

The American Bankers Association

AGRICULTURAL COMMITTEE

CHAIRMAN

JOHN H. CROCKER, *Chairman of the Board*
The Citizens National Bank
Decatur 30, Illinois

T. P. AXTON, *President*
Lafayette Savings Bank
Lafayette, Indiana

JOHN L. STAUBER, *President*
The Citizens National Bank
Marshfield, Wisconsin

FRANK W. BLACK, *Executive Vice President*
The Peoples National Bank
Barre, Vermont

C. GLENN ZINN, *Executive Vice President and Trust Officer*
Farmers' and Merchants' Bank
Morgantown, West Virginia

JOE A. CLARKE, *Executive Vice President*
Fort Worth National Bank
Fort Worth 2, Texas

ADVISERS

D. M. CROUSE, *Executive Vice President*
Stockgrowers State Bank
Worland, Wyoming

DR. AUBREY J. BROWN, *Head*
Department of Agricultural Economics
University of Kentucky
Lexington, Kentucky

C. RUPERT EVANS, *President*
First National Bank
Lake Providence, Louisiana

DR. EARL L. BUTZ, *Dean of Agriculture*
Purdue University
Lafayette, Indiana

W. D. FINNEY, *Chairman of the Board and President*
Washita Valley Bank
Fort Cobb, Oklahoma

DR. O. B. JESNESS, *Head Emeritus*
Department of Agricultural Economics
University of Minnesota
St. Paul 1, Minnesota

CHARLES H. PATTEN, *Senior Vice President*
Valley National Bank
Phoenix, Arizona

DR. TYRUS R. TIMM, *Head*
Department of Agricultural Economics and Sociology
Texas A. & M. College
College Station, Texas

DONALD B. PETERSON, *President*
The Commercial Bank of Salem
Salem, Oregon

DR. G. B. WOOD, *Head*
Department of Agricultural Economics
Oregon State College
Corvallis, Oregon

J. CARLISLE ROGERS, *President*
First National Bank
Leesburg, Florida

EDGAR T. SAVIDGE, *Secretary*
Deputy Manager, A.B.A.

DERL I. DERR
Assistant Secretary

Agricultural Committee
The American Bankers Association
12 East 36 Street, New York 16, N. Y.

WATER AND IRRIGATION

Development and Financing of Farm and Ranch Irrigation Systems

AGRICULTURAL COMMITTEE

THE AMERICAN BANKERS ASSOCIATION

12 EAST 36 STREET, NEW YORK 16, N. Y.

CONTENTS

	Page
Summary.....	4
Part I – Water and Irrigation	
INTRODUCTION	7
WATER SUPPLY	9
Available Water	9
Developing New Supplies	10
Water Uses	16
Public and Private Assistance on Reclamation Projects	17
Legal Problems	19
IRRIGATION SYSTEMS	21
Water Development Cost	21
System Design	23
Annual Operating Cost	25
IMPACT OF WATER USE ON AGRICULTURE	26
Part II – Financing Irrigation Systems	
GENERAL	35
DIRECT LOANS	36
INDIRECT LOANS	38
CREDIT STANDARDS	42
THE FARMER – THE FARM BUSINESS – THE IRRIGATION SYSTEM	44
SERVICING THE IRRIGATION LOAN	48
Appendices	
APPENDIX A – Basic Water Laws of States	51
APPENDIX B – Water Application Rates – Sprinkler Irrigation	54
APPENDIX C – Fuel Chart	55
APPENDIX D – Fuel Consumption Tables	56
APPENDIX E – Daily Water Use – Sorghum	58
APPENDIX F – Consumptive Water Requirements of Selected Crops	59
APPENDIX G – Criteria for Land Leveling	60
APPENDIX H – Furrow Irrigation Relationships	61
APPENDIX I – Border Irrigation Relationships	62
APPENDIX J – Rate of Water Use – Cotton	63
APPENDIX K – Minimum Requirements for the Design, Installation, and Performance of Sprinkler Irrigation Equipment	64

ACKNOWLEDGMENT

The American Bankers Association's Agricultural Committee gratefully acknowledges the contributions made by Guy O. Woodward, Engineering Experiment Station, Utah State University, and Wayne D. Criddle, State Engineer of Utah, in the preparation of this manual. The unselfish work of these men will enable banking to better serve rural families in their application of water management to farm and ranch operations.

SUMMARY

Water has always been an extremely important natural resource, but never before has the proper management and control of it been so essential. Agriculture's use of water for irrigation has doubled during the past three decades, and it now appears that an even greater increase will occur in the future.

This manual is designed to guide bankers in their decisions to assist farm and ranch families with the development and financing of irrigation systems.

The total supply of water is presently sufficient to serve the needs of all users; however since it is not properly distributed so as to be available where and when needed, the management of water resources is becoming extremely important. Much attention is being given to the development of "new" supplies. This, in reality, is merely a desire to change what is happening to existing supplies.

As a result of experience and accumulated knowledge, many changes are now under way which will increase man's ability to utilize the water supply more efficiently. Better methods of conveyance, distribution, land preparation, and reuse of water have added tremendously to the effective use of our water resources. In addition, the supply of usable water is being expanded since important gains are being made in the areas of desalinization, weather modification, decreasing noneconomic uses, controlling evaporation, and mosquito control.

In the past, agriculture and industry have been the two important users of water . . . industry in the East, and agriculture in the West. However, the pattern is changing in the West where industrial and municipal users are rapidly overtaking the use by agriculture as a result of the expanding population and industrial development in many areas.

Public agencies at the federal, state, and even local levels now offer assistance with water development costs. Now, more than ever before, attention is given to multiple purposes of water development projects with proper consideration to indirect as well as direct benefits to the communities involved.

Many legal problems have arisen as to the rights to water use. It is believed that water usage must be somewhat flexible, and that water must be used for the best public interest. In many areas, much needs to be done to clarify laws concerning water use. A summary, by states, of laws and agencies responsible for their administration can be found in Appendix A.

