FOR DISCUSSION ONLY

WORKINGPAPER

NUMBER 4

TITLE PROCEDURES FOR PROJECTING RURAL WATER USE IN THE CHESAPEAKE BAY AREA

AUTHOR MARK A. HELMAN

DATE March 1976

NRE ECONOMIC RESEARCH SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE

WORKING PAPER SERIES

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ABSTRACT

This report documents the procedure and results of the projection of water use in the Chesapeake Bay Study Area, an area which encompasses fifty-six counties from the states of Delaware, Maryland, and Virginia. The study was done for the Baltimore District Corps of Engineers, which is formulating long-term water and land management plans for the area, and it follows their existing conditions report.

Aspects of the water demand considered were agricultural and rural domestic water needs. In the process of formulating agricultural demand, projections were made of crop production, from which the Soil Conservation Service estimated irrigation demands, and of livestock production. Average size farms and farm population were estimated in the projection of rural domestic demand.

A Spillman type procedure was used for most of the projections, and OBERS state projections were used wherever possible as control totals. The counties were grouped into fifteen subareas, and projections were made at the subarea level.

KEY WORDS: rural water use, domestic, agricultural, projections, Chesapeake Bay, Spillman

PROCEDURES FOR PROJECTING RURAL WATER USE IN THE CHESAPEAKE BAY AREA

by

Mark A. Helman*

INTRODUCTION

The United States Army Corps of Engineers was directed by Congress to undertake a comprehensive study of the Chesapeake Bay Area for the purposes of understanding its hydrology and constructing a physical model to study solutions to its problems. As part of that study the Economic Research Service was responsible for developing methodology to estimate future rural water use in the study area. This report documents the projection procedures used in the Agricultural Water Supply Appendix and their results.

The Agricultural Water Supply Appendix to the Chesapeake Bay Study[1/] is part of a larger effort whose objectives, as stated in the Chesapeake Bay Plan of Study,[2/] were to: a. assess the existing physical, chemical, biological, economic, and environmental conditions of Chesapeake Bay and its water resources; b. project the future water resources needs of

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1/ Chesapeake Bay Future Conditions Report, Appendix 6, Agricultural Water Supply, January 1976.

2/ The Chesapeake Bay Plan of Study, Dept. of the Army, Corps of Engineers, June 1970.

Chesapeake Bay to the year 2020; and c. identify the additional studies to include hydraulic model tests that are needed to formulate a water resources management program for the Bay.

The Chesapeake Bay Existing Conditions Report, published in 1973, met the first objective of the study by presenting a detailed inventory and documentation of the existing condition of Chesapeake Bay and its water resources.[3/]

The Future Conditions Report will satisfy the last two objectives of the study.[4/] It will present the demands to be placed on resources through the year 2020, assess the ability of the resources to meet future demands, and identify additional studies required to develop a management plan for the Chesapeake Bay.

The purpose of the Appendix on Agricultural Water Supply was to: a. appraise the historical and existing rural water use by subarea; b. forecast future agricultural activity in the Chesapeake Bay Area; c. estimate future water use resulting from such activity; d. determine future water needs of rural nonfarm residents dependent upon wells; e. identify possible problems and conflicts resulting from projected agricultural production and water use; and f. assess means to satisfy future needs.

SCOPE

The study area encompassed fifty-six counties in the Chesapeake Bay area located in the States of Delaware, Maryland, and Virginia.

3/ Chesapeake Bay Existing Conditions Report, December 1973.
4/ Ibid, footnote 2/, page 1.

The counties were aggregated into fourteen subarea groupings of counties which followed the component State's planning districts. As shown in Table 1 and Figure 1, five of the subareas were in Maryland and eight were in Virginia. Delaware constituted a subarea by itself. Because the Appendix addressed rural water supply needs, water use in major cities such as Baltimore and Washington was not included. The analysis covered rural domestic water use, both on farms and by rural residents not served by municipal systems, livestock consumption, and irrigation water use. In the estimation of irrigation and livestock, water demand projections were made separately for different types of agricultural production, including 16 selected crops and 8 types of livestock, poultry, and dairy products. Farm population was projected to estimate domestic water demand.

Water use in the study area was projected to target years of 1980, 2000, and 2020, based upon historical data extending from 1949 to 1970. Among the historical data sources were the U.S. censuses of agriculture and population projections of aggregated agricultural production by OBERS[5/] and selected demographic projections furnished by the Baltimore District, Corps of Engineers.

General Assumptions and Methodology

This section documents assumptions of a general nature which we held in the analysis, and the methodology which was applied to all agricultural projections.

5/ Formerly Office of Business Economics of the U.S. Department of Commerce and the Economic Research Service.

TABLE 1

CHESAPEAKE BAY STUDY

COMPOSITION OF SUBAREAS

Subarea	County
DELAWARE	
	New Castle
	Kent
	Sussex
MARYLAND	
1.	Anne Arundel
	Baltimore
	Carroll
	Howard
	Harford
2.	Cecil
	Kent
	Queen Annes
	Caroline
	Talbot
3.	Dorchester
	Wicomico
	Somerset
	Worcester
4.	Montgomery
	Prince Georges
5.	Calvert
	Charles
	St. Marys

Subarea	County
VIRGINIA	
1.	Northampton
	Accomack
2.	Loudoun
	Fairfax
	Prince William
3.	Stafford
	King George
	Spotsylvania
4.	Hanover
	Henrico
	Chesterfield
	Dinwiddie
	Prince George
5.	Westmoreland
	Northumberland
	Richmond
	Lancaster
	Caroline
	Essex
	King & Queen
	King William
	New Kent
	Charles City
6.	York
7.	Virginia Beach
	Chesapeake City
8.	Middlesex
	Mathews
	Gloucester
	James City
	Surry
	Isle of Wight
	Southampton
	Nansemond

CHESAPEAKE BAY STUDY AREA

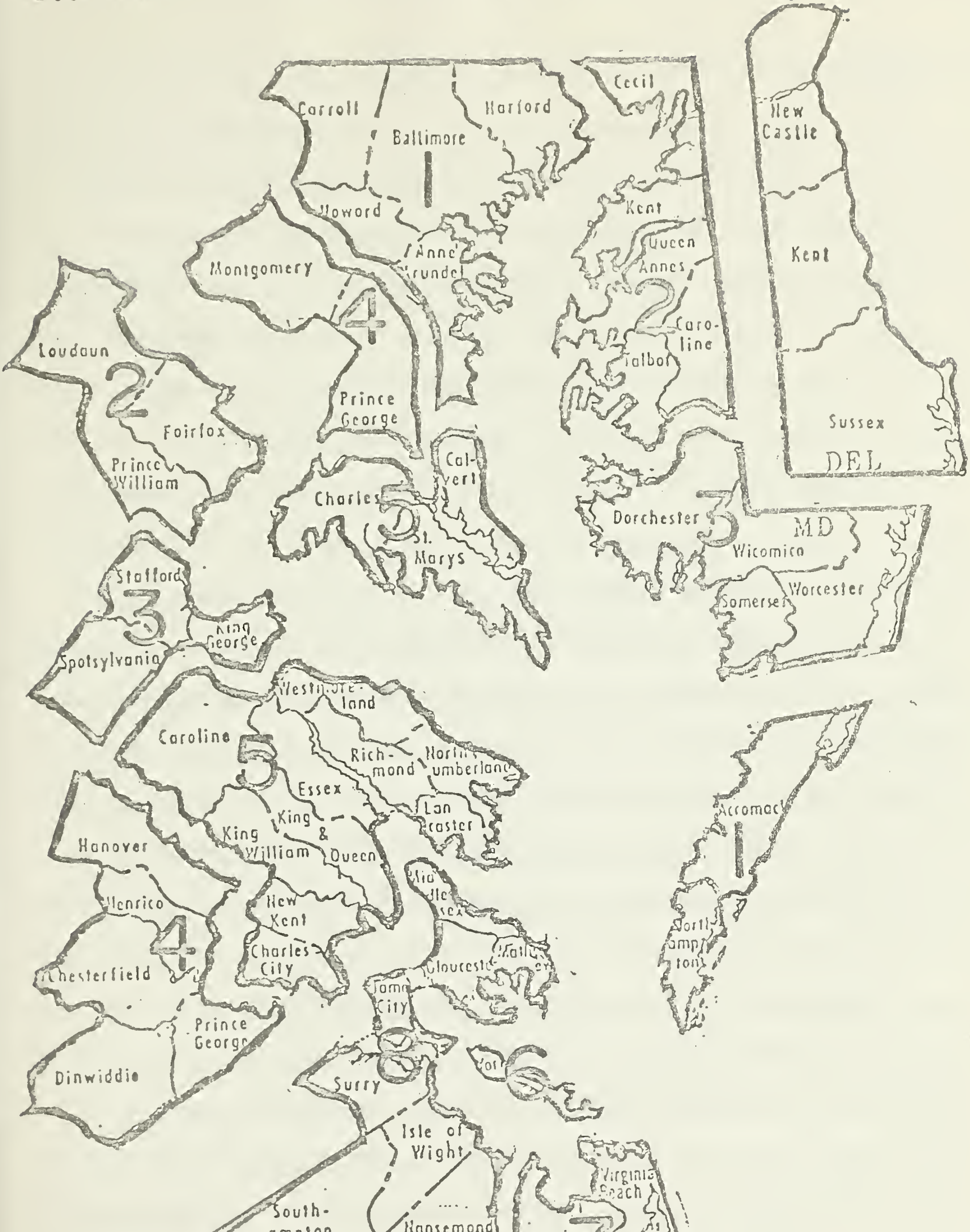


Figure 1

Methodology

The location of agricultural production is influenced by a variety of factors, each of which must be taken into account in the projection of future activity. On the demand side, projected national markets have been increasingly important with technological advances in food processing. Transportation, population, and income estimates must also be included. On the supply side, production capacity changes with both availability of resources and technological practices.

To take these factors explicitly into account, one would have to employ a relatively elaborate econometric model which specified each of the causal variables leading to a shift in agricultural production toward one area over the others. The econometric approach to agricultural projections will no doubt be increasingly refined as the period for which appropriate measures are available lengthens and more accurate causal relations are ascertained. At the present time, however, this approach is severely limited by the paucity of relevant data and information on factors which explicitly lead to changes in the distribution of output.

Even after potentially causal factors are specified, most econometric forecasting models include as an independent variable the production values from previous time periods, based on the usually high correlation of production values across time. Because of fixed investments, economic activity will rarely show a radical change from one period to the next; and many of the factors which lead to comparative advantage for an area at one time period are likely to be present in another. In agriculture, this is especially true where the physical characteristics of soils, climate, and topography seldom change from one period to the next.

Thus at the core of the method of projection used in this report is the relation of a subarea's production in one time period to its production in past periods and the response of the subarea's agriculture production to change in projected demands. Both of these elements are present in a form of regional analysis called "shift-share" analysis. A modified form of shift-share analysis was employed in the projections accomplished for the Agricultural Water Supply Appendix to the Chesapeake Bay Study.

Shift-Share Analysis. In shift-share analysis it is assumed that the change in a subarea's production from one time period to the next will vary directly with the projected change in the State's production during that period. (This assumption is particularly pertinent in the projection of agricultural production, where the State's market is of great importance in the determination of subarea production levels). If State demands are projected, the production necessary to meet these demands may be determined. The change in production at the State level, in turn, is assumed to be distributed among subareas so that each reflects the change in State production over the previous period.

In addition to the State shift is a "distributional shift," or the shift in production whereby a subarea's share of the State's production changes relative to that of other subareas. Again, this assumption is pertinent to agriculture in that many of the factors which give one subarea a comparative advantage over others -- soil conditions, climate, and topography -- may be expected to continue from one period to the next, and are reflected in a shift in production toward that region.

The change in a subarea's production is accounted for by State changes in production and shifts in the distribution of State production among the subareas.

Each of these effects is taken into account when, by the method described in this report; a subarea's share of State production is projected and applied to target date estimates of State totals. State-level production changes are allocated among the subareas in proportion to their projected shares. Subarea share changes, in turn, take into account the distributional shifts in production among the subareas.

This procedure, hereafter referred to as a "shares analysis," may be clarified by a brief graphical treatment.

