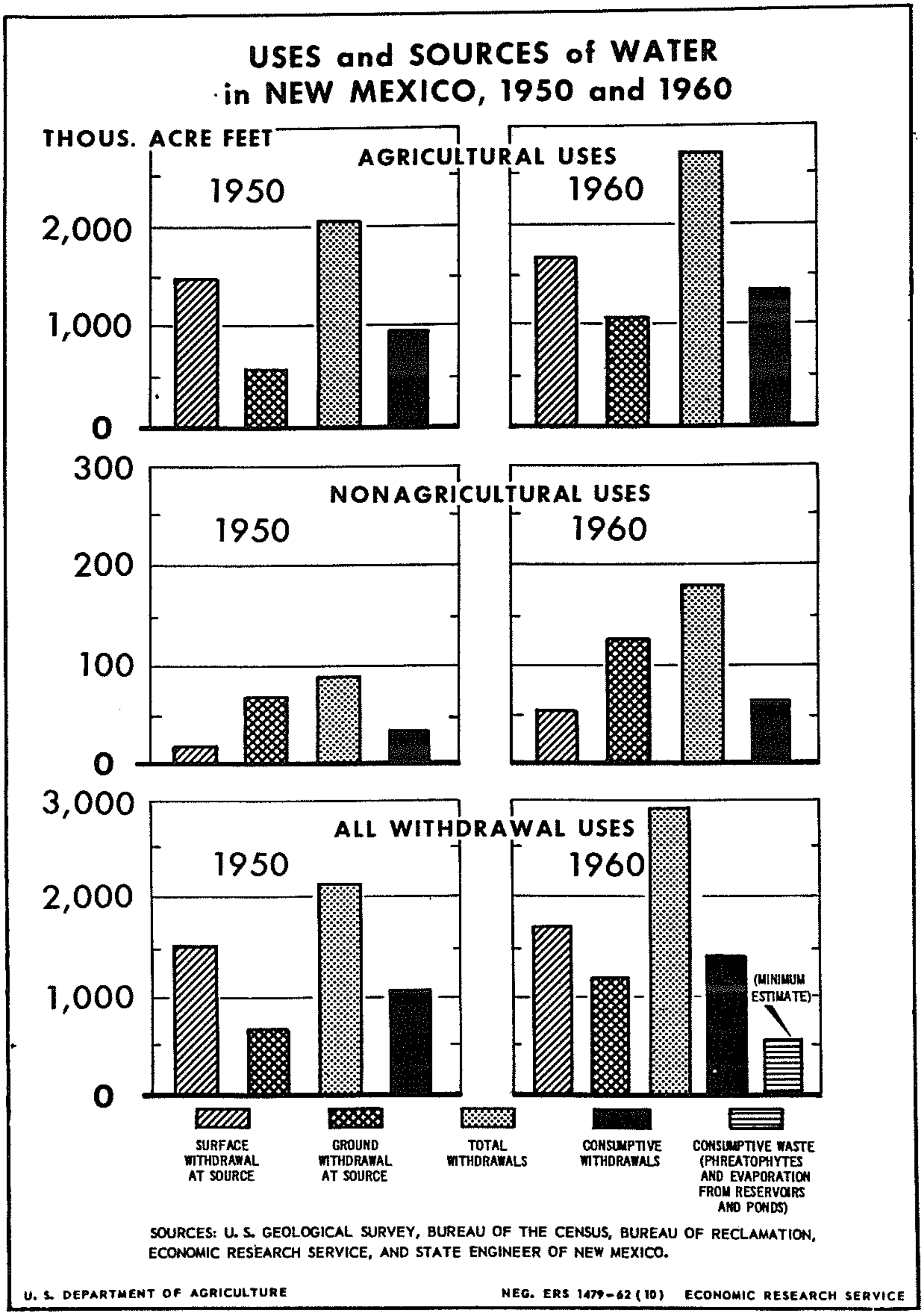
2/ Excludes at least 350 thousand acre feet of reservoir-pond evaporation and 200 thousand acre feet of consumptive waste.

3/ Includes about 5 thousand acre feet for livestock and rural domestic use, with the remaining 1,652 thousand acre feet for irrigation, 622 thousand acre feet of which is lost in conveyance.

4/ Includes about 25 thousand acre feet for livestock and rural domestic use, with the remaining 1,054 thousand acre feet for irrigation, of which 19 thousand acre feet is lost in conveyance.

5/ Includes about 16 thousand acre feet for livestock and rural domestic use, with the remaining 1,327 thousand acre feet for irrigation.

6/ About 64 percent if based on actual farm delivery.