The planning of a farm or ranch irrigation system requires careful attention to the water development cost, system design, and the annual operating cost. It is important that the banker properly evaluate all such costs and clearly determine the adequacy of the system before credit is extended for this purpose.

The importance of irrigation to agriculture varies for different

crops and for various parts of the country. However, past experience shows that it is rapidly becoming an important factor in profitable farming in many areas and certainly is having a tremendous impact on the agricultural economy through production of higher yielding and better quality crops, thus providing greater returns and a more dependable income.

More and more farmers are making the decision to develop an irrigation system for their farm operation. Such large capital investments generally require some financing. Banks throughout the country are developing programs to handle these loan requests. Two general approaches are used — the direct and the indirect. The direct loan offers an opportunity to provide a more flexible credit program and to develop a good bank-customer relationship. The indirect program is necessarily more rigid in nature, but does offer an opportunity to create a satisfactory volume of business in a relatively short period of time.

In the financing of irrigation installations, particular attention must be given to the man, his business, and the adequacy of the system being financed. The continued interest the bank demonstrates through a complete and sincere service of the loan account is as important as the original loan.

Part I

INTRODUCTION

Importance of Water

Water, now, is universally discussed as never before. "Dwindling" water supplies, the population explosion, and industrial development are being "spotlighted" by the public, and rightly so. Lack of adequate water of suitable quality as needed, and/or its best use, development, and reuse may well determine the future progress and development of our nation and the entire world.

Use of water for irrigation in the United States has doubled in the last 30 years. Recent forecasts indicate that it will again double in the next two decades. A scientific and properly controlled program of development is needed if such demands are to be met. Many legal, economic, agricultural, engineering, and social problems must be studied and solved so that future ventures will be in the best interest of the individual, community, state, and nation.

With these thoughts in mind, the Agricultural Committee of The American Bankers Association decided to prepare this manual. It covers many aspects of irrigation. Competing needs for this precious resource, its uses, development programs, legal problems, economics, government participation, types of irrigation systems, and financing are all discussed.

Guide for Bankers

This manual is intended primarily to serve as a guide for banks beginning to extend credit in the field of irrigated agriculture. However, banks already engaged in this field may find some of the material of benefit. Although many interrelated factors are involved, sound, sensible approaches must always be considered in extending agricultural credit. In fact, such loans often may form the basis by which the economy of an entire area becomes stabilized and effective. Dealers, distributors, manufacturers, and all businessmen will benefit, thus strengthening the community, state, and nation.

For the reader with limited time to study this report, the important points to consider in irrigation design layout are tabulated on the following page (Table 1). The reader will find more detail and explanation on subsequent pages. However, it must always be kept in mind that any water development must be in accordance with the laws of the state. See Appendix A for a summary of the laws for each of the 50 states.

THROUGHOUT THIS PUBLICATION THE TERM "FARM"
WILL BE USED TO INCLUDE BOTH "FARM" AND "RANCH."

WATER SUPPLIES

Available Water

If we talk about the entire world, there is a great amount of water. But it is not usually distributed as needed for man's use. According to Nace,¹ "The total surface area of the earth is 197,000,000 square miles. About 140,000,000 square miles (71%) is covered by the world ocean, about 6,651,000 (3.4%) by polar ice caps and glaciers, about 300,000 (0.15%) by natural fresh-water lakes, and about 200,000 (0.1%) by natural saline lakes. About 50,500,000 square miles² (about 25%) is continental dry land. Somewhat more than 18,000,000 square miles (about 38%) of the land area is arid to semiarid."

Mr. Nace has also estimated the distribution of the world supply of water in Table 2.

TABLE 2
Distribution of World Supply of Water

Location	Volume of water (billions of acre-feet)	Percentage of total
World ocean	1,060,000	97.39
Water on the continents*		
Glaciers and polar ice caps	19,927	1.83
Fresh-water lakes	101	.0093
Saline lakes and inland seas	68	.0063
Average in stream channels	.253	.00002
Root zone of the soil	10.2	.00094
Ground water, above 2,500 ft.	3,700	.339
Ground water, 2,500 to 12,500 ft.	4,600	.424
Subtotal on land	28,406.5	.0011
Atmosphere	11.5	
Rounded total	1,088,418	100

*The total land area, including that under ice caps is about 51,970,000 square miles.

The average precipitation on the continental United States is about 30 inches, of which 21 inches is consumed where it falls. This leaves nine inches of manageable water. Presently only about three inches is withdrawn from the underground and from streams, and about one inch is consumed. If precipitation were uniformly distributed over the country, and if it were distributed throughout the

1R. I. Nace, "Water Management, Agriculture, and Ground-Water Supplies," United States Geological Survey, Washington, D. C., November, 1958, pp. 1 and 5.

²Nace further points out that the land area of the United States contains only 5.3 per cent of the total world land area. Consequently, if the ground-water supply above 2,500 feet were equally proportioned, our share would amount to 196-billion acre-feet. In contrast, the large lakes on the North American continent contain one-fourth of all the fresh water on the globe.