First a situation is examined in which only the change in production at the State level bears upon the subarea's production. Where R_T, R_F, S_T, and S_F represent production in the subarea and State, respectively, at times T (present) and F (future),

$$R_F = \left(\frac{S_F}{S_T}\right) . R_T$$

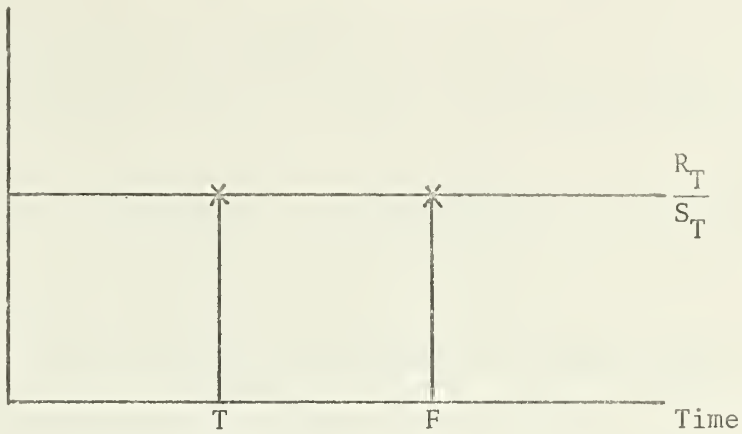
$\left(\frac{S_F}{S_T}\right)$, the State's rate of production growth, is applied to production in a subarea at the base time T. This implies that

$$R_F = \left(\frac{R_T}{S_T}\right) . S_F$$

or that the subarea's share of State production remains constant from time T to time F, as seen in Figure 2.

Figure 2.

Example of constant share



Now a distributional effect -- the shift in production toward one subarea over others -- is introduced. Let R_Δ represent the quantity a subarea produces over or under the production attributed to the national effect.

$$R_F = \left(\frac{S_F}{S_T}\right) \cdot R_T + R_\Delta$$

$$R_F = \left(\frac{R_T}{S_T}\right) \cdot S_F + \left(\frac{R_\Delta}{S_F}\right) \cdot S_F$$

which may be put in terms of State production in the future at F as

$$R_F = \left[\left(\frac{R_T}{S_T}\right) + \left(\frac{R_\Delta}{S_F}\right)\right] \cdot S_F$$

This equation, which expresses regional production as a share of the projected State production, is fundamental to the method of projection described in this report.

All subarea production estimates for the target period were derived by projecting the subarea's share -- the term in brackets -- and applying it to the published OBERS State totals. Its share at time T,

$\left(\frac{R_T}{S_T}\right)$, when multiplied by S_F, yields the regional production at F

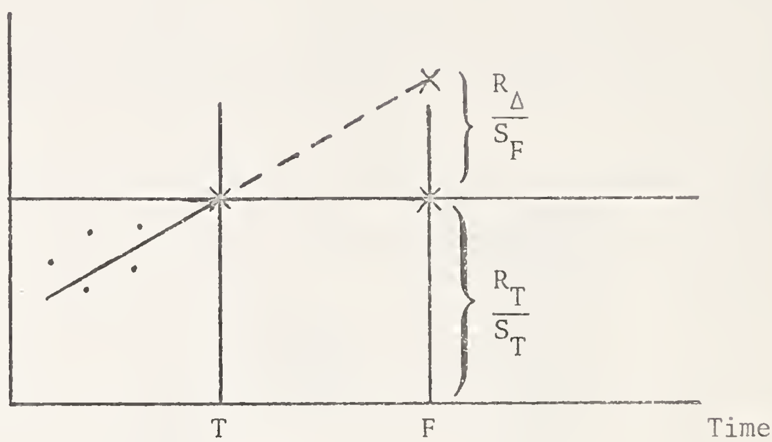
accounted for by the State effect. The change in the region's share

$\left(\frac{R_\Delta}{S_F}\right)$, when similarly multiplied, indicates the distributional

effect (see Fig.3).

Figure 3.

Example of changing share



A curvilinear projection of the subarea shares was found to be appropriate in the projection of agricultural activity. If a subarea's share increased rapidly in the historical period, it was assumed that such increases would not be sustained through the target dates, and they would gradually be toned down. Similarly, if a subarea's historical shares of State production showed rapid decreases in the historical period, it was assumed the decreases would not be sustained through the target dates.

A projection function which was well suited to these characteristics of agricultural production is the "Spillman" function. For rising subarea shares, the Spillman set limits by means of a linear regression; it estimated target date shares to approach these limits in a curvilinear fashion, thus registering less rapid increases with time. For a falling trend, the shares were assumed always to remain positive; zero was set as a limit, with the shares approaching it again in a curvilinear fashion to register less rapid decreases with time. See Appendix A for a more detailed description of the Spillman function.

The State totals which were allocated among the subareas in this analysis were provided by OBERS. Since they were an important part of the projection procedure, it is desirable to go in some depth into the assumptions which underlie the OBERS State-level projections.

OBERS Assumptions

The OBERS projections are the output of a program of economic measurement, analysis, and projection. The program is run under cooperative agreement with the Water Resources Council; it has been an integral part of the comprehensive water resources planning program and national assessments of water and related land resources.

The objectives of the OBERS program, as listed in its manual, are the development of: a) a regional information system with provisions for rapid data retrieval; b) near-term (1980), mid-term (2000), and long-term (2020) projections of population, economic activity, and land use; and c) analytical systems for use in water resources and other public investment planning.[6/]

6/ U.S. Water Resources Council. OBERS Projections: Economic Activity in the United States. Vol. 1. "Concepts, Methodology, and Summary Data."

There were two levels of assumptions in the OBERS projections which were relevant to the Chesapeake report: those of a general nature underlying all OBERS economic projections, and those specific to the projection of agricultural production.

The general assumptions were those pertaining to the economic activity. They included the following, which, being fairly straightforward, are reproduced in their entirety:

a. Growth of production will be conditioned by a decline of fertility rates from those of the 1962-1965 period. This is true of both Series C and E projections. Series C projections were used in the Agricultural Water Supply Appendix.

b. Nationally, reasonably full employment, represented by a 4 percent unemployment rate, will prevail at the points for which projections are made. As in the past, unemployment will be disproportionately distributed regionally, but the extent of the disproportionality will diminish.

c. No foreign conflicts are assumed to occur at the projection dates.

d. Continued technological progress and capital accumulation will support a growth in private output per manhour of 3 percent annually.

e. The new products that will appear will be accommodated within the existing industrial classification system, and, therefore, no new industrial classifications are necessary.

f. Growth in output can be achieved without ecological disaster or serious deterioration, although diversion of resources for pollution control will cause changes in the industrial mix of output.

The following are assumed for the OBERS State economic projections:

a. Most factors that have influenced historical shifts in regional "export" industry location will continue into the future with varying degrees of intensity.

b. Trends toward economic area self-sufficiency in local-service industries will continue.

c. Workers will migrate to areas of economic opportunities and away from slow growth or declining areas.

d. Regional earnings per worker and income per capita will continue to converge toward the national average.

e. Regional employment/population ratios will tend to move toward the national ratio.[7/]

In addition to this general class of underlying assumptions, there was a set of assumptions which are specific to agricultural projections. Based on the Series C projections of population and per capita income projections, per capita consumption of agricultural products were estimated as follows:

	1963-65 Av.	1968-70 Av.	1980	2000	2020
	Pounds				
Beef and veal	103	115	130	135	140
Poultry	39	47	59	63	65
Dairy products	627	570	475	450	425
Citrus fruit	66	88	110	118	120
Non-citrus fruit	102	101	99	92	86
Potatoes	110	117	110	110	110
Wheat	158	153	150	141	134
Total	1,205	1,191	1,133	1,109	1,080

Source: OBERS projections, Vol. 1 (1972).

7/ Ibid, footnote 6/, page 11.

These figures take into account a rising trend of prices of livestock products relative to those of field crops, but the demands for agricultural products were projected under the assumption that the price of agricultural products relative to all other consumer products "will not be materially altered." There were assumed to be no shortages.

In addition to food demands for agricultural products, several nonfood uses of crops were incorporated into the OBERS projections.

The livestock and poultry populations were assumed to exert a significant demand on feed grains, protein feeds, and roughage, the extent of which depends upon feed utilization per unit of livestock output. Feed utilization in 1980 was assumed to be consistent with current practices and performances. From 1980 to 2020, however, total feed utilization was assumed to decline by 10 percent as more efficient use of feed concentrates, expanded use of substitutes for concentrated food sources, and improvements in management and breeding take effect.

The other domestic nonfood uses of crops are in manufacturing and seed production.

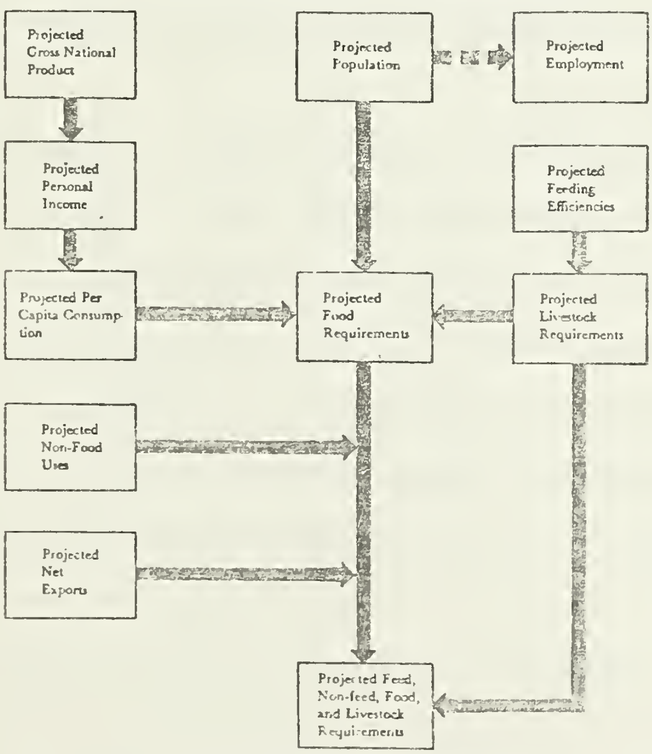
The rate of change between a 1959-61 average and the 1980 level was utilized in making the 2000 and 2020 projections of the other nonfood uses of feed grains. Nonfood uses of vegetables, potatoes, and noncitrus fruit were projected to change at the same rate as their respective food uses; projected changes for other agricultural products were based on extensions of historical data.

A final component of the projected agricultural demands is net exports. Underlying the OBERS projections in this area was the assumption that, beyond 1980, U.S. exports will, despite their continued increase, represent a smaller share of total U.S. production. No attempt was made to predict changes in national trade and food aid policies. The export projections are considered an interpretation of the policies as they existed when the projections were made.

In sum, the OBERS agriculture projection incorporated several underlying assumptions pertaining to all economic activity. From projections of gross national product and population use were derived per capita and total domestic food consumption; the livestock requirements, in turn, were assumed to exert a further demand on crop production, as were projected nonfood uses and exports.

The procedure is schematically represented in the OBERS documentation, and it is reproduced here in a summary reference (Fig.4).

Figure 4—Projected National Framework Of Production Requirements



Source: Water Resources Council 1972, OBERS Projections Volume 1, "Concepts, Methodology and Summary Data."

Irrigation Water Demand

This section documents assumptions and methodology specific to the projection of irrigation water demand for the Chesapeake Bay Study Area.

Crop Production

Water demands for irrigation were estimated with reference to crop demand, yield, and total crop acreage. Data used were agricultural census data for crop production and acreage, at both the State and county levels, and OBERS projections of State crop production in the target years. County data were aggregated into subarea groups before use.

To begin with, crop production in each subarea was projected by a shares analysis to take into account both distributional shifts among the subareas and the OBERS-projected changes in State-level demands for each crop.

Yields were then projected. It was assumed, as in the OBERS projections, that, during the period 1970 - 2020, the rapid rate of increase in agricultural research and development since the second World War would continue, but at a slower rate. Although more extensive use of fertilizers and pesticides, and improved crop varieties and management practices are expected in the target period, investment in agricultural research and development may be dampened. In addition, a lag is expected in the implementation of new technologies. Both factors would tend to diminish the rate of yield growth.

Historical yields were found to vary consistently and significantly; for each crop there appeared differences not only between the Chesapeake Bay Study Area and the rest of the States involved (a discrepancy which was especially large for Virginia), but among the subareas themselves. In the most obvious example, yields of subareas in the Delmarva Peninsula differed for almost all crops from the yields for the Western Shore subareas. It was therefore decided to individually estimate target date yields, by crop, for each subarea.