USES and SOURCES of WATER
in NEW MEXICO, 1950 and 1960
THOUS. ACRE FEET
AGRICULTURAL USES
1950
1960
2,000
1,000
0
300
NONAGRICULTURAL USES
200
100
3,000
ALL WITHDRAWAL USES
(MINIMUM ESTIMATE)
SURFACE WITHDRAWAL AT SOURCE
GROUND WITHDRAWAL AT SOURCE
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SOURCES: U. S. GEOLOGICAL SURVEY, BUREAU OF THE CENSUS, BUREAU OF RECLAMATION, ECONOMIC RESEARCH SERVICE, AND STATE ENGINEER OF NEW MEXICO.
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Figure 4

The crude calculations just given explain current pressures in the State and elsewhere for allocating scarce water to industry in preference to agriculture, even to the extent of modifying historic prior appropriation and other legal doctrines. We are not concerned here with the legal or equity aspects of reallocating water rights, except to note that a more promising alternative for increasing nonagricultural allocations may well lie in basinwide programs for evaporation suppression, phreatophyte elimination, and seepage reduction. For while nonagricultural diversions (in the above example) may effectively total 1.5 acre feet for every acre foot denied agriculture, they effectively total 3.1 acre feet for every acre-foot reduction in consumptive waste. The simultaneous possiblity in New Mexico for increased agricultural diversion of around 2 acre feet per acre-foot reduction in consumptive waste would seem to set the stage for cooperative water conservation programs, the costs of which might be shared in proportion to the benefits observed to accrue to appropriators not fully supplied under preprogram conditions. Data on economic values of water in different uses could thus be useful in formulating programs for economic reallocation through water conservation as well as argument for discouraging low-value but beneficial uses. Such programs would be similar in concept to situations where appropriated water can be reallocated on a seasonal basis under the various lease, rental, and other arrangements as those studied by Anderson (3) in Colorado.

Macroeconomic planning aspects

From an economic standpoint, future aspects of water allocation can be discussed in terms of three fairly distinct approaches to estimating water use patterns that might or should prevail at a given date. The first alternative is the prediction of future water uses and the future extent of water development activities from historical data, either directly or indirectly through preliminary prediction of such related variables as population growth, land use trends, industrial and agricultural output, and so on. The predictions may or may not be limited to extrapolation of historical trends and relationships. The essential point is that no judgments are made as to the economic desirability of the water use pattern emerging from the analysis. Emphasis is on description rather than planning keyed to predetermined policy objectives. However, the predictive approach has an important economic implication for policy-based analyses. It can aid evaluation of the possible benefits of policy changes, in that a benchmark is provided for evaluating the potential economic benefits of not allowing matters to take their own course.

A second approach is to determine a water-use pattern or patterns consistent with predetermined levels of population, industrial output, agricultural output, general land use patterns, or other factors, some of which may have been assumed (as population and crop yields) and others calculated as necessary for achieving given levels of domestic or foreign consumption. Resulting water use or other resource use patterns are commonly called "projections," to emphasize their lesser reliance on statistical prediction than the foregoing historical approach. Their main application to resource allocation is for suggesting policies and programs that might be instrumental in achieving the given levels of consumption, by encouraging or otherwise facilitating the indicated changes in present resource use.

The best example of an essentially projective analysis of land and water allocation is the familiar work of the Senate Select Committee on National Water Resources in all major water resource regions of the United States (22). Comprehensive planning to meet projected consumption needs for 1980, under the Committee's medium U. S. population assumption of 244 million, was considered essential in the Upper Missouri, Rio Grande-Pecos, Colorado, South Pacific and Great Basin water resource regions, thus verifying that the Nation's water allocation problems come into sharpest focus in the southwestern States.

For the country as a whole, the Committee projected total annual water withdrawals of 626 million acre feet by 1980. This is 86 percent over the 337 million acre feet of withdrawals the Committee calculated for its base year of 1954, and a virtual doubling of the 303 million acre feet estimated by the Geological Survey to have been withdrawn in 1960 (table 1). The apparent decline in water withdrawals between 1954 and 1960 is largely explained by the per-acre irrigation withdrawal rates of the Senate Select Committee analysis being based on considerations of adequacy rather than on actual use, although future gains in the efficiency of water conveyance and application expected by the Committee would tend to equalize its future withdrawal rates with the current rates of the Geological Survey. This comparison is not made to question either the Committee's projective findings or the Geological Survey's current estimates, but to point up the sensitivity of any national water allocation study to assumptions and predictions involving irrigation, which will remain the primary consumptive user of water in the United States well beyond 1980.