TABLE 1

Items to Consider for Overhead Sprinkler and Surface Irrigation Methods*

Item	A COSTS	B. RETURNS
1. Interest	(a) All original costs of obtaining and developing water (b) Total investment on sprinkler system (c) Land in ditches not available for cropping (d) Special farm equipment needed for irrigation purposes	(a) Gross returns from crops (b) Any fire control benefits (c) Other benefits
2. Depreciation	(a) On all equipment, both portable (15 years) and stationary (15-30 years) (b) On special irrigation equipment (create 30 years)	(a) Drainage system to remove excess rainfall and irrigation water (b) Drainage system required to remove excess rainfall and deep-percolation from irrigation
3. Power	(a) Power for obtaining water (1 1/2¢/foot of lift/acre-foot) and for operating sprinkler system (approximately \$1.50/acre-foot) (b) Power for land preparation equipment (c) Power for pumping if source of supply is not at highest point on farm	(a) Maintenance on sprinkler systems (usually amounts to about 20 per cent of the labor cost) (b) Service on power units (c) Same as sprinklers (c)
4. Water Cost	(a) Annual cost of water from source including operation and maintenance on water supply (b) Annual cost of water from source	(a) Moving of sprinkler laterals (1/4-1 hour/acre), pump and screen cleaning, and valve regulation† (per application) (b) Storage of equipment for winter, moving to harvest crops, etc. (c) Same as sprinklers (c)
5. Labor	(a) Farrowing out crop, making borders, etc. Adjusting and controlling water, including installation of siphons, spiles, gated pipe, headgates, (1/2-1 hours/acre/application) (b) Same as sprinklers (c)	(a) Farrowing out crop, making borders, etc. Adjusting and controlling water, including installation of siphons, spiles, gated pipe, headgates, (1/2-1 hours/acre/application) (b) Same as sprinklers (c)
6. Maintenance	(a) Maintenance on sprinkler systems (usually amounts to about 20 per cent of the labor cost) (b) Drainage system to remove excess rainfall and irrigation water (c) Drainage system required to remove excess rainfall and deep-percolation from irrigation	(a) Maintenance on sprinkler systems (usually amounts to about 20 per cent of the labor cost) (b) Drainage system to remove excess rainfall and irrigation water (c) Drainage system required to remove excess rainfall and deep-percolation from irrigation
7. Drainage	(a) Drainage system to remove excess rainfall and irrigation water (b) Drainage system required to remove excess rainfall and deep-percolation from irrigation	(a) Drainage system to remove excess rainfall and irrigation water (b) Drainage system required to remove excess rainfall and deep-percolation from irrigation

*Subirrigation is so limited in usage that it is not itemized here.
†Larger mechanical moves may be much less.
Source: Compiled by Messrs. Woodward and Criddle.

year as needed for agriculture, industry, municipalities, and other users, our water problems would be much simpler. There is a great dry "fan" extending generally from the Columbia River, which runs westerly into the Pacific Ocean, and the Mississippi which flows southerly into the Gulf of Mexico. Both of these rivers discharge tremendous quantities of unused fresh water to the ocean each year. If part of the Columbia River flow could be shifted southward and part of the Mississippi westward, great areas deficient in water supply could be firm up. True, the cost is great, but needs and benefits may someday warrant such costs. But with all the water that falls on our more humid eastern area, more and more irrigation will be required to meet the needs of many quality foods - particularly vegetables.

With all our trouble in getting adequate usable water to meet our needs, we still have a tremendous ground water reserve in the United States. Assuming Nace's estimate to be correct that the annual recharge to the ground water is 1.2 billion acre-feet within the upper 2,500 feet of the earth's surface, tremendous droughts extending for long periods of time can be weathered if the country is properly prepared. The big problem right now is that drafts on local "branch banks" are not uniform. Some of the locals are being heavily overdrawn. Others are receiving no drafts. Thus, water management must enter into the picture to assure more uniformity.

WATER NEEDS

Water is basic to all our needs. Even in the midst of perennially water-short areas, few users know what this need really is. True, many irrigators may know how much they like to divert to keep labor and structure needs to a minimum. However, few realize that in many areas, for every four acre-feet diverted from the source, only one reaches the plant roots for actual use by the plants. Only recently have irrigators begun to understand that a wheat crop in producing 60 bushels per acre needs only about 15 inches of water for consumptive purposes, and that part of this may come from rainfall on the field itself. Likewise, many cities go on year after year without metering water to their consumers, never finding out how much water is really needed, nor how much is being wasted.

Developing New Supplies

Talk about developing new supplies of water is, in reality, merely hope of changing what is happening to existing supplies. Actually, new supplies cannot be developed. They are simply "new" to the new use to which they are put. Development simply stops some natural use from occurring or prevents water from wasting to the ocean.

Natural uses resulting in little or no economic returns to the country are tremendous. Such uses continue even while we talk about water shortages. Evaporation from water surfaces and moist land

areas, and the amount used by so-called "phreatophytes" continues at a phenomenal rate.

Water supply development is controlled and limited by many factors. The unavailability of water may offer a physical limitation that simply cannot be overcome.

Closely associated with physical availability is the economics of the development. Before extending credit for an irrigation project, costs and physical feasibility of water development must be known. In fact, all factors affecting costs and the benefits must be known to determine the soundness of the venture. A number of these factors will be discussed under a later heading, "Water Development Costs."

It is possible that water development for irrigation may be sound both physically and economically, but still should not be pursued. Some of the reasons for hesitating could well be state or area policies, or other uses with a higher priority such as industrial needs or municipal expansion.

Legal aspects *must* be carefully investigated. The right to use water can be denied even after construction has taken place if water laws are not followed. Appendix A gives a brief summary of the laws of each state as they affect water use. This also shows the agency responsible for water rights administration. Water laws should be well understood for the state in which a person is interested. Some states, for example, require and grant limited time permits to use water for irrigation. Others require no permits. Still others grant rights to use water on a priority basis which means first in time is first in right. Lack of sufficient basic information on state water laws has proved detrimental to water supply developments of all kinds. The projects have failed because all of the basic information was not gathered and used. Still other potentially successful projects have been refused because of being judged on only a portion of the facts.

CHANGES UNDER WAY

What is often considered as the total usable water supply may be far from correct. As knowledge and understanding of this great resource and its uses increase, man's ability to use it more beneficially will increase. Consequently, as in all fields of endeavor, more basic data is needed.