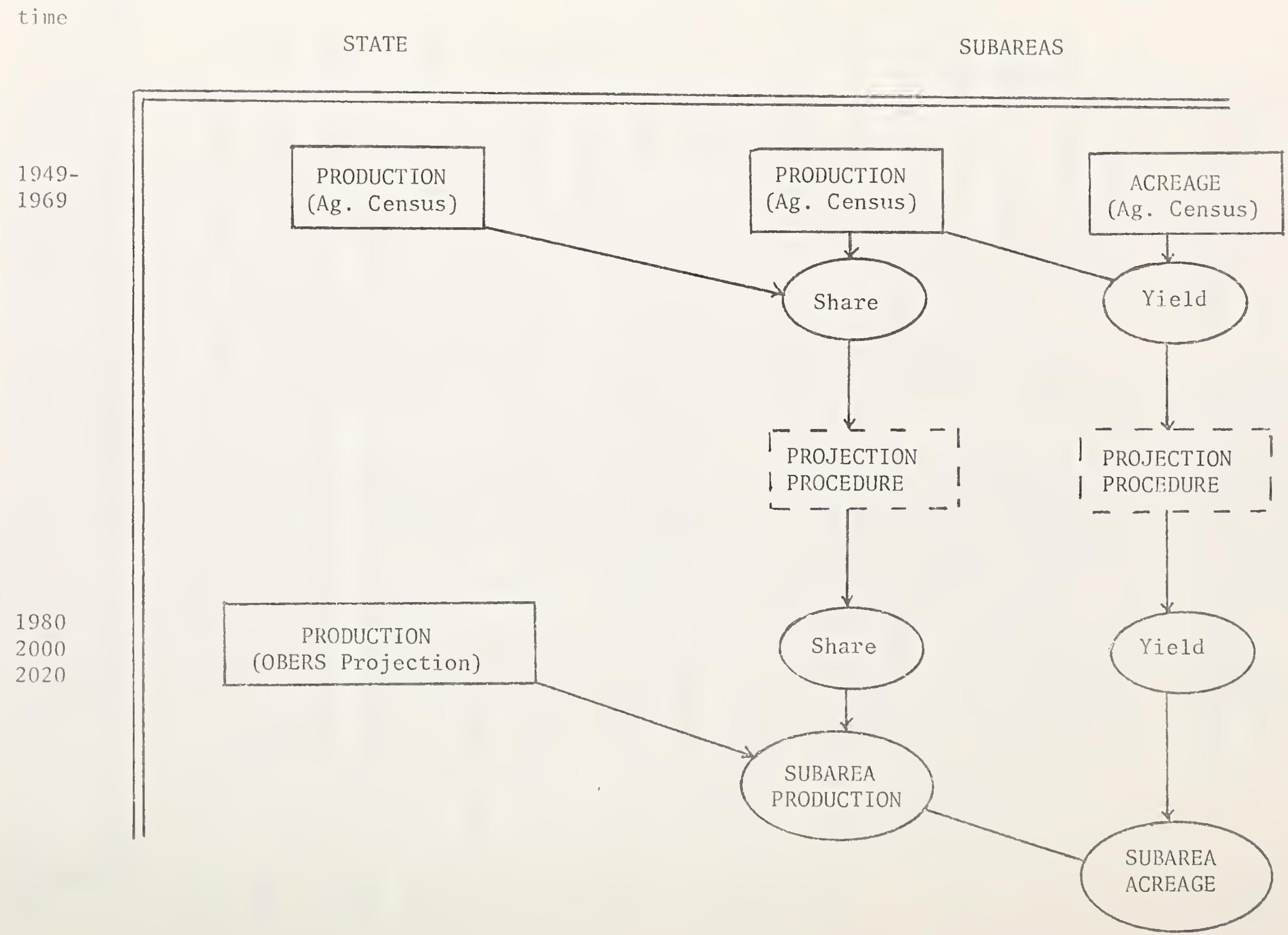
Yields were projected by the function employed in the projection of subarea production shares, with a slight alteration to allow them to vary with time more than the subarea shares of state production were allowed to.[8/]

It was possible to estimate acreage for each crop from the estimates of future crop production and expected yield (production per acre). The procedure is easily broken into its component parts (see fig. 5). First, future State crop production was disaggregated into subarea production according to the estimated shares accounted for by each of the subareas. Data used were historical State and subarea crop production figures (directly from or aggregated from the agricultural censuses) and projected state production estimates from OBERS. Historical shares were calculated by dividing subarea production figures into State totals for each of the census years.[9/]

8/ For full documentation see OBERS projections, Ibid, footnote 6/ p. 11

9/ In 1969, agricultural census data for the counties was for most crops given for Class 1-5 farms. This was not considered a serious limitation, since farms in those categories accounted for 99.5% of all irrigated acres in the study areas.

Figure 5. Projection of production and acreage by crop



A Spillman extrapolation (labeled PROJECTION PROCEDURE in fig. 6) was then performed on the trend of historical shares to estimate future shares accounted for by each subarea. The estimated future shares, applied to the OBERS projections of State totals, gave future subarea production estimates for the target dates (see fig. 6).

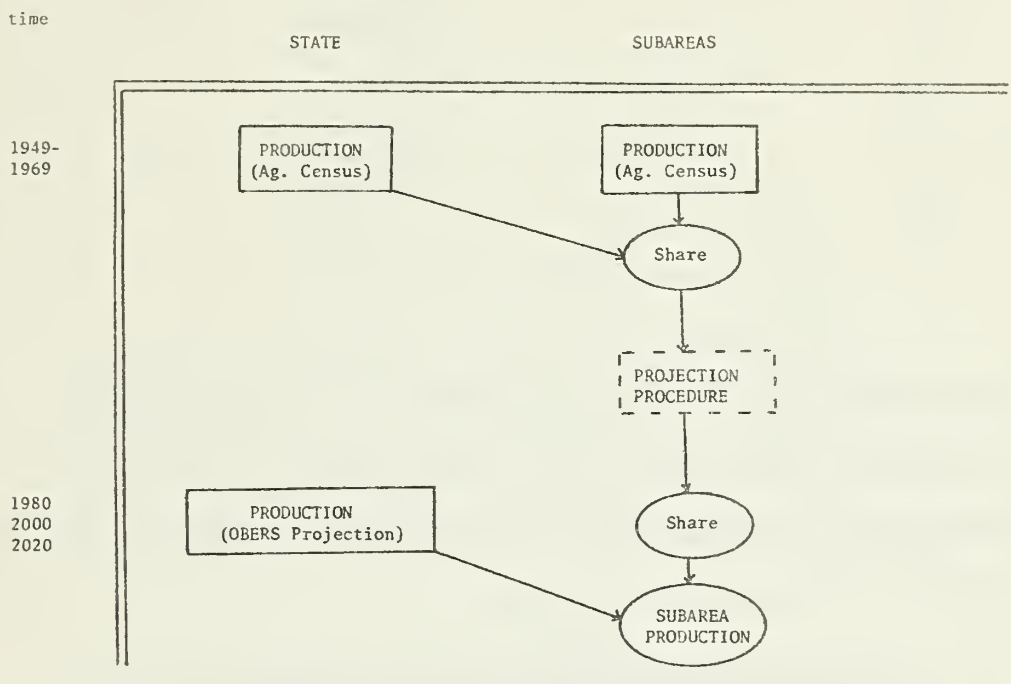


Figure 6. Projection of subarea production

The next step in the procedure was the projection of crop yields (see fig. 7). Data used were historical production and acreage figures, for each crop, from the censuses of agriculture. To calculate historical yields in each subarea, historical crop production was divided by acreage. The Spillman projection procedure was then used to obtain estimated target data yields from past yield trends.

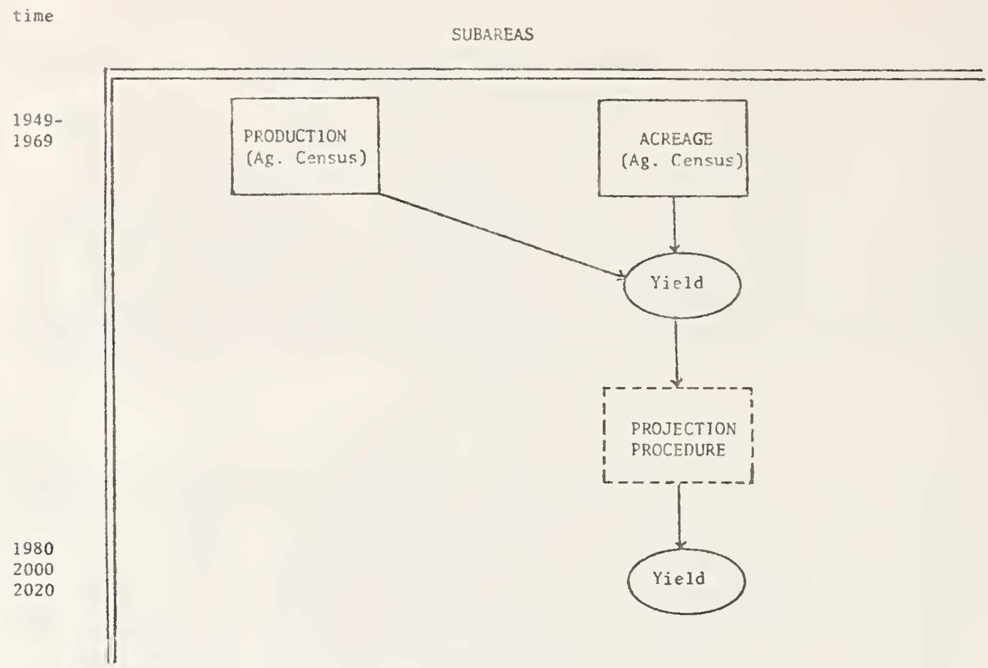


Figure 7. Projection of subarea yield

Following these two steps, the estimated acreage requirements in each subarea were easily calculated by dividing its projected crop production by the yield (production per acre) expected in that subarea (see fig. 8).

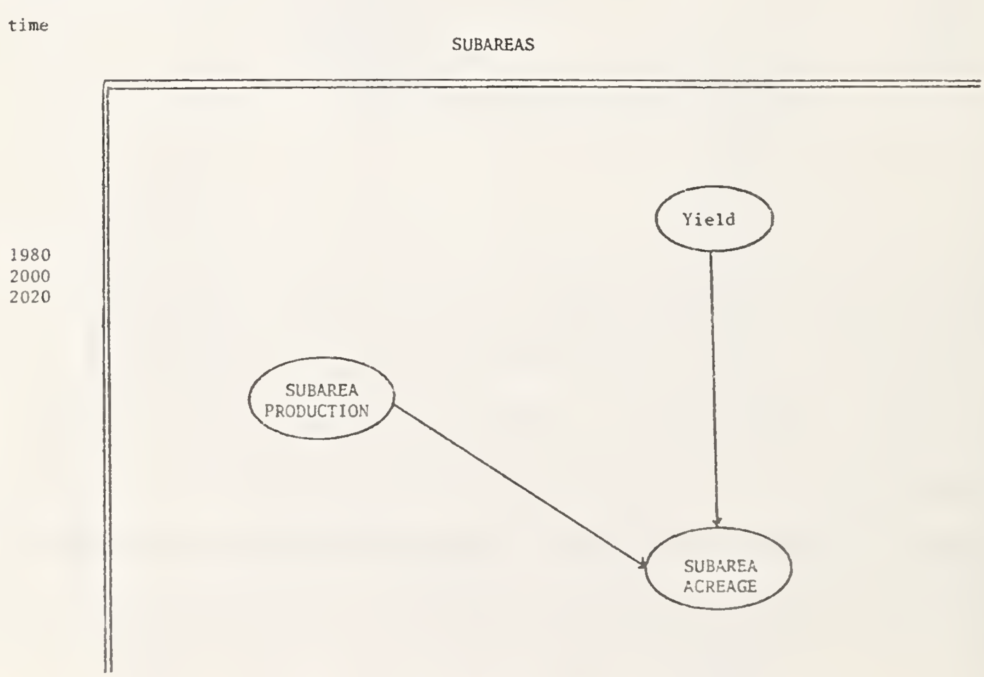


Figure 8. Derivation of subarea acreage

The procedure was repeated for each of the selected crops[10/], and the results were forwarded to the Soil Conservation Service (SCS) for use in projections of irrigation water demand.

Irrigation Water Use

SCS estimated irrigation water demand for each crop and subarea as a function of crop acreage. From past trends and knowledge of present irrigation usage, individuals in each subarea estimated the proportion of subarea acreage to be irrigated in the target period. These proportions were applied to the estimates of total crop acreage to obtain total irrigated acreage. The net irrigation water requirement in acre-feet per year for the estimated irrigated acreage of each crop was then projected by the SCS Computer Center which, using a computer program in its library, followed the procedure outlined in SCS Technical Release Number 21[11/]. Data considered were subarea averages of latitude, temperature, and rainfall; and crop transpiration curves for water use during the growing season.