An example of a resource allocation study that combines historical prediction with the projective approach taken by the Senate Select Committee is given by a recent report (20) of the Department of Agriculture's Land and Water Policy Committee. This Committee assumed a U. S. population of 261 million for 1980, which coincides with the average of the Senate Select Committee's medium (244 million) and high (278 million) population assumptions for the same year. Shifts in land use (including a 51 million acre net reduction in total cropland) needed to meet specified crop, pasture, livestock and timber demands corresponding to export and domestic consumption requirements were estimated by first dividing per-acre yields into the requirements to obtain needed acreages devoted to crop, livestock, and timber production, and then comparing the computed acreages with the present use of land for these purposes.[9/]

Estimates of future water use were derived more directly from historical data. For example, trends since 1940 in per-acre rates of water withdrawal and consumption for irrigation were analyzed separately for withdrawals from streams and ground water. Between 1940 and 1960, withdrawals averaged 3.87 acre feet per acre irrigated from surface sources and 2.00 acre feet for ground water irrigation, with no consistent upward or downward trend in the rates in either case. As shown in figure 2, however, ground water irrigation is know to have increased steadily, and now amounts to about 45 percent of the total acreage irrigated in the United States, compared with 17 percent around 1940. Statistical extrapolation of this trend, qualified by limitations on the remaining extent and capacity of aquifers, indicated that about 50 percent of the total acreage irrigated in 1980 would be served from ground water, with a corresponding average surface-ground withdrawal rate in 1980 of 2.93 acre feet per acre (3.05 acre feet per acre in 1960). Total irrigation withdrawals in 1980 were thus estimated conservatively at 124 million acre feet for 42.4 million acres of land expected to be irrigated as determined from extrapolated Census trends. This estimate and time-series-derived minor agricultural and nonagricultural estimates for 1980 are shown in figure 1. Total estimated withdrawals of 670 million acre feet determined from statistical projection are about 7 percent over the Senate Select Committee's medium estimate for 1980 of 626 million acre feet.

A third economic approach to formulating future water allocation policies or programs requires that planning be keyed to a quantitatively defined economic objective, such as

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9/ For more detail on the conceptual basis of the Land and Water Policy Committee's land use projections, see Harry A. Steele and Norman E. Landgren. Demands for land for agriculture: Past, Present and Future. Address before Homestead Centennial Symposium, Lincoln, Nebraska, June 12, 1962. (To be published in Symposium Proceedings).

the minimization of costs or the maximization of net benefits, subject to specified limitations on the resources available for planning, the productivity of these resources in creating benefits by alternative measures, the comparative costs of each measure, and given institutional conditions. Solutions to planning problems of this nature can be obtained through "equilibrium" types of analysis for which mathematical programming techniques have been found to be quite efficient. Possibilities for planning water development and allocation with programming techniques as well as the more classic methods of economic analysis are best illustrated by the research conducted in the Harvard Water Program (10). The major difficulty in applying such methods is the lack of empirical data necessary to establish continuous functional relationships relevant to actual planning situations.

A variant of this approach, similar in concept to programming for maximum benefits, but where basic data collection can be flexible with respect to data availability and available planning resources, involves comparative analysis of two or more specified allocation patterns with respect to maximum income or minimum costs. The selected pattern or program is considered optimum in the sense of yielding more benefits or involving less costs than any of the others. In varying degree this approach characterizes most current water resource planning activities. As refinements are introduced in the way of the number and empirical detail of alternative patterns evaluated, the approach becomes more synonymous with programming or other formal types of analyses based on precise mathematical relationships. In essence, it can identify points on a "benefit surface" that would at least be feasible and highly economic if not the precise optimum solutions that might result from programming. Moreover, such feasible solutions might be considered analogous to "program activities" and programmed themselves to identify an intermediate optimum solution.

The New Mexico-Resources for the Future evaluation of water allocation in the San Juan and Rio Grande Basins (29) is an excellent example of a macroeconomic study of alternative water use patterns based on the income-generation effects of different allocations of water to various sectors of a State's economy. This research examines the impact on State income of two levels of interbasin water diversion (110 and 235 thousand acre feet from the San Juan to the Rio Grande Basin), six allocations of the diverted and remaining unappropriated water to irrigation, six allocations to industry, and three allocations to recreation through fish and wildlife-habitat development.

Conceptually, each of the eight postulated patterns of use accommodating these different allocations represented an alternative program for water development in the two basins, with 1954 as the base year and 1975 as the target year. It is unnecessary to examine here the specific values assigned to various water uses or the aggregate effects of the various allocation patterns on State income. Though none of the study's conclusions are questioned they aid in focusing on current water allocation problems needing additional research, particularly problems for which microeconomic methods of analysis and welfare economics principles may be applicable.