A complete inventory of all water falling on each drainage and its disposal must be known eventually. This is especially important in the arid West where surface run-off now represents less than 5 per cent of the precipitation falling on the watershed above. Small changes in the amounts retained on the watershed may cause a great effect on the flow in the valley below. And, although the quantity of water coming off the watershed is important, the way in which it comes is equally important. An infrequent high peak flow without storage will not serve man's need. And, often, natural storage caused by improv-

ing the watershed may be cheaper than building complete artificial storage.

CONVEYANCE

It has been estimated that up to 25 per cent of the water diverted from streams for irrigation purposes is lost from the canals and ditches en route to the fields. This offers a real source of water saving and salvage. The increased use of lined canals or pipelines is eliminating many of these losses that have existed over the years. Also, the use of plastics, chemicals, and highly dispersed sediments to seal leaky canals is becoming increasingly popular. With present techniques and materials, these conveyance losses should be held to a minimum.

DISTRIBUTION

Distribution of water among users and application to the land become extremely important for efficient use of irrigation water supplies. For surface irrigation, land improperly leveled and lacking a good irrigation system layout will result in wasted water regardless of how much personal attention is given by the irrigator. Likewise, irrigation requires some attention even with the best prepared land surface and best irrigation system. Without proper attention, low efficiency in the use of water will occur.

Thus, both suitable irrigation equipment and good technical guidance for the layout of the farm irrigation system and establishment of proper irrigation practices should be sought. Irrigators should be encouraged to utilize this help which is generally available through the United States Department of Agriculture, various state colleges, or private specialists in the field.

DRAINAGE AND REUSE OF WATER

Large areas of our country are presently unsuitable for agriculture because of lack of drainage. Even in the arid West, natural or man-made wet areas are wasting great quantities of water back to the atmosphere and keeping land out of productivity. The man-made wet areas are usually the result of canal seepage or overirrigation.

Man now understands the problems of drainage much better than ever before. Wet lands can and should be drained and the water put to beneficial use. Oftentimes the more saline drainage waters cannot be used directly for irrigation; however, dilution with fresh water is an accepted practice.

PHYSICAL LIMITATIONS

Since World War II there have been tremendous changes in machinery and equipment. Conversion of land which a few years ago could not be considered as suitable for leveling and irrigation is now

entirely feasible. Now farms are constructed to meet the desire and need of the owners. If topsoil is shallow, it is simply stock-piled to one side until the subsoil is leveled to the desired grade. The good topsoil is then uniformly spread over the field. Also, canals can now be constructed and lined in record-breaking time. Continuous underground concrete pipelines can be poured in place at considerably less cost than if constructed from precast sections.

It is now quite possible to move mountains and construct earth-fill dams — projects far from practicable a few years ago. Owners of irrigated farm land are now "thinking big." And so they must, if they are to keep pace with the changing civilization and its moon rockets. Our top farmers have been one of the leading groups in enlisting mechanical know-how and applying new developments. But the gap between the good farmers and the subsistence farmers is tremendous and must someday be closed.

Thus, when we see the Mississippi and Columbia Rivers discharge great quantities of water into the ocean every year, we must start thinking about 1,500-mile moves of this water. Such "pipe dreams" could not even be imagined a few years ago because of the physical limitations (nor could most of us believe a flight to the moon possible in our lifetime). A mountain in the way doesn't bother us now. We can either go around it or through it. And we will do just that when our population demands more food and fiber.

SPECIAL MANAGEMENT CONSIDERATIONS

We must keep in mind that water can be used over and over until it is literally worn out. As an example of this thinking, we might go through the cycle of uses that often occur from the time precipitation falls on the watershed until some residual part of it eventually reaches the sea.

Snowfall on high mountains forms the basis for much winter recreation. Skiers are taking to the hills in ever greater numbers. They are able to use the "water" before it melts and starts its trip downward.

After the snow melts, part is retained to grow timber and range plants. Some goes into stream channels furnishing fishing streams and watering wild life. It may then go through a power plant to generate electricity on the way down to centers of population.

By this time, the water has already been used at least three times. Now, part of it heads for agriculture, part for industry, and part for municipal uses. But water diverted for agriculture may be diverted and then rediverted several times. Only part of that originally diverted reaches the plant roots and is transpired back to the atmosphere. A major part percolates into the ground and either returns naturally to the stream or is drained or pumped out of the ground and reused.

Industry generally uses water for cooling, washing, or transporting. As a result, most of that originally diverted is available for reuse. The same is true of that diverted for municipal uses. A relatively small part is actually consumed. Under some of these uses the quality may be greatly impaired; however, we know how to clean up effluent from agricultural drains and from industrial and municipal uses. Such reclamation costs money; but water, as long as it is wet, will probably justify the cost of reclaiming as time goes on.

Now, after once serving the needs of these primary users, (agriculture, industry, and municipalities) the remaining water may be reused by any one of the other users although normally it is not desirable to have municipal and industrial effluents reused for municipal purposes. But both agricultural and industrial interests are becoming anxious to use treated sewer effluents.

And toward the low point on the "totem pole" of water users are wild life refuges. Ducks and other game birds on the refuges which receive the final effluent oftentimes thrive.

DESALINIZATION OF WATER

There seems to be little difficulty in desalting sea water or making brackish water potable. The problem is to find processes by which the ends can be achieved at economical cost. To date, the costs have been from about \$1,000 down to about \$300 per acre-foot. The most optimistic figures to date suggest that costs in the neighborhood of \$125 to \$150 per acre-foot might be reached. Such costs, while practical for certain industrial and domestic uses, are far out of line with respect to what agriculture can pay.

WEATHER MODIFICATION

Rainmaking, by one means or another, has been attempted from time to time for many decades -- or even centuries. In fact, man's interest in weather modification can be traced back through records and artifacts to the Stone Age.

Although results to date have not been too encouraging, increased studies by high-altitude observatories and more basic information on the effect of the sun upon our weather and water supplies may offer some interesting ways of modifying our weather and rainfall conditions.