Of major importance in the calculation was potential evapotranspiration (PE), or the amount of water which would be lost to the atmosphere through transpiration from a green crop and evaporation

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10/ For the categories "fruits and nuts" and "vegetables", acreage was directly computed by the "shares" method, without reference to production or yield. Since it is difficult to aggregate production data for various fruits and vegetables into the tonnage measurement used in the OBERS projections, subarea shares were computed on the basis of acreage. These shares were applied to state acreage estimates, which were calculated from OBERS projections of State production and yield.

11/ For fuller documentation the original guide may be consulted: Irrigation Water Requirements: Technical Release Number 21. United States Department of Agriculture, Soil Conservation Service, Engineering Division. 1967 (Revised 1970).

from the soil surface. For each subarea, potential evapotranspiration was calculated using a modified Blaney-Criddle formula, as a function of daylength (itself a function of latitude), temperature, and the transpiration rates of crops under study at different stages of their growth. The net irrigation requirement was then calculated as the difference between PE, and effective rainfall plus carry-over soil moisture.

Effective rainfall consists of precipitation available to meet the consumptive water requirements of crops, not including precipitation lost to deep percolation below the root zone or to surface runoff. Factors entering into its calculation were total precipitation, consumptive use by crops, and net irrigation applications, all of which affect the storage capacity of the receiving soil. Where total precipitation is high, as it is in a humid area such as the Chesapeake Bay, storms often produce water in excess of that which can be stored for consumptive use; the remainder is lost through surface runoff or percolation. Where the consumptive use rate of a crop is low, available soil moisture is depleted less rapidly, and rainfall effectiveness is again reduced. Finally, rainfall effectiveness is reduced by smaller, more frequent net irrigation applications which tend to maintain a relatively steady level of moisture in the soil profile.

For the Agricultural Water Supply Appendix, the level of precipitation was estimated in two ways:

Normal year precipitation. Irrigation water demand was first projected under the assumption of "normal" precipitation. In this projection, total precipitation was assumed to be the 30-year mean for each subarea.

Dry year precipitation. Since for the Chesapeake Bay Study critical water needs were judged most important, a second projection of irrigation water demand was run assuming less than average precipitation. For small vegetables and other specialty crops[12/], effective rainfall during the growing season in each subarea was estimated assuming a 90-percent chance of occurrence, or assuming the rainfall which is expected to be equalled or exceeded 9 years out of 10. For field crops and orchards, effective rainfall was estimated assuming an 80-percent chance of occurrence.

Consumptive use rate varied by crop and by stage of growth. The third factor influencing effective precipitation, net irrigation depth, was brought into the analysis by assuming 1- to 2-inch applications. In the calculation of carry-over soil moisture, the soil water-holding capacity was assumed to be uniformly that of a loam soil (medium capacity). The amount of water available to a crop under study varied, however, with its rooting depth, with relatively more water available to deeper rooted crops.

Once the net irrigation requirement was projected, gross demands were estimated under the assumption of a 65-percent rate of irrigation

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12/ The estimated irrigation water demand of nursery and specialty crops is based upon individuals' estimates of nursery and specialty acreage in their subareas. Included in this category are nursery stock, golf courses, and other miscellaneous crops not addressed in the OBERS projections.

efficiency. Only 65-percent of the total water application is assumed to be available for crop use. The gross irrigation demand was therefore projected by multiplying net demands by the reciprocal of 65-percent, or the factor 1.5385.

Livestock Water Demand

Livestock consumption and sanitary uses represented a second major demand for water in the target years. Assumptions and methodology specific to its projection are presented in this section.

Livestock Production

As in the estimation of irrigation water demand, livestock water use was projected by first estimating production in each subarea. This was accomplished using a shares analysis. Data used in this part of the study were agricultural census data for livestock numbers at the State and county levels, and OBERS projections of State demands for livestock and livestock products in the target years. County data were aggregated into subarea groups before use.

In this procedure, the shares analysis was modified somewhat to take into account the form of the OBERS State livestock projections, which were in terms of live weight demanded at the market in the target date years. Once State-level estimates of live weight at market were allocated among the subareas, it was necessary first, to convert market weight into livestock numbers, and second, to take into account the supportive livestock population.

State-level demands for livestock and livestock products were converted to livestock numbers by dividing them by a set of average livestock weights and -- in the case of chickens and milk cows -- productivity. The set of average livestock weights developed for the conversion of production to livestock numbers is given in table 2. While the weights roughly paralleled the 1970 market weights for the Chesapeake region, they nonetheless reflected changes in livestock production now underway. The conversion weights for pork and sheep were slightly higher than current levels, taking into account the development of more efficient feeding practices and improved breeds. Similarly, milk and egg production were assumed to increase over current levels, due to improvements in nutrition and management practices permitting performance tests and selective breeding The average weight assumed for turkeys, however, was assumed to be slightly below current levels, due to market preferences for slightly smaller birds.

Table 2--Projected average market weights

Product	Unit	1980	2000	2020
Hogs - pigs	lb	230	230	230
Sheep - lambs	lb	110	110	110
Broilers	lb	3.5	3.5	3.5
Turkey	lb	15	15	15
Eggs/chicken	eggs	240	265	280
Milk/cow	lb	10,818	12,097	12,218

Marketed livestock represent only part of the total livestock population; they exert only part of the total livestock water demand. In support of marketed livestock or producers of livestock products are breeding flocks and herds which exert a substantial demand for water. In addition, not all animals are expected to reach marketable age; those who do not also exert demand for water. It was necessary to take these portions of the livestock population into account in addition to the livestock needed to meet the demands projected by OBERS. This was done through the use of numbers coefficients which expressed the total number of animals required to meet market demands. Given a level of market demand, the number of animals needed to meet that demand could be determined using average weight or productivity coefficients. Ratios were then developed to determine mortality, and the numbers of animals in breeding flocks and herds needed to support such marketed animals. The sum of the three components represented total livestock numbers.

In practice, each of the components were taken into account simultaneously by combining coefficients into a single number. In the Chesapeake Bay Study, each coefficient set forth in table 4 takes into account average productivities and weights of table 2 and breeding flocks and herds and mortality as set forth in table 3. The numbers coefficients were applied directly to subarea demand for livestock products to determine total livestock numbers.

Figure 9 shows the procedure used to project livestock water demand in a subarea. First, historical shares of State-level livestock production were calculated from census data for each subarea. The shares are projected using the Spillman function (labeled PROJECTION PROCEDURE). OBERS estimates of State-level demands for livestock products are then allocated among the subareas according to their expected shares at each target date. Applying a number coefficient to projected demands gave an estimate of the

Table 3--Livestock water use rates: 1980, 2000, and 2020, Chesapeake Bay Study

Livestock Products Marketed	Water use component	1980 Coefficient 1/	1980 Water use coefficient	1980 Period of use	2000 Coefficient	2000 Water use coefficient	2000 Period of use	2020 Coefficient	2020 Water use Coefficient	2020 Period of use
			Gallons	Days		Gallons	Days		Gallons	Days
Hogs										
	Marketed animals	1.0	4/day	180	1.0	4/day	180	1.0	4/day	180
	Breeding stock	14.5	4/day	365	16.0	4/day	365	17.0	4/day	365
	Mortality	.10	1/day	82	.07	1/day	78	.05	1/day	75
Sheep										
	Marketed animals	1.0	1.5/day	180	1.0	2/day	150	1.0	2/day	140
	Breeding stock	1.2	2/day	365	1.25	2/day	365	1.25	2/day	365
	Mortality	.10	.8/day	90	.07	1/day	75	.05	1/day	70
Eggs										
	Laying flock	1.0	26/year	*	1.0	26/year	*	1.0	26/yr.	*
	Mortality	.08	2.5/day/100 2/	180	.06	3/day/100	180	.05	3/day/100	180
Broilers										
	Marketed birds	1.0	1.5/yr.	*	1.0	1.5/yr.	*	1.0	1.5/yr.	*
Turkeys										
	Marketed birds	1.0	18/yr.	*	1.0	18/yr.	*	1.0	18/yr.	*
	Breeding flock	50.0	12/day/100	365	50.0	14/day/100	365	50.0	14/day/100	365
	Mortality	.08	6/day/100	70	.06	6.5/day/100	62	.05	6.5/day/100	62
Milk										
	Milk cows	1.0	14/day	365	1.0	14/day	365	1.0	14/day	365
			24/day (for milk)	300		27/day (for milk)	300		28/day (for milk)	300
	Calves 3/	.6	12/day	365	.6	12/day	365	.6	12/day	365
	Mortality	.04	6/day	180	.03	6/day	180	.03	6/day	180

1/ Coefficients relate (1) numbers of marketed animals, or producing animals, to (2) number of breeding flocks or herds, and (3) mortality. Numbers of marketed animals or producing animals are estimated by relating projected demands for livestock products to average weights or productivity. Numbers in breeding flocks or herds are estimated by dividing (1) by the coefficients pertaining to (2). Mortality is estimated by multiplying (1) by the rates listed for (3).

2/ Gallons per day per 100 birds.

3/ Dairy calves not sold for beef or veal. Numbers are determined by multiplying number of milk cows by factors listed.

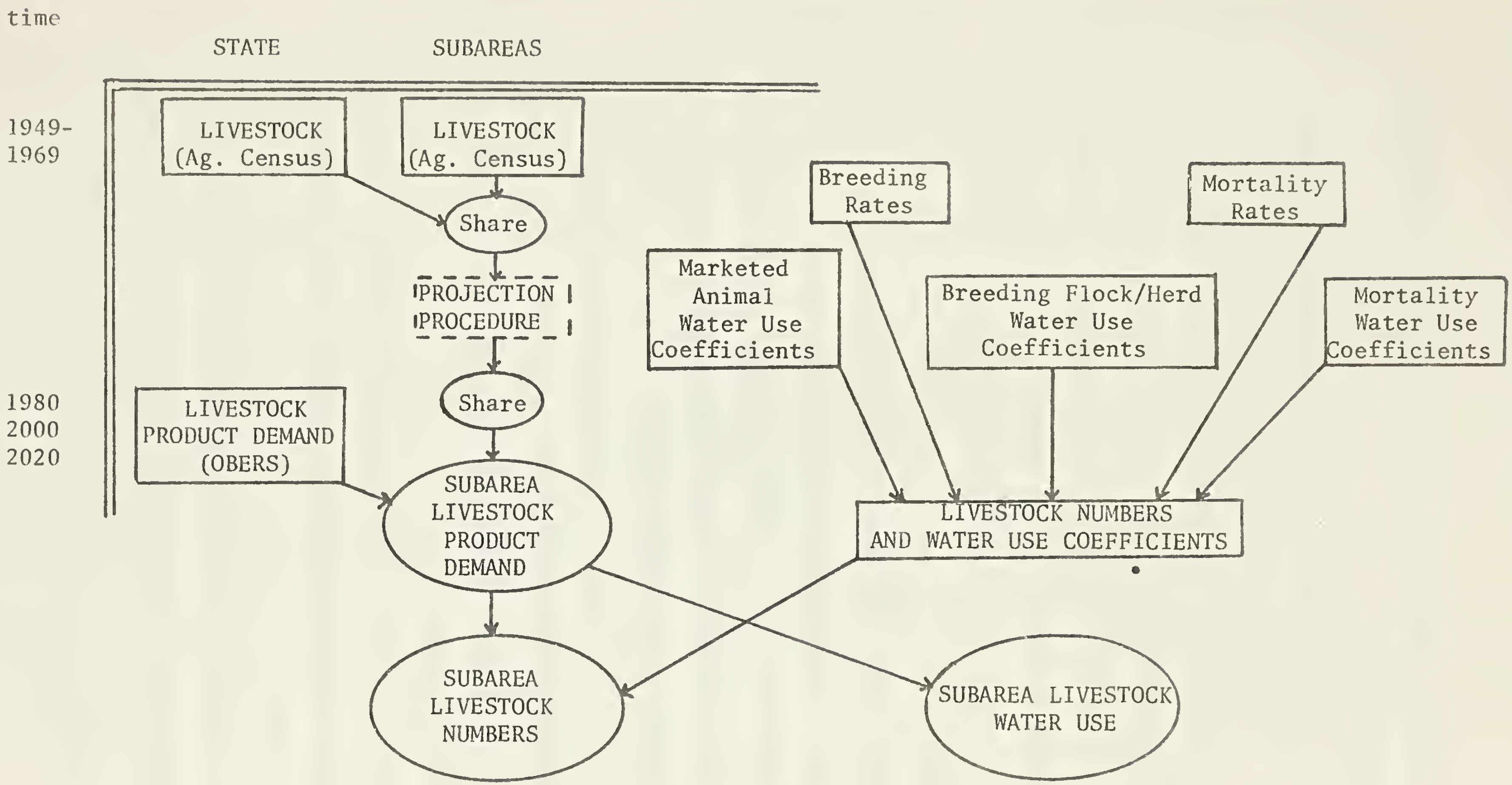
Table 4--Coefficients of livestock numbers and water use 1/

Type		1980	2000	2020
Hogs	Number	0.005082	0.009924	0.004821
	Water use	3.603868	3.550913	3.520141
Sheep	Number	0.017576	0.017000	0.016818
	Water use	8.050303	8.084091	7.886364
Chickens	Number	0.004500	0.004000	0.003750
	Water use	0.109833	0.099336	0.093821
Broilers	Number	0.285714	0.285714	0.285714
	Water use	0.428571	0.428571	0.428571
Turkeys	Number	0.073333	0.072000	0.071333
	Water use	1.280800	1.284253	1.281567
Milk cows	Number	0.000152	0.000135	0.000133
	Water use	1.397723	1.320782	1.314420

Source: Tables 2 and 3

1/ Applied to estimated annual demand for live weight at market or for livestock products (milk, eggs).