Planning With Microeconomic Techniques

A conclusion of the San Juan-Rio Grande study with far-reaching implications for agriculture in New Mexico and other arid States relates to the minimal computed values of water if used for irrigation rather than for industrial and recreational purposes, even with recreation evaluated only for its secondary effects on the regional economy. An estimated contribution in one of the better agricultural patterns of only $50 per acre-foot to the State's gross product from additional water use in irrigation compared with estimated contributions of $250 from recreational use, and up to $3,500 for industrial use. The answer to the question of which economic activities should be accelerated to maximize State income is fairly obvious, assuming no substantial variations in such average values as different allocations were made. The study in question properly considered possible ranges in per-unit values of water in each use by its analysis of the eight alternative allocation patterns.

A related conclusion concerned the dependence of industrial values of water on the actual existence of the industries in the target year. If the implied expansion of industry or other potentially high-value sectors cannot be assumed unequivocally, the selection of optimum patterns can be appropriately qualified in view of the most probable rates of expansion. This question was created by not emphasizing the effects of the optimum pattern to the exclusion of other patterns possibly more consistent with current rates of industrial expansion and recreation development.

It may be useful at this point to review how an optimum water allocation can be determined microeconomically; that is, from a schedule of total supply costs and schedules of demand (or average benefits) per unit of water that might be allocated to, say, industrial use versus irrigation use. Such demand schedules could be derived from a series of allocation models as those set up in the San Juan-Rio Grande study or perhaps from detailed field surveys. They would likely reflect diminishing returns to water used in both irrigation and industrial production and, if included in a planning framework, could be discounted for uncertainty to account for different probabilities of given allocations actually being demanded at different dates.

The economic theory underlying water allocation in a multiple-use framework is fairly straightforward and derives from multiple-product or multimarket monopolistic firm theory. Notable contributions are those of Castle (27), Ciriacy-Wantrup (26), Regan (26) (28), and Timmons (18) (26). Where resources are nonlimiting, the necessary theoretical condition for maximization of aggregate net benefits is that the incremental (marginal) total costs of development be equated with the incremental aggregate benefits for all uses combined, and that the incremental benefits from allocation to all uses also be equated. Where resources such as capital benefits are maximized by allocating the newly-supplied water to the alternative use or combination of uses in which incremental benefits are greatest; that is, in a manner that minimizes the rate of decline in aggregate incremental benefits as greater total quantities of water are supplied.

While the economic literature is replete with discussion and elaboration of these principles, little attention is given the mechanics of their application in concrete situations, with resulting overestimation of their complexity by project planners. Appendix I gives an example of how optimum total capacity for a reservoir or an optimum interbasin diversion of water might be determined where the water can be used economically in either industry or irrigation.[10] Only the relations between (1) total supply and costs; (2) average industry values per acre-foot; and (3) average irrigation values per acre-foot are essential for this determination. In view of present New Mexico conditions, note the higher average and incremental values for initial increments allocated to industry, but a more rapid decline in these values than in the irrigation values as allocations are increased (equations 3, 5, 8, and 9). Also, the procedure simultaneously considers the allocation of water and water-supply costs between the alternative uses, recognizing the inter-relatedness of water allocation and cost allocation in project planning.

10/ The mathematics of solving joint production problems of this nature are outlined in Tintner (19, ch. 18). The graphics of optimum allocation between competing uses involve the classic theory of price discrimination in separate markets as given in standard texts; see Weintraub (25, ch. 14). However, the difficulty of generalizing to more than several alternative water uses limits application of graphical methods, which in any case rely on mathematical functions.

An additional note on the San Juan-Rio Grande study involves the method of estimating recreational values of water. The primary value of water for recreation was considered indeterminate, while the primary values of water for irrigation and industrial use were estimated as the net returns to farmers from irrigation water use or the net returns of water use in industry. The assumption followed from observations that recreation in the study area is not ordinarily a salable commodity in itself. This somewhat implies that recreational water use could be evaluated as completely industrial and irrigation uses in cases where the provision of water-based recreational services was or could be made a function of private enterprise. But by focusing on the secondary as well as primary values of competing water uses, a major contribution of the San Juan-Rio Grande study may well be its indication that the primary values of water for recreation are academic in cases where its secondary values alone (per unit) substantially exceed the more completely determined values for competing uses (over the range of feasible different allocations). In other words, the difficult evaluation of primary recreation or other intangible values might best be deferred until the more easily measured values had been determined, and then attempted only if the allocation decision might otherwise hinge on partially-estimated recreation values that appeared unduly low or were marginal.