DECREASE NONECONOMIC USES

Perhaps the most practical and economical means to get some immediate relief to some water supply problems, particularly in the West, is by taking water away from plants and other water users that are of little or no economic value. Undoubtedly as time goes on, water use will be evaluated in terms of the returns expected per unit of

water used and the need for the use to which the water is put. Certain heavy-water-using crops and processes may be restricted in areas of extreme water shortages.

CONTROLLING EVAPORATION

According to a report to the Committee on Interior and Insular Affairs, United States Senate, 85th Congress, 2nd Session, dated April 14, 1958, a great amount of water is lost directly by evaporation. In the Western States, such losses due to evaporation from water surfaces average 11.5 million acre-feet per year. Evaporation from Lake Mead alone exceeds 700,000 acre-feet annually.

MOSQUITO CONTROL

Mosquito control problems have been created by improper irrigation and drainage practices and should be considered both as a farm and community problem in irrigation system design. A good system should be designed so that no mosquito problems are created nor allowed to exist.

In many irrigated areas of the West, mosquitoes are a menace to the health of human beings and cause economic losses because of their effect on animals. Those areas bothered most severely seem to have several conditions in common. Usually the soils are tight, the slopes flat, and generally poor irrigation and drainage practices are used.

Contrary to popular belief, permanent streams and sloughs do not produce all of the mosquitoes. In fact, because of the minnows and many other natural enemies of the mosquitoes that develop in these waterways, few of the mosquito larvae ever reach the adult stage.

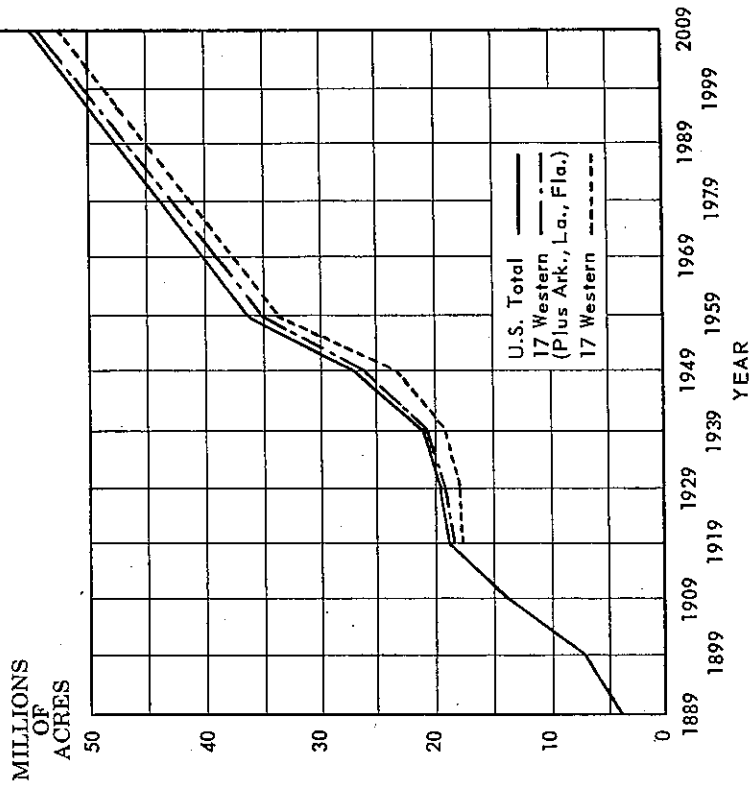
The greatest production of mosquitoes, however, is in those areas flooded intermittently and where water stands for one to three weeks. According to the entomologists, the adults of certain kinds of mosquitoes lay millions of eggs in the soft mud as the water recedes. These eggs lie dormant as long as a year, if need be. Just as soon as water hits them again, and if the temperature is right, they hatch out and, within about a week develop into adult mosquitoes that are hungry and ready to go to work on people and animals. If the free water disappears in less time than it takes to develop the mosquitoes, we have no problems.

Thus, mosquito control plays right into the field of conservation irrigation. During the heat of the summer, alfalfa and many of our better legumes and grasses will be killed in less than 24 hours by ponding water. Only water-loving plants can withstand extended periods of ponding. Therefore, if a farmer raises good alfalfa on his field, he cannot raise mosquitoes. On the other hand, if he allows ponds to develop which will raise mosquitoes, he cannot produce alfalfa.

Water Uses

Expansion of irrigation in the United States (see Figure 1) has been greatest since 1939. In 1939 about 21½ million acres of land were reported as irrigated in the United States. This figure rose to 27 million in 1949, and to over 36 million in 1959, or almost a 70 per cent increase during the 20-year period. In the past, agriculture has been the greatest single user of fresh water in the United States. From three to four million acre-feet are used daily during peak periods. Nearly half of the total fresh water used annually is for irrigation purposes. Well over 90 per cent of this total use for irrigation has been in the 17 Western States.

FIGURE 1
Trends in Irrigated Acreage in United States,
17 Western States Plus Ark., La., Fla., &
17 Western States — 1889-2009



Source: Prepared by Messrs. Woodward and Criddle. Data from Irrigation Census and various projections by others were used in preparation of this chart.

Industry has been the next largest consumer of water. It also requires nearly half of the water used in the United States. Major uses for industry have been in the eastern half of the country.

Public and rural supply constitutes only a small percentage of the total water use — some 6 per cent.

However, the pattern of water use is changing rapidly in the West. Because of the expanding population and industrial development, municipal and industrial use of water is rapidly overtaking the use by agriculture. These new uses produce more income per unit of water and allow for greater utilization of man power than does agriculture. As an example, California made tremendous changes from 1950 to 1955 according to McGauhey and Erlich.³ In 1950 agricultural uses were reported as being 68 times as much as industrial uses. By 1955, the ratio had decreased to 3.8:1. This was not the result of any decrease in irrigation. Reported irrigation use actually increased 12.6 per cent in the five-year period. But industrial uses increased over 2,000 per cent. And eventually, agricultural uses may be reduced because economics will allow industrial users to purchase water rights from agricultural users.