Figure 9. Projection of livestock water use



numbers of livestock needed to meet the demand, the backup herds and flocks, and mortality.

An exception to this procedure was the estimation of beef cattle numbers. The dairy cow population is expected to contribute salvage, heifers, and veal calves to beef demand. The feedlot beef population was estimated only after such dairy components were subtracted from beef demand allocated to each subarea (see app. 2). In addition, backup inventory was estimated in proportions consistent with each subarea's historical trends.

Livestock Water Use

Water demand of the estimated livestock population was projected on an annual basis to take into consideration different time periods during which each of the three components exert demand. Breeding flocks and herds were assumed to exert water demand throughout the year, while livestock to be marketed only exert demand during the period in which they are raised. Given that mortality has an equal chance of occurrence at any moment during that time, it was assumed that mortality numbers exert water demand during roughly half the longevity of marketed animals.

Livestock water use was estimated also with reference to the separate use rates of marketed animals, breeding flocks and herds, and mortality as shown in table 3.

In theory, each of the separate use rates would be applied to numbers of the appropriate part of the livestock population; the water use of the subpopulations would be summed. Once again, however, it was found most straightforward to combine the use rates and numbers coefficients to a single water use coefficient for each type of livestock as shown in table 4. Each coefficient thus takes into account the water use rates of different components of the livestock population -- marketed animals, breeding flocks and herds, and mortality -- weighted by their numbers. Applied to the estimated subarea demand for livestock products, they produced an estimate of the total livestock water use required if the projected market demand is met.

If the livestock water use projected in this way is divided by the numbers, per unit water use is almost uniformly lower than the per unit use rates listed in the U.S. Geological Survey,[13/] the main source of data for the livestock section of the Chesapeake Bay Study Existing Conditions Report. The difference in rates is largely attributable to the methodology employed in the projections.

The use rates listed in the Geological Survey largely reflect the water use of mature animals, a use which corresponds most closely with that of marketed animals. In the Agricultural Water Supply Appendix, however, the water use of breeding herds or flocks and mortality were estimated in addition, each with explicit reference to the number of days such livestock consume water and their consumption rate. The analysis of the livestock population with respect to water consumption was therefore more detailed than a simple measure of inventory or sales, and it was judged that the aggregate nature of the Geological Survey water use rates were no longer appropriate.

13/ Geological Survey Circular No. 556. Estimated Use of Water in the United States, 1965.

More explicitly, several factors can be listed which would tend to alter the annual per unit water use rates for livestock:

Inclusion of breeding stock with lower water use rates. This is the case in the analysis of water demands exerted by milk cows. Breeding stock -- including heifers and calves -- swelled numbers by an average of 64 percent, yet their average water use rate was estimated at only 35 percent that of a milk-producing cow.

Inclusion of marketed livestock with lower water use rates. Measurement of numbers by inventory in some cases excludes marketed livestock from the analysis. An inventory of sheep taken on January 1 (as in the 1969 census of agriculture) would not include lamb sales, whose 180-day period of water consumption does not begin until later in the year. Though their use rate approximates those of the backup herd, lambs have a shorter life span. Annual water use for this portion of the sheep population is thus cut to a fraction of that of the backup herd. It depresses the aggregate per unit use rate.

Inclusion of mortality. Inclusion of mortality has a dual effect on the per unit water use rate aggregated over all components. Not only does this component tend to increase the numbers of livestock counted, but, due to the truncated life span of the animals it represents, its annual use rate is less than that of the rest of the herd. The use rate over all components is thus diminished by its inclusion.

Increased productivity. In some cases, water use rates were projected to increase due largely to expected increases in per unit output. This effect is seen, for example, in the per unit rate for chickens. The basic rate is projected to jump from 22 gallons per year in 1970 to 26 gallons per year in the target period, an increase due to an expected increase in annual egg production per bird.

Domestic Water Demand

In addition to crops and livestock, the rural population was taken into account in the projection of agricultural water demand in the Agricultural Water Supply Appendix. The rural water demand expected to be satisfied by central water supply systems was projected by the Baltimore District, Corps of Engineers, with the results presented in Appendix 5 of the Chesapeake Bay Study Future Conditions Report. In the Agricultural Water Supply Appendix, water demand was estimated for the remainder of the rural population, or the population not served by central water supply systems. The residual, in turn, was divided into its farm and nonfarm components.

Farm Water Demand

Farm Population. Farm population was projected as a function of historical land in farms, number of farms, and average per farm population. These factors were selected as measures which most directly affect the farm population.

First, State-level projections of land in farms were allocated among the subareas by a shares analysis, taking into account the distributional shifts among the subareas. These estimates of land in farms were then combined with projections of a second factor, average farm size, to estimate the number of farms in each subarea at the target dates. Finally, the average per farm population in each subarea was projected[14/] and applied to the projected subarea number

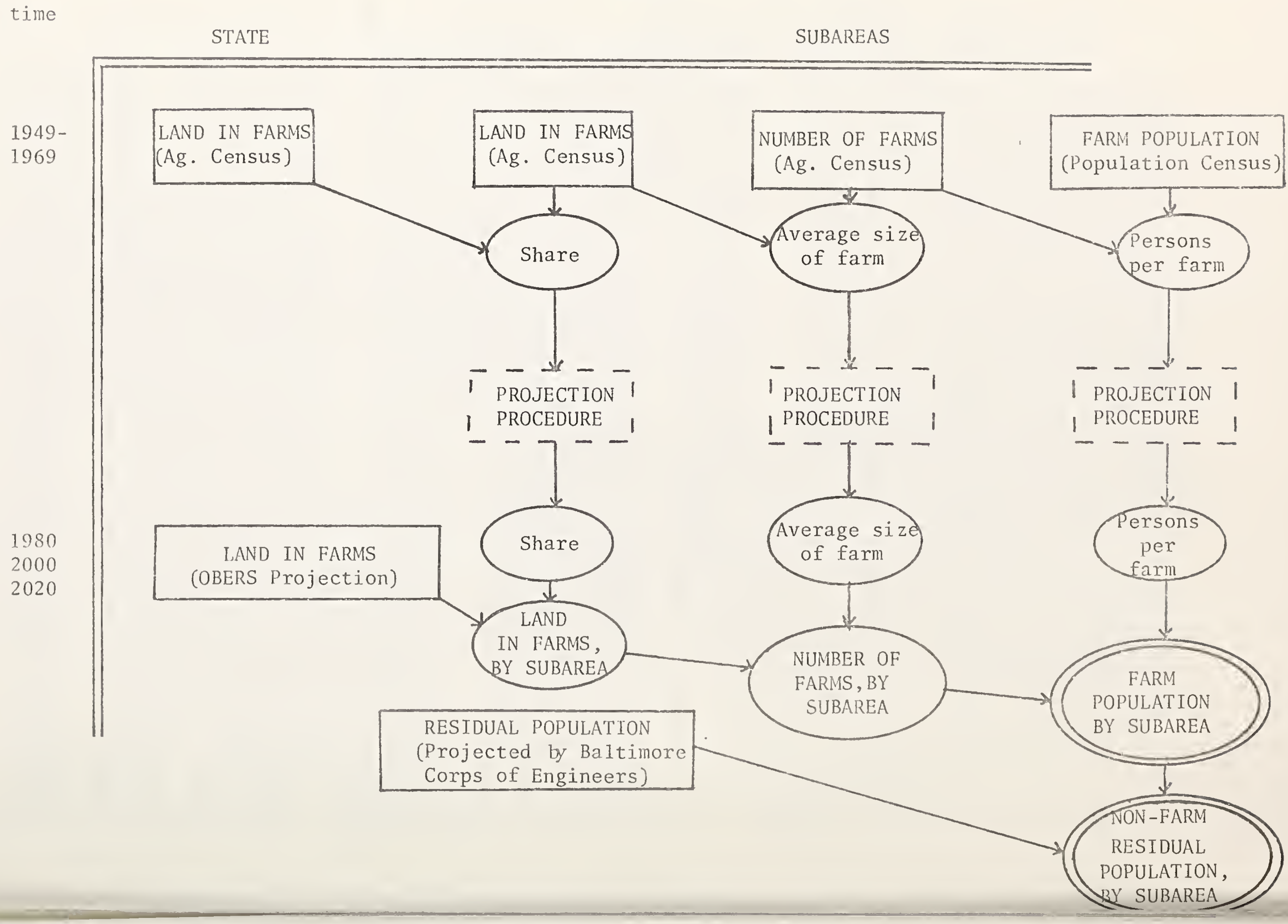
14/ The projections were accomplished using the Spillman function. The average for farm population was not expected to fall below 2.5 persons.

of farms, yielding estimates of farm population. The estimates obtained by this method -- incorporating projections of land in farms, average size farm, and persons per farm -- were commensurate with past trends in farm population. This procedure is graphically represented in fig. 10. Land in farms data at the state and subarea levels were obtained from the agricultural census, as were subarea numbers of farms. Subarea farm population data was obtained from the census of population. Target date estimates of State-level land in farms were obtained from OBERS.

The first step in the procedure was the projection of subarea land in farms by a shares analysis. Historical shares of State land in farms were calculated by dividing subarea land in farms into the appropriate state total for each of the census years. A Spillman extrapolation (labeled PROJECTION PROCEDURE) was then performed on the trend of historical shares to estimate future shares accounted for by each subarea. Target date estimates of State-level land in farms were disaggregated to the subareas according to the projected shares of each (see fig. 11).

The second step in the procedure projected farm size, and, combining size with estimates of land in farms, estimated farm numbers. The historical average farm size was calculated for each subarea by dividing land in farms by the number of farms. A Spillman extrapolation was then performed (PROJECTION PROCEDURE) on the average farm size. The average farm size estimates from that projection were then divided into the projections of subarea

Figure 10. Projection of farm and non-farm population served by independent water supply