The increasing general emphasis on recreation in land and water resource development in all parts of the country, with accompanying difficult problems of benefit evaluation, raises a significant question on the applicability of conventional methods of water allocation to planning projects that provide recreational benefits.[11/]

Welfare Principles and Allocation Techniques

The difficulty of measuring recreation and other intangible benefits in the same way as other project benefits suggests that the results of benefit-cost analyses may be so qualified by the intangibles as to be of questionable value in the decision-making process. This implies that future water allocation decisions may need a stronger economic footing than the monetary benefits that could be estimated for any project purpose, and that it may be useful to fall back on the criteria that guided water resources development before benefit-cost procedures become highly refined. For example,

11/ See the general report (14) and a separate report on water recreation (21) of the Outdoor Recreation Resources Review Commission. See Clawson (4) for a review of evaluation problems and techniques.

one must admit that while prior appropriation and beneficial use concepts may not result in the same water use patterns as those resulting from the interplay of competitive market forces, they have been considered necessary for economic development in many areas--suggesting that institutional and comparative-value concepts of water allocation stem from a common philosophy, somewhat akin to the idea of the "the greatest good for the greatest number."

Translating this rather nebulous objective into clear form for guiding water allocation policy is difficult, but one approach would pose the question of how satisfied the opposing potential users might be made and what price they would be willing to pay for recreational or other water in order that project costs could be recovered. This states the problem a little differently than conventional studies, which frequently accept costs or prices actually paid as indicators of recreational benefits, with the result that benefits can be easily underestimated but not likely overestimated.

These points all indicate the need for allocation techniques that incorporate the two objectives of maximum satisfaction and equitable price from all uses and for all users of water--in other words, a goal of making all users feel as well off as possible without making any potential user feel worse off. The analytical framework for objectively pursuing this goal is given by the theory of "welfare economics," in which monetary benefits and costs would play an important but not all-important role in determining the particular allocation of water among different uses that would maximize the satisfaction of the potential users.12/

The core of a welfare approach to water allocation would be a series of utility (indifference) functions, each showing the dependence of a potential user's satisfaction on various combinations of all commodities or services he might consume, including such services as recreational use of leisure time. Given the costs of producing various quantities of goods and services and consumer incomes, it would then be possible to determine the quantities of each commodity or service purchased by each consumer in order to maximize his level of satisfaction, as well as the market prices paid for each commodity or service.

12/ Basic references on modern welfare theory include Reder (15) and Little (9). In addition see Weintraub (25) for a welfare-based analysis of alternative cost allocation policies appropriate to water allocation as well as other production problems. Welfare principles for water allocation have been discussed previously and discarded, but largely on practical rather than theoretical grounds; for example, Castle (27).

The logic and mechanics of a welfare approach to water allocation can be made more apparent with a simple example. Suppose an irrigation farmer's general satisfaction with his lot in life could be expressed as an index dependent on two factors: (1) A feeling of income security provided by irrigating; and (2) an additional element of satisfaction derived from his using water for recreational as well as irrigation purposes. In other words, he would be willing to sacrifice some of the incomes and satisfactions from irrigation if they were outweighed by increased satisfactions from recreational water use. This irrigation farmer would have different ideas on the best use of a reservoir site than one with no apparent interest in water-based recreation, and would be interested in irrigation as a source of revenue for building on recreational storage capacity as well as a source of total disposable income to spend on both purposes.

The information essential for planning a reservoir on this basis would include: (1) The functional relationship (or utility function) between irrigation and recreation capacity, showing the incremental rate at which the farmer would substitute one for the other in maintaining the same level of utility or total satisfaction; (2) the usual functional relation between reservoir capacity and costs, regardless of how the capacity were allocated between competing uses; and (3) the usual functional relation between net farm revenues from irrigation and irriation water use. The latter revenues are the income from which the farmer must recover reservoir costs, assuming personal consumption by the farmer of all capacity allocations to recreational use.

Appendix II illustrates how optimum total storage capacity can respective allocations to irrigation and recreational water use would be determined in view of maximizing a given utility index instead of net revenues. Note that it is not necessary to estimate the monetary benefits of recreation to arrive at a design that is optimum in a maximum welfare sense as well as economically and financially feasible in the conventional sense.

The method outlined could be workably generalized, although computing requirements would multiply rapidly with the number of competing water uses and users considered. Nevertheless, increasing competition for water for productive and recreational uses, combined with continued improvements in computer technology, indicates that practical considerations will not limit the application of such methods to the extent they have in the past. A corresponding implication for future water resources planning in New Mexico and elsewhere is that utilizing all appropriate and theoretically-consistent water allocation techniques in arriving at water development decisions will be of great benefit.