From an agricultural loan standpoint, this trend should not be considered serious. The change will occur only if industry can properly reimburse agriculture, and this should fully safeguard the security of the loan.

Public and Private Assistance on Reclamation Projects

There are a number of agencies that can assist on irrigation projects and help individual farmers. These include both federal and state agencies, and occasionally there is assistance at the county level.

WHAT ABOUT RECLAMATION?

Irrigation water development projects benefit not only the irrigation farmers but all activities within the area. Indirect benefits often greatly exceed direct benefits. Thus, more attention is being given to multiple-purpose projects and to community benefits that result from these developments. Also, in many areas, development for agricultural uses is merely "banking" water or temporarily using it until a higher economic use develops. Through due process of law, water then can be taken over by other users. Agricultural users will get along on less water per acre of ground or retire some land from irrigation.

Regardless of the development, its location, and the use to which

³P. A. McGauhey and Harry Erlich, "Economic Evaluation of Water," *Proceedings of American Society of Civil Engineers*, Vol. 85, No. IR-2, Paper 2059, Ann Arbor, Michigan, June, 1959, p. 13.

it is to be put, all factors affected should be given proper credit for any benefits to each. New irrigation projects can no longer be justified economically with only part of the factors included. Indirect and public benefits are just as real in many cases as are the direct benefits to the farmers. The public must be made aware of these benefits and must accept the responsibility of paying for them.

PUBLIC AGENCIES

United States Bureau of Reclamation — The Bureau was established over 50 years ago to construct projects beyond the physical capability of the local people. Originally the Bureau constructed purely irrigation projects, all construction costs to be repaid by the water users. Over the years has come a gradual change in the policy of the Bureau until today most projects are multipurpose in scope. Oftentimes nonreimbursable flood control and fish and wild life interests constitute a major part of the cost. And power development which must be repaid with interest is forming a mighty work horse on which other interests must lean in order to make the project feasible. We now have the "Basin Account" concept under which projects that are predominantly for power production are constructed and their net revenues used to assist other water development projects in the basin. Under the policy of the Bureau, only the large projects would be constructed, including the storage and diversion works and the canals and main laterals on the project lands. More recently, project drainage and smaller laterals have been considered as proper work, also. Salvage of water from phreatophytes is likewise now considered as a proper function of the Bureau.

In 1956, Public Law 984 was passed by the 84th Congress, 2nd Session, allowing the Bureau of Reclamation to assist on small reclamation projects where the total costs did not exceed \$5-million. Such projects actually tend to get into land developments as well as project development. Under this law, the Bureau can assist in the construction of the complete distribution system to deliver water to each individual field.

United States Army Engineers — Civil projects of the Army Engineers are largely in the field of Harbors and Flood Control. However, recently some municipal water storage and water salvage has been built into their projects. Although flood control projects are considered nonreimbursable, any water conservation must be paid for by the beneficiaries.

United States Department of Agriculture — Under programs of the U. S. Department of Agriculture, both technical and financial aid is given water conservation projects.

The Soil Conservation Service program, with its districts established under state law, supplies most of the technical assistance for

all soil and water conservation work within the Department. Assistance on individual farms and to small groups has been the major effort of this agency. S.C.S. also operates the small watershed program under Public Law 566, passed by the 83rd Congress, 2nd Session. This program provides for working with state and local officials in establishing complete conservation programs on watersheds of 250,000 acres or less. It also allows for making studies on larger watersheds in cooperation with state and other federal agencies, to develop a framework plan under which the various agencies can work in a coordinated effort.

The Agricultural Conservation Program assists individual farmers and groups financially in getting permanent conservation practices on the farms. The technical aspects of this program are handled by the Soil Conservation Service technicians.

The Farmers Home Administration makes available loans at a low interest rate to worthy farmers to assist in the farm operation. Frequently, such loans are made to assist in the construction of water conservation structures or practices.

State agencies — Most states give assistance in the development and construction of water conservation projects. Usually such help is given in the form of interest-free loans and technical help.

Also, in cooperation with the Extension Service of the U. S. Department of Agriculture, a rather complete educational program is offered in the field of water conservation. Educational assistance is available through the County Agent and Extension Service Specialist programs. Most of the Western States have an irrigation engineer on their extension staffs, and his services are made available to the individual farmer and to farmer cooperatives.

Private assistance — Farmers wishing technical help may often get considerable assistance from the equipment dealers and operators in the area. However, the tendency of such technicians to push their particular equipment, and the possibility of the farmer not hearing all sides is to be expected. Nevertheless, a well-informed person can get a great deal of help without making improper requests of the company representative.

Private capital is also available for many agricultural developments. But generally the long-term loan does not appear to be too attractive. The sale of revenue bonds has been suggested as a reasonable approach for some of the larger projects.

Legal Problems

Water law in the eastern United States has been based on the theory of riparian rights; i.e., the rights of the owner of waterfront property. With respect to streams, riparian rights include the right to have flow of water continue past his property undiminished in

quantity and unpolluted in quality. Obviously this, taken literally, will not allow any development for consumptive purposes. Most uses cause some stream depletion, and quality is also usually affected to some degree by any usage.

In the West, the law of prior appropriation and beneficial use generally governs. Agriculture (largely irrigation) was the first major user. And it seems to be only human nature for any appropriator to attempt to tie up more of the usable water than actually is needed. But assuming the first appropriators do use the water beneficially, later users must purchase water from older users to assure its availability for their needs. This may be entirely proper since industries and other users often return many times what agriculture does per unit of water; and because of its greater value to them, it is worth their while to purchase it.

Thus, in the public good, it is believed that water usage must be somewhat flexible; i.e., that water must be used in the best public interest. It is not suggested that a man doing a good job of irrigation farming should be deprived of his right to the use of water except under due process of law. If the water is needed for a higher use, the new user must pay a proper amount for the right. But the vehicle for accomplishing the changes necessary for public good must be available, and the public made aware that such is possible.