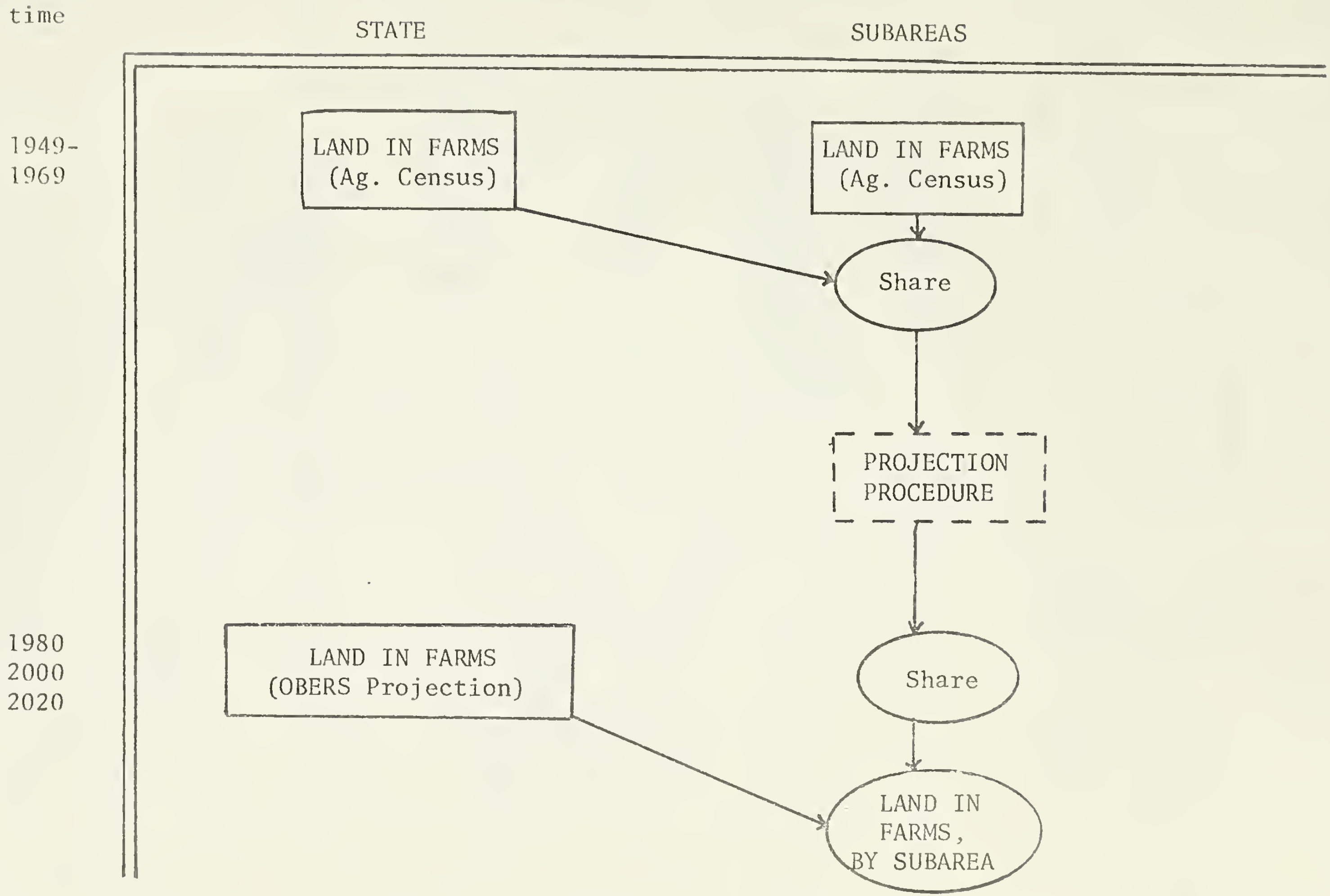


Figure 11. Projection of subarea land in farms

land in farms to obtain expected numbers of farms (see fig. 12).

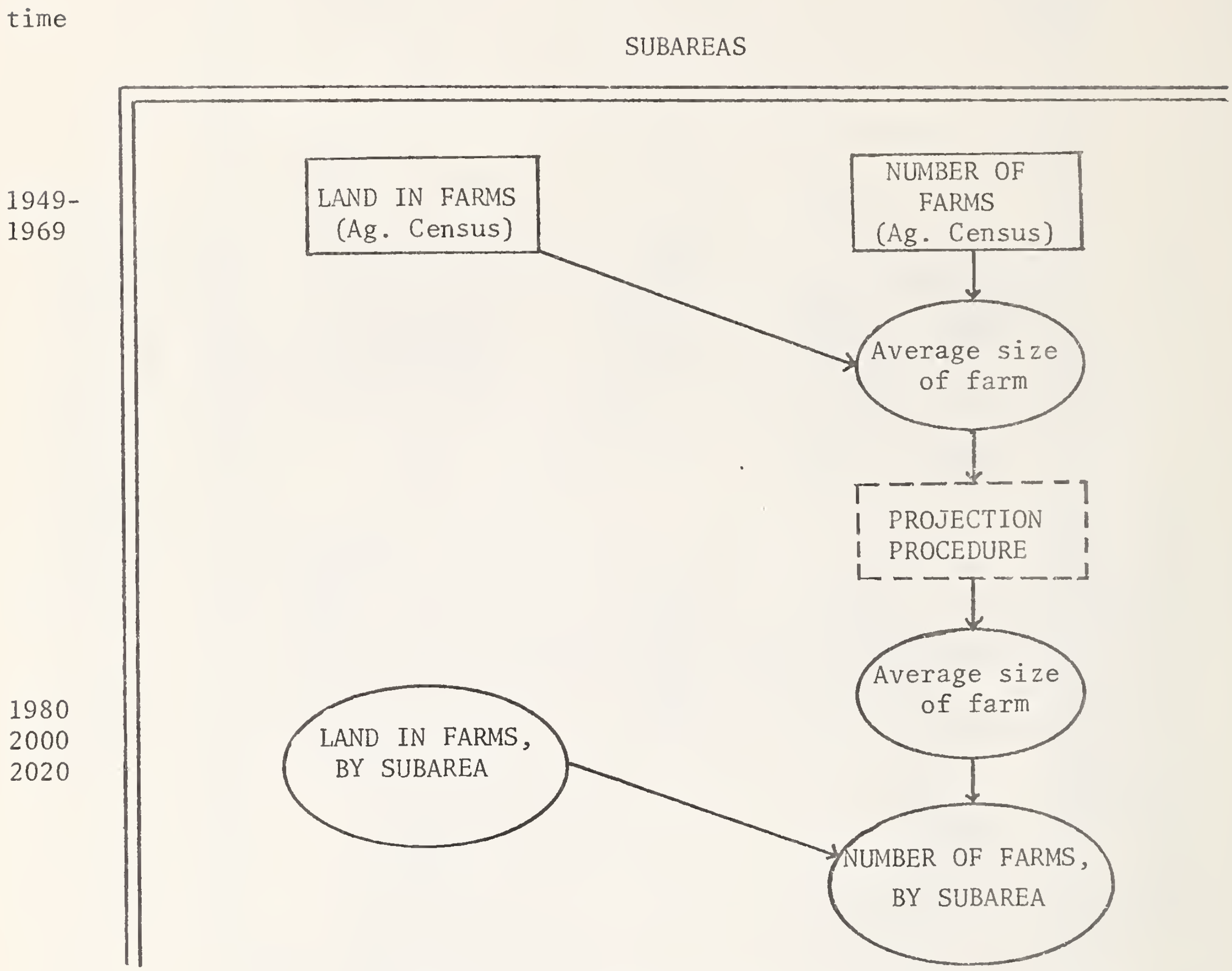


Figure 12. Projection of subarea number of farms

Finally, the farm population was estimated by combining farm numbers with the expected number of persons per farm in each subarea. Dividing each subarea's farm population by its number of farms obtained persons per farm in the historical period. Those figures were then projected to the target dates by a Spillman extrapolation (PROJECTION PROCEDURE), and multiplied by the estimated number of farms to obtain the expected farm population (see fig. 13).

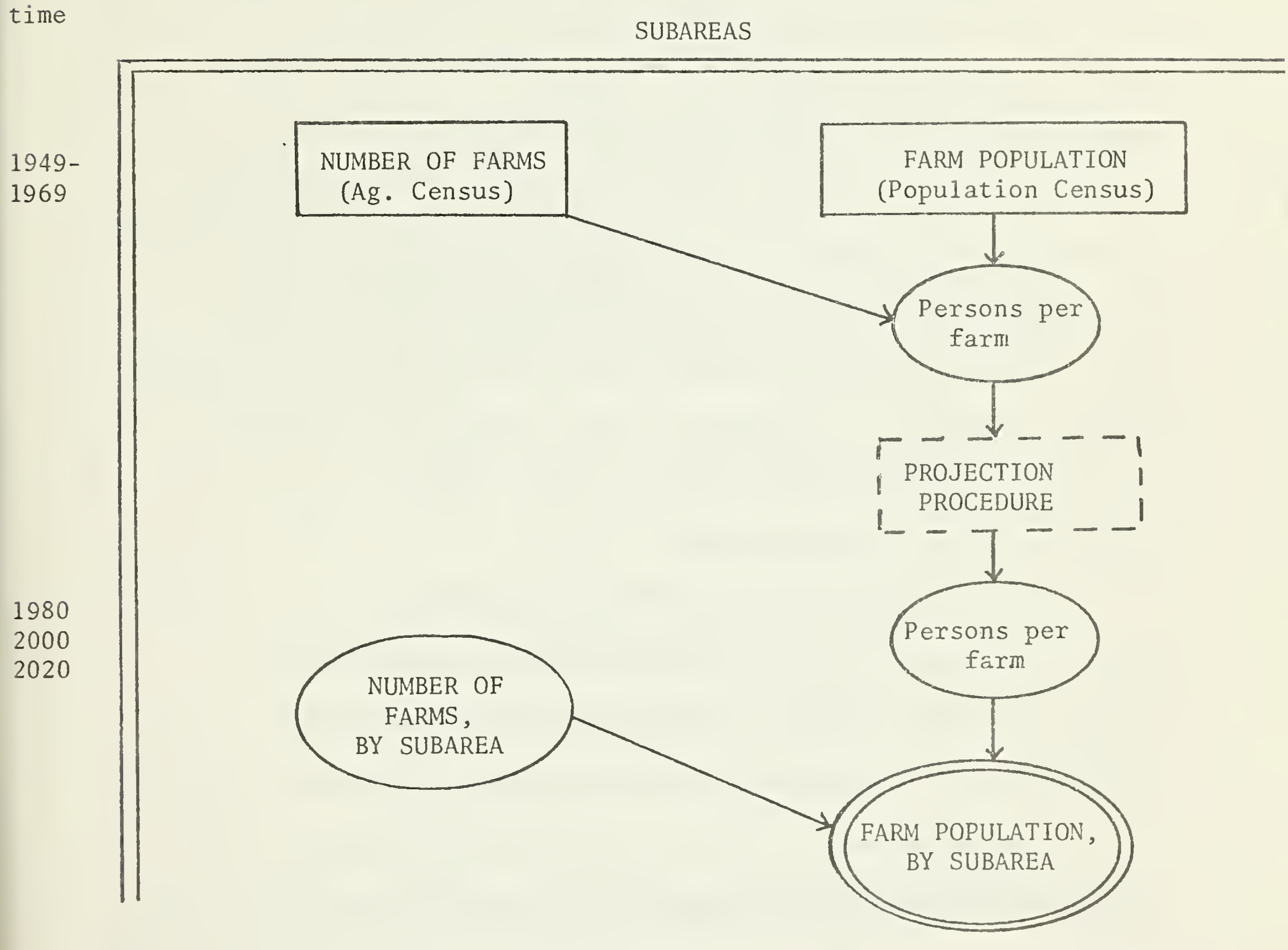


Figure 13. Projection of subarea farm population

Farm Water Use Rate. The farm water use rate in a subarea was estimated for the target period by projecting from census data the proportion of farm households with and without running water. The farm water use rate varied between the projected rates of farms with and without running water according to this proportion.

In the determination of farm water use rates, a major factor is the large-scale conversion of farm households to running water systems. In the Agricultural Water Supply Appendix, there was assumed to be a changing mix of farm households with and without running water, with the former consuming substantially larger quantities of water per capita than the latter. That consumption differential is recognized by the Geological Survey in its estimates of use rate was 50 gallons per capita per day (60 in Delaware), while for farm households without running water the comparable rate was only 10 gallons. The domestic water demand exerted by farms with running water is thus estimated at five times that exerted by households without running water.

A further difference between farm households with running water and those without is that only for the former do water use rates regularly rise.[15/] Since per capita income has also tended to rise, the increase in water use may be due to the use of income to purchase water-using conveniences. This was assumed to be the case in the projection of use rates for households with running water: that as

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15/ Estimated Use of Water in the United States -- 1950-1960-1970. USGS Circular 115, 456, and 676.

per capita income rises during the target period (see Chesapeake Bay Study Appendix 3, Economic and Social Profile),[16/] there will also be a rise in per capita water consumption.

The water use rate of households with running water were therefore simulated by a function which grew over time. To take into account the satisfaction of demand for conveniences, though, the rate of growth was assumed to diminish, leading to a leveling off of the water use rate as its absolute size increases. In that function, when water use is 40 gallons, the annual rate of increase is 3.0 percent. When the use rate increases to 80 gallons, the rate of increase drops to 1.0 percent, and it tapers off to 0.5 percent when a use rate 150 gallons is reached.[17/]

Assuming continuous compounding, use rates may be projected through an integration procedure (see Appendix 3 to this report), from the equation

$$U_T = \left[T(3.735966) + U_o^{1.279948}\right]^{.781282}$$

where

U_T = use rate at time T

U_o = base rate at time T_o

T = elapsed time, in years from base year T_o

The function is labeled EXTRAPOLATION PROCEDURE in fig. 14, next page

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16/ This appendix is part of the Chesapeake Bay Future Conditions Report Appendixes which will be published by the Department of Army, Corps of Engineers, by the end of 1976.

17/ This relation, used by the Corps of Engineers in the projection of use rates of the population served by central systems, was first developed for the Ohio River Basin Framework Study, U.S. Department of the Interior, Federal Water Pollution Control Administration, 1963.