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APPENDIX I

Benefit-Cost Analysis of Optimum Storage Capacity

Givens are: (1) Irrigation, i, and industry, m, as alternative uses (and users) of total storage capacity; (2) a maximum of net benefits from the two uses combined as the planning objective; and (3) the assumption that costs will be allocated to each of the two uses in proportion to their share of gross benefits. The planning problem is to determine how to maximize aggregate net benefits--by determining the optimum total capacity to develop and the optimum allocation of this capacity between the two uses, and then to distribute costs between the two uses and indicate the resulting distribution of maximum net benefits. Only equations (3), (5), and (10a) need to be determined in pre-planning investigations. Storage capacities, benefits, and costs may be defined in any convenient units.

<u>Total storage capacity</u> (S_t) as sum of capacity for irrigation (S_i) and industry (S_m):

$S_t = S_i + S_m$ (1)

<u>Total benefits</u> (B_t) as sum of benefits for irrigation (B_i) and industry (B_m):

$B_i = S_i D_i = 11 S_i - 0.50 S_i^2$, where (2)

$D_i = 11 - 0.50 S_i$ (average benefit per unit irrigation allocation) (3)

$B_m = S_m D_m = 22 S_m - S_m^2$, where (4)

$D_m = 22 - S_m$ (average benefit per unit industry allocation) (5)

$B_t = B_i + B_m = 11 S_i + 22 S_m - 1.50 S_i^2 - S_m^2$ (6)

$D_t = (B_i + B_m) / S_t$ (average benefit per unit total capacity) (7)

<u>Incremental total benefits</u> from irrigation (B_i ') and industry (B_m ') allocations, where B_i ' and B_m ' are first derivatives of (6) with respect to S_i and then S_m:

$B_i ' = 11 - S_i$; $B_m ' = 22 - 2 S_m$ (8)(9)

<u>Total costs</u> (C_t) in terms of total developed storage (S_t) as allocated to irrigation (S_i) and industry (S_m):

$C_t = 2 S_t + 0.02 S_t^2$, which from (1) is expanded to . (10a)

$C_t = 2 S_i + 2 S_m + 0.02 S_i^2 + 0.04 S_i S_m + 0.02 S_m^2$ (10b)

<u>Distributed costs</u> to irrigation (C_i) and industry (C_m), proportionately in relation to benefits:

$C_i = (B_i / B_t) C_t$; $100 (B_i / B_t) =$ pct. costs to irrigation (11)

$C_m = (B_m / B_t) C_t$; $100 (B_m / B_t) =$ pct. costs to industry (12)

Average costs ($\overline{C}$) on basis of cost distribution and allocated capacities:

$$\overline{C}_t = C_t \ / \ (S_i + S_m) \qquad (13)$$

$$\overline{C}_i = C_i \ / \ S_i \ ; \ \overline{C} = C_m \ / \ S_m \qquad (14) \ (15)$$

Aggregate net benefits, from total benefits in (6) less total costs in (10b):

$$N_t = 9 \ S_i + 20 \ S_m - 0.52 \ S_i^2 - 1.02 \ S_m^2 - 0.04 \ S_i \ S_m \qquad (16)$$

Net benefit distribution from (2) and (11), and (4) and (12):

$$N_i = B_i - C_i \ ; \ N_m = B_m - C_m \qquad (17) \ (18)$$

Maximization of aggregate net benefits in (16) by first computing incremental net benefits to irrigation and industry where N_i' and N_m' as incremental net benefits are partial derivatives of (16) with respect to irrigation and then industry:

$$N_i' = 9 - 1.04 \ S_i - 0.04 \ S_m \qquad (19)$$

$$N_m' = 20 - 2.04 \ S_m - 0.04 \ S_i \qquad (20)$$

Determination of optimum allocations to irrigation and industry by increasing respective allocations until incremental net benefits are zero. Setting (19) and (20) equal to zero gives a pair of simultaneous equations:

$$1.04 \ S_i + 0.04 \ S_m = 9 \qquad (21)$$

$$0.04 \ S_i + 2.04 \ S_m = 20 \qquad (22)$$

Solutions of (21) and (22) are $S_i = 8.29$ units of optimum storage for irrigation; $S_m = 9.64$ units of optimum storage for industry, and $S_t = 17.93$ units of total developed storage. By substitution total benefits (B_t) are 175.96 from (6), total costs (C_t) are 42.27 from (10) and aggregate net benefits (N_t) are a maximum of 133.69 from (16). Remaining data are summarized in Table 3.