IRRIGATION SYSTEMS

Irrigation systems discussed here will be limited to the privately owned family farm. In order properly to evaluate such systems for extension of credit, it is first necessary to determine the adequacy of the irrigation system.

Water Development Costs

In extending credit, consideration should be given to all of the costs involved in developing the water and transporting it to its place of use.

All items of importance affecting the cost of irrigation water supplies should be known, and added to that of the overall irrigation system.

WELLS

The cost of constructing and developing a well should be amortized over its expected life. For example, a receding water table may limit the life of a well. Geologists, well drillers, or others having such knowledge for the area in question should be called on.

The type of water-bearing formation, quality of water, casing material, or some such factor may also limit the expected life of the well. Such information is needed before extending credit for irrigation.

Water-use permits or rights in some areas may be given for only a specific time. Construction and development estimates should always be obtained from the contractor in advance of drilling.

DAMS

Unless a sedimentation problem exists, dams need not be depreciated. With proper maintenance, dams should be as good in 100 years as when constructed. Proper annual maintenance charges will be needed as will interest on the investment.

Where sedimentation or silting occurs, an estimate of the life of the reservoir should be made from the silting rate. If dredging or cleaning is feasible, maintenance could be prorated on an annual basis.

Costs of dam construction, including the necessary spillways to protect the dams, can be estimated rather accurately. In some cases, spillway costs exceed the cost of the dam itself.

STREAM-FLOW DEVELOPMENT

Costs of developing water supplies from streams can also be quite accurately estimated. Diversion works and conveyance facilities must not be overlooked. Bridges, culverts, rights-of-way, and maintenance costs should be carefully checked.

DEVELOPMENT OF SPRINGS AND SEEPS

The same general considerations should apply in this category as with the surface streams. All costs should be considered.

OTHER DEVELOPMENT COSTS

Where electric power is to be used, the possible cost of extending the power lines should be considered. This is an important, but often overlooked, item which the local power company may not install without cost to the new user.

The original cost of a farm irrigation system is important, but does not indicate operation, maintenance, and replacement costs. The greatest item in the original cost of developing land for surface irrigation is leveling. With good maintenance, depreciation is negligible. Without maintenance, depreciation should be charged against land leveling at a rate which is consistent with experience in the area.

Other costs of land preparation may include brush clearing, terracing, and surface and subsurface drainage. Costs of conveyance systems, either open channel, closed conduit, or a combination of the two must be considered. Regardless of the type of system, annual maintenance is necessary and should be budgeted.

Irrigation structures such as drops, checks, turnouts, division boxes, spiles, siphons, and gated-pipe, and farm machinery such as floats, ditchers, border-drags, furtowers, and/or other equipment are always involved.

If a well and pumping plant is a part of the system, interest and depreciation must be considered as well as the annual operation and maintenance costs.

As in most undertakings, labor is a most important item in costs. It must not be overlooked.

Sprinkler irrigation costs should be measured by the same economic "yardstick" as surface irrigation; i.e., the total annual costs and benefits per acre. Although water development costs may not vary directly with the type of irrigation system used, generally surface irrigation requires large streams for efficient application, while sprinkler irrigation can utilize either small or large streams with equal efficiency.

Costs of a distribution system for sprinkler irrigation can be broken down into three main headings: mainline, lateral, and system control equipment.

Although mainline equipment could have been considered under water "Conveyance," it is generally considered to be a part of the farm distribution system. Pipe sizes should be chosen to give maximum economy. To accomplish this, the annual cost of the pipe added to the annual fuel cost should be studied for each size of pipe that will do the job. Only then can the most economical size pipe be determined.

Annual costs of sprinkler laterals should also be considered on a

per-acre basis, and the pipe size should be determined to prevent wide pressure fluctuations from one end to the other. Pressure variation along the lateral line should not exceed 20 per cent.

Control equipment, such as T-valves, should be included. The additional cost for these items is usually readily offset by the saving in labor.

Subsurface irrigation development costs may be quite similar to surface irrigation costs. With this method of irrigation, the distribution system consists of feeder ditches with regulating devices to maintain the water at a specified depth in the ditches. Subirrigation as a method of artificially applying water is limited to special site conditions not generally found throughout the country. Labor costs are usually low.

System Design

Detailed information in the form of "irrigation guides" is available for the various areas in each state. These guides, available from the Extension Service or Soil Conservation Service, show the flow rates and volume of water needed for each irrigated acre. The total farm requirement in gallons per minute and/or the acre-feet per year can be computed using the acreage under consideration to determine if the system design is ample.

Recommended frequency of application for each crop is shown in the "irrigation guides" for various soil types, depths, water-holding capacities, and so on. An irrigation system design should show this information. Some conditions may justify a variation from these recommended standards, but the justification should be stated.

A sprinkler irrigation system design will show the number of sprinklers and the spacing of sprinklers on the lateral line as well as the spacing of laterals on the main line. Appendix B was prepared for use in determining the depth of water that will be applied on the field in any given time. Application rates are important and should be consistent with those shown in the irrigation guides. A rate higher than maximum can cause soil compaction and run-off. A rate that is too low will allow for excessive evaporation and wind drift.

For surface application, recommended lengths of run and stream sizes are available for each site condition. A design for surface application should be consistent with the irrigation guides in this respect, also.

Pipe size determination has been discussed elsewhere, and if the economics of the mainline or supply lines has been considered, there should be no further concern on this phase. Lateral sizes have also been discussed, but perhaps should be rechecked for pressure variations along the line.

The horsepower needed for various pumping loads can be computed or determined from tables. An electric motor will deliver the

horsepower stamped on the specification plate. But combustion engine usable horsepower varies with elevation and temperature and must be so adjusted. Also the horsepower rating of engines is made for a bare engine without fan, generator, or other equipment and, hence, must be adjusted for these accessories as well. A further reduction in usable horsepower to only 50 per cent of the rated horsepower may result from noncontinuous operation.