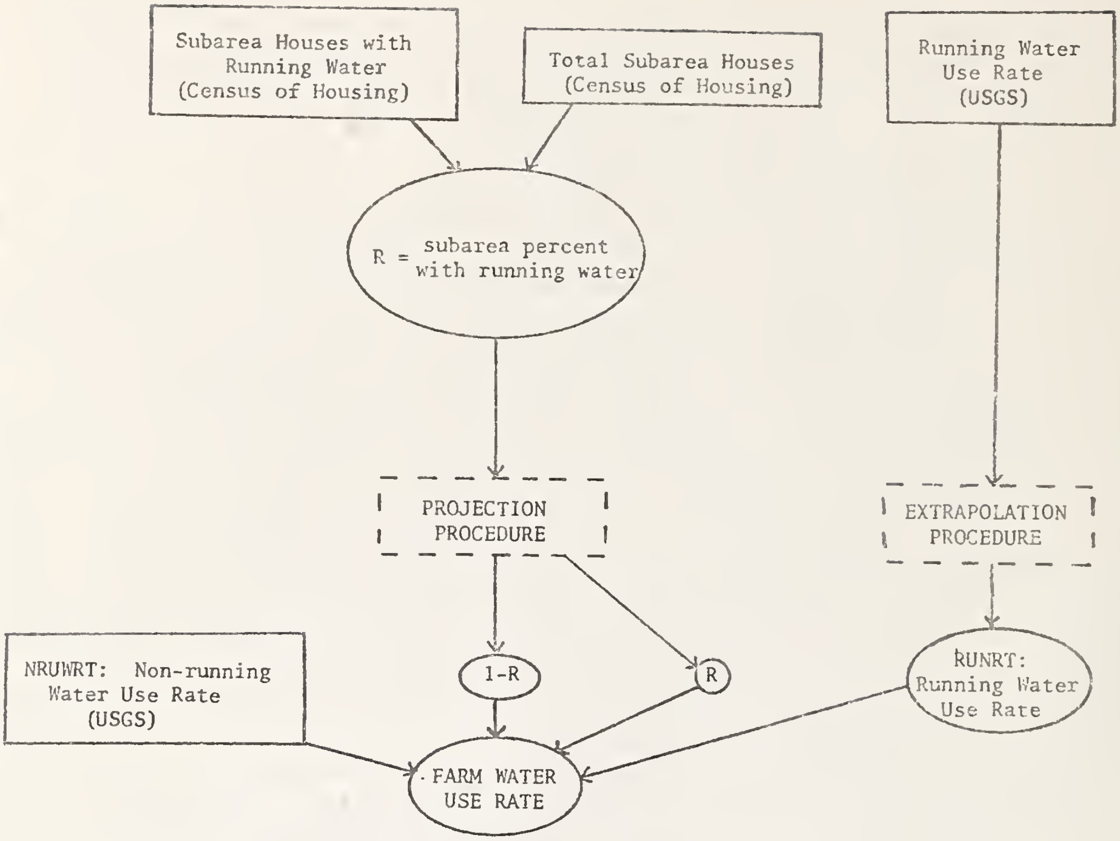

Figure 14. Projection of farm water use rate

and its results are given in Table 5.

Table 5--Running water use rates, farm population

	1970	1980	2000	2020
	-----gals. per capita per day--			
Delaware	60	69	86	103
Md., Va.	50	60	77	94

The use rate for households without running water was held constant at the 1970 level, 10 gallons, a figure reported by the Geological Survey in 1960 and 1950 as well.[18/]

Once target date water use rates were estimated for households with and without running water, an overall farm water use rate could be determined by weighting the two according to the relative size of their respective populations. The overall farm use rate thus varied between the running water use rate (RUNRT) and the use rate for households without running water (NRUNRT) according to the estimated proportions of the population with running water and without running water (see fig. 14). Data used were, from the census of housing, total numbers of farm households and numbers of those served by running water. Historical percentages of farm households with running water were calculated, and a Spillman extrapolation (labeled PROJECTION PROCEDURE) was run on the historical trend to estimate the future proportions in each subarea. The weighted average farm use rate was then estimated as the sum of two figures: (RUNRT) multiplied times the proportion of households so served; plus (NRUNRT) times the proportion of households so served.[19/]

$$\text{farm water use rate} = (R\%)\ (RUNRT) + (1 - R\%)\ (NRUNRT)$$

where R% = projected proportion of households with running water

RUNRT = projected water use rate for households with running water

NRUNRT = projected water use rate for households without running water

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18/ See Estimated Use of Water in the United States--1950-1960-1970, USGS Circulars 115, 456, and 676.

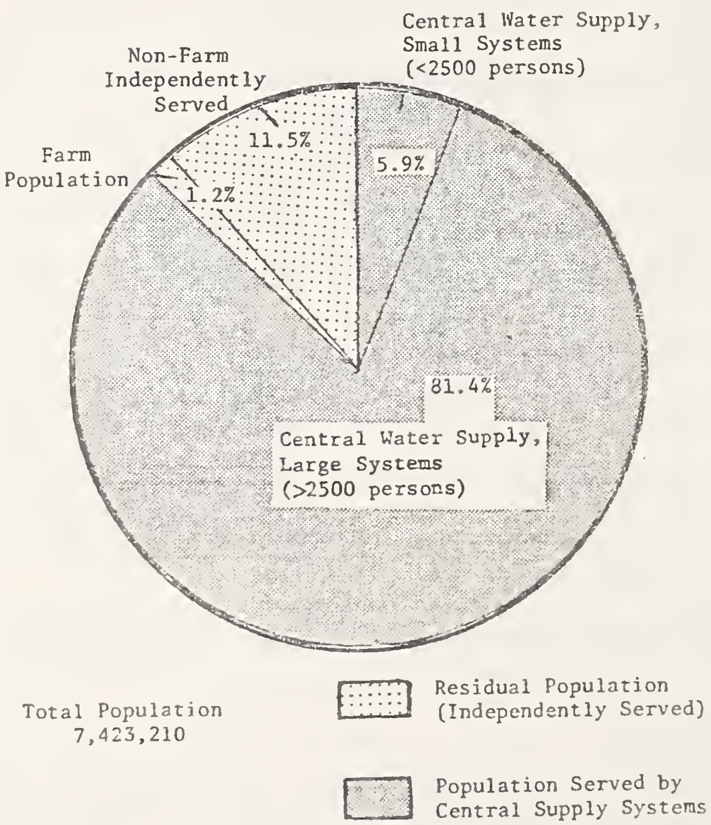
19/ It may be noted that multiplying the farm population by this weighted average is the mathematical equivalent of multiplying each component by its appropriate use rate and summing the two.

Rural Nonfarm Water Demand

The rural nonfarm water demand addressed in the Chesapeake Bay Study pertained only to the population unserved by central water supply systems, or the "residual" population.

Nonfarm Residual Population. The nonfarm residual population was projected as the difference between target date estimates of the residual population and target date estimates of farm population. It was assumed that, due to efficiencies of water service in farm areas, no farm households would be served by central water supply systems (see fig. 15).

Figure 15. Water service in 1970: population served by central supply systems, and residual population (independently served). Cheasapeake Bay Study Area



Conversely, in subareas with relatively few farms, the nonfarm residual population was assumed to have income and demographic characteristics similar to the population served by small central supply systems, and its water use rate would accordingly approach the small systems users' rate.

As shown in fig. 16, the estimated nonfarm residual use rate varied between the farm use rate and the small systems rate in proportion to the relative size of the farm population in the residual. Where the farm population was a large part of the total residual, the nonfarm residual use rate approached the farm rate; where it was not, the nonfarm residual rate approached that projected for small systems.

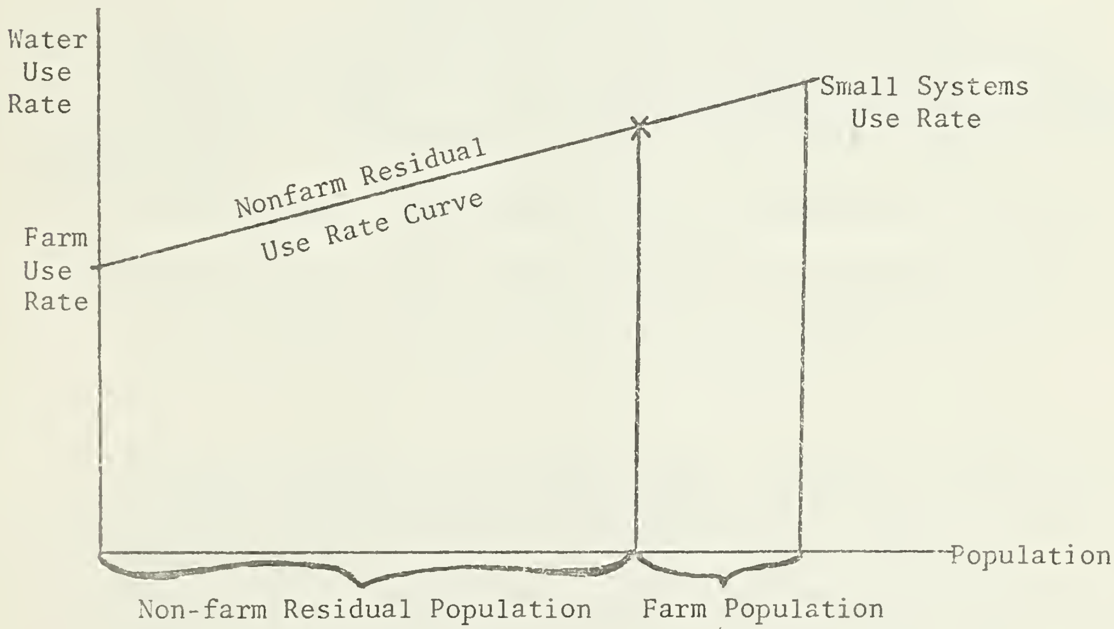


Figure 16. Nonfarm residual water use rate curve

The Baltimore District, Corps of Engineers projected the residual population as the difference between total population and population centrally served. The latter was divided into population served by large systems (serving more than 2500 persons) and that served by small systems (serving fewer than 2500 persons). The former was estimated individually in each subarea and for each large system, the latter as a function of total county population.[20/] The nonfarm residual population was therefore equal to projections of total population less the estimated centrally served, where:

NONFRESID = TOTPOP - CENTPOP - FARMPOP

NONFRESID = projected nonfarm residual population

TOTPOP = projected total county population

CENTPOP = projected population centrally served

FARMPOP = projected farm population

Nonfarm Residual Water Use Rate. In estimating the nonfarm residual use rate, the central assumption relates that rate to income and demographic characteristics of the population. In subareas in which farm household numbers dominated the residual, it was assumed that the nonfarm residual use rate would approach the farm rate.

20/ Population served by large systems were linked to the BEA projections of urban areas. Population served by small systems was projected by relation to county population growth rates, under the assumption that such a relation would be similar to the one between population growth in small towns and county growth. County growth and small town growth were then linked to the growth of small water service areas. See Chesapeake Bay Study Appendix 5, Municipal and Industrial Water Use, for elaboration.

$$\text{nonfarm residual use rate} = FMRT + K\left[SYSTRT - FMRT\right]$$

where K = percentage of residual population not residing on farms

FMRT = projected farm use rate

SYSTRT = small systems use rate

The small system water use rate used in the Chesapeake Bay Agricultural Water Supply Appendix corresponded to that projected for the Municipal and Industrial Water Supply Appendix to the same report. It was estimated at current levels and projected to increase accordingly to the running water use growth curve.[21/]

The 1970 level of water use judged appropriate to small systems was 100 gallons per capita per day total use, and 85 for nonindustrial use. In researching small systems use, it was found that the former figure was frequently reported for water use in small communities. Of that total, 10 to 20 percent was estimated to apply to industrial water use, leaving roughly 85 gallons for nonindustrial, small systems consumption.[22/]

21/ Elaborated under Farm Water Use Rate.

22/ See Cheasapeake Bay Study Appendix 5, Municipal and Industrial Water Use.

APPENDIX 1

The Spillman Projection Function

The Spillman projection function[23/] essentially extends a trend line within predetermined limits, so that it approaches those limits in a curvilinear fashion. The curvilinear function is of exponential form.

The values to be projected are first paired with their historical dates, with the latter given in number of years from a base date (1949 in the Agricultural Water Use Appendix). To aid in setting the limits a best fitting trend through this historical data is estimated using linear regression, and the historical values are projected to target years. The initial regression determines whether or not the historical trend rises, and the pace of its change.

There are drawbacks to the use of the linear regression, however. If the trend rises, the resulting values might not take into account fundamental constraints on figures such as the percentage of a State's total area represented by a subarea. If the trend falls, on the other hand, extrapolated values of less than zero are frequently the result for the target dates -- a result which would be without meaning in the projection of agricultural production.