Table 3. Benefits and costs of optimum allocation of storage capacity to irrigation and industry

Items	Equation references or notes	Competing uses: Irrigation	Competing uses: Industry	Total or averages
1. Developed and allocated storage capacity	21, 22, 1	8.29	9.64	17.93
2. Total benefits from storage	2, 4, 6	56.81	119.15	175.96
3. Percent total benefits (and costs)	11, 12	32.29	67.71	100.00
4. Total benefits per unit capacity	3, 5, 7	6.86	12.36	9.81
5. Incremental total benefits	8, 9	2.72	2.72	2.72
6. Incremental total costs	1/ 10	2.72	2.72	2.72
7. Total costs per unit capacity	2/	1.65	2.70	2.35
8. Total costs of storage	10, 11, 12	13.65	28.62	42.27
9. Total benefits per unit costs	3/	4.16	4.16	4.16
10. Net benefits of storage	4/ 16, 17, 18	43.16	90.53	133.69
11. Net benefits per unit capacity	5/	5.21	9.66	7.46
12. Incremental net benefits	19, 20	0	0	0

1/ Differentiate 10 with respect to S_t, S_i, and S_m
2/ Divide item 8 by item 1.
3/ Divide item 2 by item 8.
4/ Alternatively, item 2 less item 8.
5/ Divide item 10 by item 1.

APPENDIX II

Welfare Analysis of Optimum Storage Capacity

Givens are: (1) Irrigation, i, and recreation, r, as competitive uses of total storage capacity for a given potential user of both, whose utility or indifference function is known; (2) an objective of maximizing the utility index through an optimum allocation of capacity to the two uses; (3) the assumption that all costs must be recovered through the income-creating effects of irrigation alone; and (4) that the user will charge off irrigation and recreation capacity costs at the same average rate (price). The planning problem is to determine how to maximize the utility index--by determining the optimum total capacity to develop and the optimum allocation of this capacity between irrigation and recreation, and then to distribute costs between the two uses. Only equations (1), (5), and (8) need to be determined in pre-planning investigations (eqs. 5 and 8 are from Appendix I). Storage capacity, revenues, and costs may be defined in any convenient units.

<u>Utility function</u> in terms of storage capacity for irrigation (S_i) and recreation (S_r):

$$U = S_i \, S_r \qquad (1)$$

<u>Marginal rate of substitution</u> in consumption of recreation capacity for irrigation capacity:

$$U'_r \,/\, U'_i = S_i \,/\, S_r \text{, where } U'_r \text{ and } U'_i \text{ are marginal utilities of recreation and irrigation} \qquad (2)$$

<u>Cost-consumption relation</u> between recreation and irrigation under the assumption of equal average costs ($\overline{C}_r$ and $\overline{C}_i$) per unit capacity (see assumption 4 in par. 1):

$$(S_i \,/\, S_r) : (\overline{C}_r \,/\, \overline{C}_i) = 1 \text{ ; so} \qquad (3)$$

$$S_r = S_i \text{ (all capacities will be equally divided to } S_i \text{ and } S_r\text{)} \qquad (4)$$

<u>Total costs (expenditures on irrigation and recreation)</u> in terms of total developed storage (S_t) and allocations to irrigation (S_i) and recreation (S_r):

$$C_t = 2\,S_t + 0.02\,S_t^2 = 2(S_i + S_r) + 0.02\,(S_i + S_r)^2 \qquad (5)$$

$$C_t = 4\,S_i + 0.08\,S_i^2 \text{ , since from (4), } S_r = S_i \text{ and } S_t = 2\,S_i \qquad (6)$$

<u>Total revenues</u> from irrigation available for recovering storage costs, whether storage is for irrigation or recreation:

$$B_t = B_i = S_i\,\overline{B}_i = 11\,S_i - 0.50\,S_i^2 \text{, where} \qquad (7)$$

$$\overline{B}_i = 11 - 0.50\,S_i \text{ (average revenue per unit irrigation capacity)} \qquad (8)$$

Maximization of utility index by maximizing expenditures on irrigation and recreation, provided revenues from irrigation production are sufficient to recover these expenditures. Since total costs and total revenues are now in terms of irrigation capacity (S_i), optimum S_i is solved for by equating (6) and (7):

$$4\ S_i + 0.08\ S_i^2 = 11\ S_i - 0.50\ S_i^2 \tag{9}$$

$$-0.58\ S_i^2 + 7\ S_i = 0;\ S_i = 12.06, \text{ and } S_r = 12.06 \text{ from (4)} \tag{10}$$

Maximum utility index is 145.44 from (1) and optimum equal allocations of 12.06 units to irrigation and recreation as determined from (4) and (10). Optimum total capacity is 24.12 units. Total revenues from irrigation and total costs of irrigation and recreation combined are 59.94, from (6), (7), and (10). Average costs per unit capacity are 2.49; they are assumed from par. 1 to be equal for irrigation and recreation. Allocated costs to irrigation and recreation are equal at 29.97. Net revenues from irrigation are also 29.97 but are all spent to obtain recreational capacity. This equilibrium is point A on figure 5. Point B is a suboptimal welfare position resulting from simple maximization of irrigation net revenues, also subject to the condition that total capacity be allocated equally to irrigation and recreation.

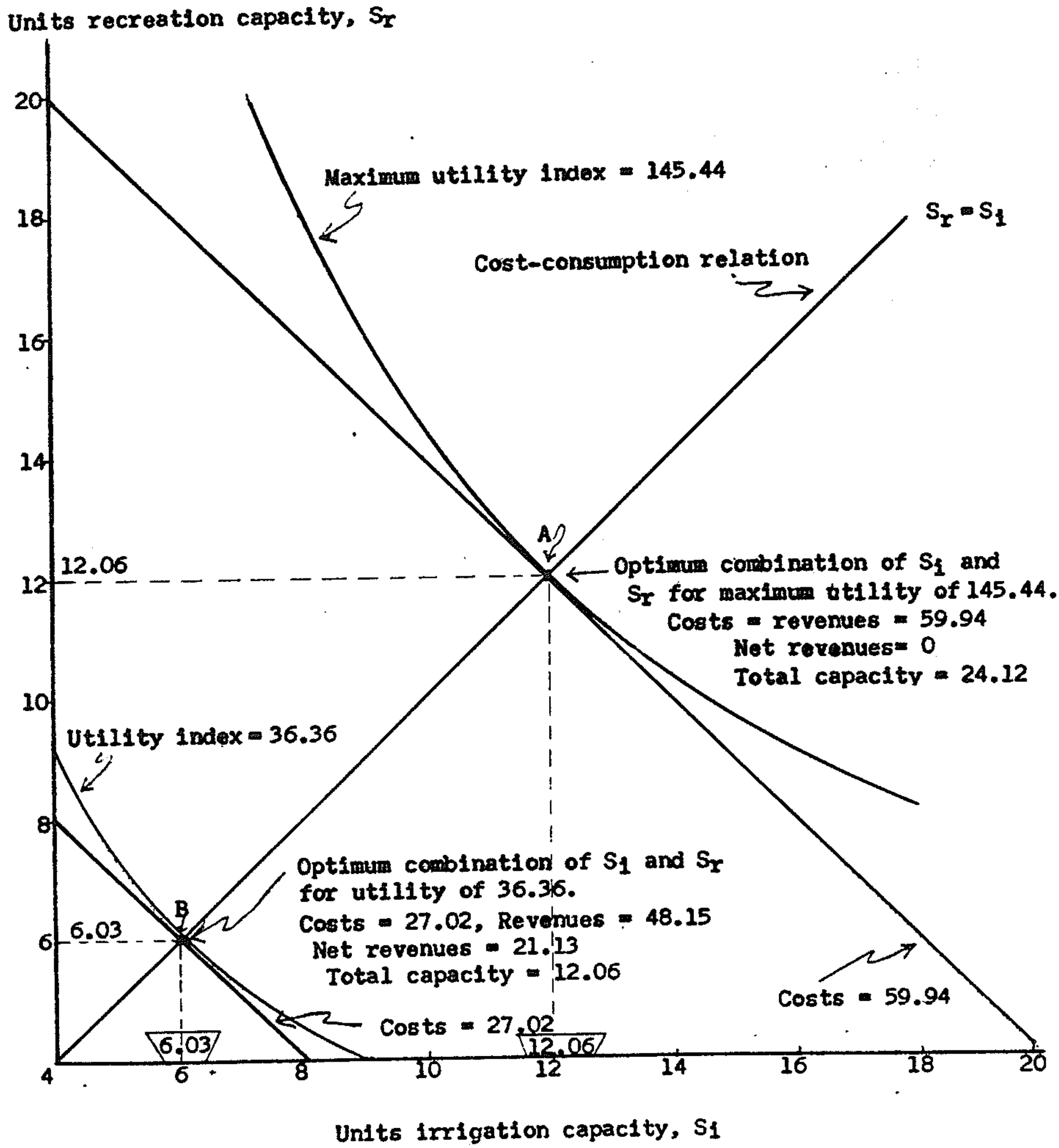

Figure 5. Determining optimum combination of irrigation and recreation storage capacity to maximize a utility index