These drawbacks are mitigated by the procedure of setting (reasonable) bounds to the projections, a procedure in which the preliminary linear extrapolations prove of great value. Since diminishing returns

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23/ OBERS Projections: Vol. 1: Concepts, Methodology and Summary Data, Washington: U.S. Water Resources Council, 1972.

characterize much agricultural activity, for a rising trend the linear trend often lies above the most recent historical values. The linear extrapolations could therefore be used as limits above which the projections would not go. The corresponding limit for a falling trend is zero.

Consistent with the OBERS methodology, the Agricultural Water Use Appendix assigned the value of the linear trend for 1990 as the ceiling for a subarea's percentage of State land in farms and production. Higher ceilings were set for measures such as yield and average farm size which were constrained by factors other than the subarea's relative size. Again, to be consistent with the OBERS methodology, the extrapolation date on the linear trend for these values was set at 2020. An exception to the zero base value was established for numbers of inhabitants per farm, an average which consistently fell during the historical period for each of the subareas. Although the decline was quite sharp in some subareas, it was felt that this average would not realistically drop below 2.5 persons per farm in view of farm labor needs. The limits set in this manner were adjusted where the resulting projections seemed unreasonable.

The limits set, a trend line is constructed which approaches the upper or lower bound in a curvilinear fashion. This is accomplished by transforming into logarithms the differences between historical figures and the limits. A "loglinear" regression extends these transformations to the target dates, where they are converted back to linear distance by taking their antilogarithms. Subtracting the antilogarithms from the ceiling or adding them to the base yields a trend with the desired properties.

This procedure is easily seem in diagram form. A case which exhibits increasing historical values is illustrated. First, limits are set through the use of preliminary linear regression, extended to the target dates as described above (see fig. 17).

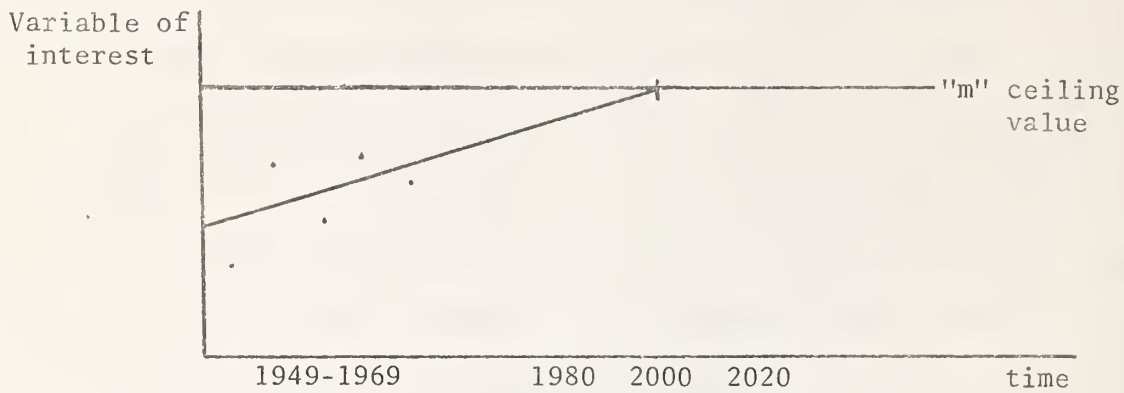

Figure 17. Ceiling Value Set.

Logarithms are then taken of the difference between historical values and the ceiling or base (fig. 18).

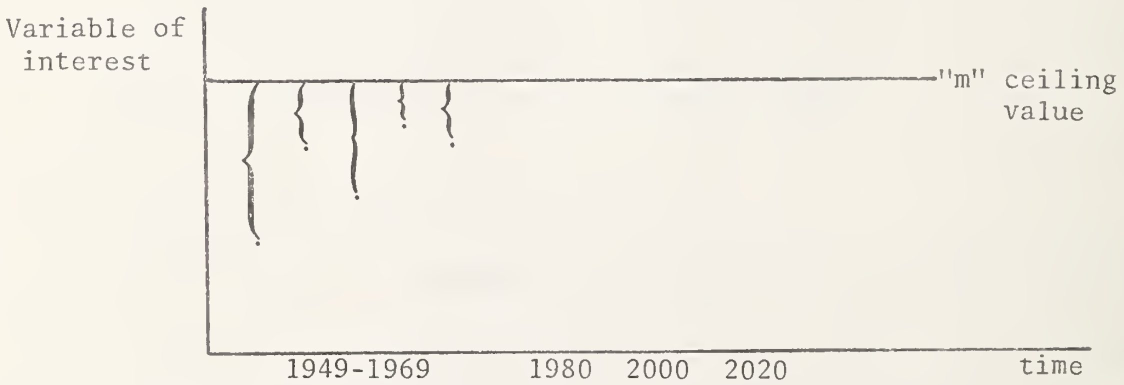

Figure 18. Logarithms of difference computed.

Third, the best fitting line through the logarithms of the differences is computed and extrapolated to the target dates (fig. 19).

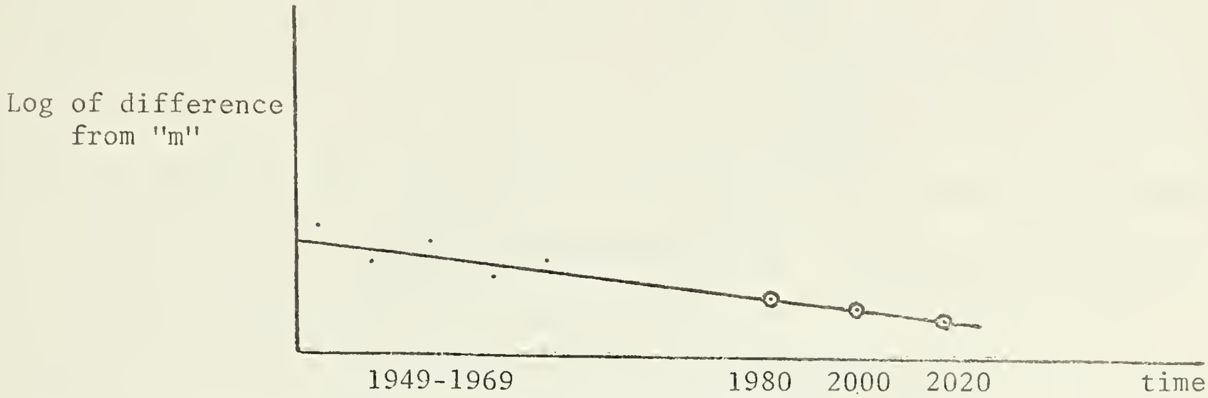

Figure 19. Logarithms of differences projected.

Finally, the extrapolated values are transformed back to linear distance by taking their antilogarithms. Subtracting the antilogarithms from the ceiling figure or adding it to the base yields the projection values of interest for the target dates (fig. 20).

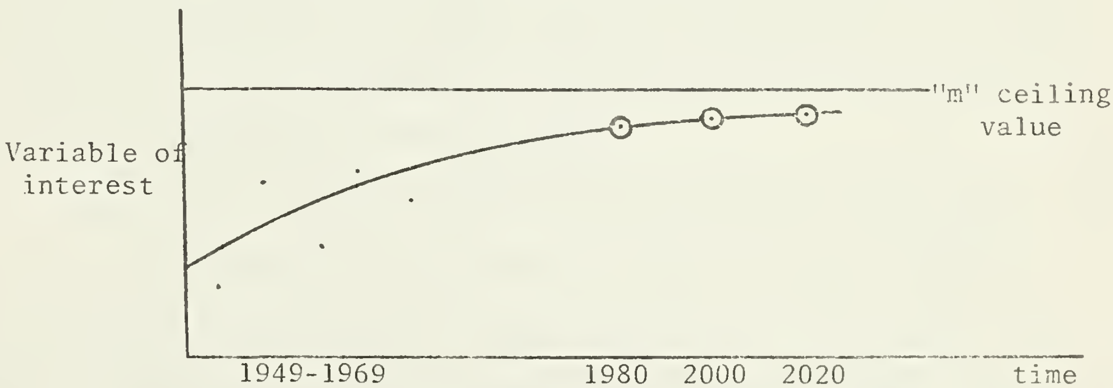

Figure 20. Antilogarithms taken and projection values obtained.

The general form of the equation used is

$$Y = M \pm ab^X$$ Where M represents the base or ceiling figure

In regression format,

$$\log \left| Y - M \right| = A' + B'X$$

where $A' = \log a$

$B' = \log b$

and the quantity to be operated upon on the left side represents the loglinear distance to the ceiling or base figure.

Estimation of Beef Cattle Numbers and Water Demand[24/]

In the estimation of beef cattle numbers and water use, as in the procedure employed for other livestock, OBERS projections of State-level market demands in the target years were allocated among the subareas by a shares analysis. The beef demand differed, however, in that it is not solely satisfied through feedlot operations; additional sources of supply are dairy salvage, dairy veal, and steers and heifers from dairy cattle. From subarea estimates of beef demand, therefore, was substracted beef expected to be furnished by the latter three components. The difference represented beef demand to be met by feedlot operations.

The components of beef supply were estimated as follows:

Dairy salvage. Numbers of dairy salvage cows were estimated by dividing projected numbers of dairy cows by average longevity. Multiplying the result by average weight at slaughter obtained an estimate of the weight of beef supplied by salvage. The longevity of dairy cows was estimated at 8 years, and slaughter weight at 1,100 pounds. To avoid double counting the water consumed by living dairy cows, no additional water demand was attributed to dairy salvage.

Dairy beef. Both dairy veal and steer and heifers for beef were derived from estimates of the dairy calf crop. The calf crop was estimated from projected numbers of dairy cows under the assumptions of a 95-percent conception rate and a 10-percent calf mortality rate, resulting in 85 calves per 100 cows.

24/ This section follows closely the method used by Christensen in The Economic Base of the Southeast Rivers Basin. Reference Report 13, Economic Research Service, USDA. 1970.

a. Dairy veal. Calves for dairy veal were estimated to comprise 23 percent of the calf crop projected for 1980, 20 percent of the crop in 2000, and 18 percent of the crop in 2020. Veal calves were assumed to contribute 250 pounds per head to the beef supply, and to consume 12 gallons of water per day for 90 days.

b. Steers and heifers for beef. Steers and heifers for beef were estimated to comprise 40 percent of the calf crop estimated for 1980, 45 percent of the estimated crop in 2000, and 48 percent of the crop in 2020. They were assumed to contribute 300 pounds per head to the beef supply, and to consume water at 12 gallons per day for 150 days.

Feedlot operations. Feedlot operations were assumed to fill the remaining beef demand, after the above dairy-derived elements were subtracted out. The water use of feedlot cattle was determined by dividing the remaining demand by estimates of average market weights in the target dates, and multiplying the result by an average water use rate. The average market weight of feedlot cattle was assumed to be 610 pounds in 1980, 560 pounds in the year 2000, and 530 pounds in 2020. Water consumption per head is expected to total 12 gallons per day throughout the year.

Finally, feedlot beef cattle which do not reach market were taken into account. A mortality rate of 4 percent was assumed for 1980, and 3 percent for 2000 and 2020. Water consumption was estimated at a rate of 6 gallons per day for 150 days.

APPENDIX 3

Projection of Running Water Use Rates

On the basis of findings of the Ohio River Basin Study[25/] a graph was constructed relating percentage growth in water use rates to the current level of water consumption. A double log linear curve was then fitted, in the relation

$$\log \frac{\frac{dU}{dT}}{U} = a - b\,(\log U), \quad \text{where} \quad \begin{aligned} U &= \text{water use rate} \\ \frac{dU}{dT} &= \text{yearly growth of use rate} \\ a &= 1.071187 \\ b &= 1.279948 \end{aligned}$$

Taking the antilog of both sides, it followed that

$$\frac{\frac{dU}{dT}}{U} = e^{a}\,U^{-b}$$

Multiplying both sides by U^{b} dT and taking the integral,

$$\int U^{b-1}\,dU = \int e^{a}\,dT$$

$$\frac{1}{b}U^{b} = e^{a}T + C$$

$$U = (e^{a}bT + Cb)^{\frac{1}{b}}$$

25/ Ohio River Basin Framework Study, U.S. Dept. of the Int., Federal Water Pollution Administration, 1963. The relevance of these findings was indicated by Steven R. Stegner, of the Baltimore District Corps of Engineers.

The value of the constant term, Cb, was found by fitting into the equation the water use rate at the base year (U_o at T = 1).

$$U_o = (0 + Cb)^{\frac{1}{b}}$$

$$(U_o)^b = Cb$$

Thus, in final form,

$$U = (e^a bT + U_o^b)^{\frac{1}{b}}$$

$$U = \left[(3.735966)T + U_o^{1.279948}\right]^{0.78128}$$