Labor requirements in irrigation vary with method of irrigation, experience, type of equipment, and many other site conditions. A few checks of potential labor costs may be in order, however.

In sprinkler irrigation, labor for hand-move systems varies from 0.5 man hour per acre per move to over 1 man hour per acre per move. An experienced man under good conditions should be able to approach or beat the half-hour time. As crops grow taller, more time is required. Mechanized laterals and wheel lines can be moved in just a few minutes, greatly reducing the time and drudgery of the job. Consideration should be given to labor-saving devices and automation.

A good surface irrigation system will compare favorably with sprinkler irrigation in the labor requirement. Consideration should also be given here to automation and labor-saving equipment.

Fuel types will be mentioned under "Annual Operating Cost." The suggested tables are sufficiently accurate to be used in estimating costs. If actual fuel consumption greatly exceeds that shown in the tables, the pumping plant and piping system should be checked by a qualified person.

Irrigation system management is the key to success in this venture. Water should be applied when and in such quantities as needed. A "feel" chart, Appendix C, was developed to indicate, by the feel of the soil, how much moisture is available for crop use. Study and practice in the use of this chart will give the operator greater effectiveness in irrigation and can well result in increased crop production.

All irrigation structures should be given proper care. Siphons, spiles, and plastic and canvas dams should be cleaned and stored when not in use. Irrigation pipe should be piled on racks above the ground for overwinter storage. Rubber gaskets should be stored in water over winter. Pumps and engines should be kept dry and properly serviced according to the manufacturer's recommendations. During freezing weather they should be drained and covered for proper protection.

Irrigation systems may have some "off season" uses of value to the owner. Fire protection is an important consideration. Emergency water supplies may be another. Settling dust in roads and in yards is easily accomplished, as are a number of other jobs that require a supply of water.

Here, again, it should be emphasized that a competent engineer can be most helpful to one not fully familiar with irrigation practices and system requirements and can often save him a great deal of money. Only an engineer thoroughly familiar with irrigation

system design and one who has had experience along this line of work should be consulted.

Annual Operating Cost

Land preparation for irrigation is a continuing cost. Good surface irrigation of annual crops requires "floating" — dragging the surface to remove small irregularities — preferably in two directions.

Operation and maintenance of the system is a "must." Costs for repairs, operation, and maintenance of the irrigation structures, and costs for the pumping plant, must be listed. All labor, such as that needed for pipe moving, surface irrigation, ditch cleaning, and weed control on ditch banks, must be considered.

Fuel costs for pumping can be quite closely estimated (see Appendix D) by knowing the hours per season of expected pumpage. In the case of electricity, standby charges or other fixed costs should be added to the total calculated fuel consumption costs. Oil and grease may be considered with the operation and maintenance costs.

A cost item often overlooked in irrigation is the value of land lost to production because of ditches, roads, and the like. This land out of production will reduce the overall returns and should be given appropriate weight in any cost-and-return analysis.

IMPACT OF WATER USE ON AGRICULTURE

Proper irrigation requires the uniform and efficient application of water to soils as needed to keep plants rapidly growing. Since growing crops require plant food, water, and air in their root zone, too much or too little of any of these will slow down or stop growth. The purpose of irrigation, whether in arid or humid areas, is the same; i.e., to make water a nonlimiting factor in crop production. In most areas of the United States drought periods occur. In the Southwest, long periods of drought are expected. In the more humid regions, drought periods may be of only a few days' or a few weeks' duration. But droughts *do* and *will* occur, and plants that get too dry just once each summer may not produce any more than if the entire summer were dry.

WATER REQUIREMENTS OF CROPS

The quantity of water required for consumptive use of each crop is rather uniform throughout areas of similar climatic conditions. This consumptive requirement can be met by rainfall, moisture stored in the soil from winter precipitation, moisture from a high water table, and/or water from irrigation. If sufficient water is available from any one or a combination of the natural sources, then irrigation is not needed. Soils play an important part in the amount of water that is made available for crop use from these natural sources, and only the deficit needs to be supplied by irrigation. Also, the efficiency with which the irrigation water can be applied is affected by the soil characteristics; and soils must therefore be taken into consideration in designing the irrigation system.

Investigators of irrigation have found that most precipitation falling during the summer or growing season in irrigated regions is available for consumptive use by the crops. However, in those areas where rainfall is heavy and where considerable spring run-off occurs, corrections must be made for the noneffective precipitation. After the effective precipitation has been determined and after the moisture contributions from other natural sources have been evaluated, it is then possible to estimate the net consumptive water requirement that must be supplied by irrigation.

The daily use of water by grain sorghum in the High Plains area of Texas is shown in Appendix E. It will be noted from the figure that at the time of planting about .05 of an inch of water is lost daily by evaporation from the land surface. By the time the sorghum has reached the "boot stage" (some 50 days after planting), daily water use has reached a maximum of over .30 of an inch per day. This higher rate includes both evaporation from the land surface and transpiration through the plants. After the "boot stage," the use of water de-

creases until harvest time when the only loss is evaporation from the land surface. The total seasonal consumptive use is about 24 inches, of which precipitation supplies about 11 inches in this area.

The consumptive water requirement for some major crops at selected points throughout the western United States is shown in Appendix F. In using this table, it must be remembered that the effective precipitation should be subtracted from the depths shown and this deficiency should then be supplied to the crop for optimum production. Also it must be remembered that more water will be needed at the farm than this net amount, since some excess is always needed in applying the water and storing it in the soil for use by the plants. The efficiency of application should be in the neighborhood of 60-80 per cent, depending on the method of application, the soil, and the climatic conditions under which the water is applied.

APPLICATION OF IRRIGATION WATER

Irrigation water may be applied to the land by surface, sprinkler, or — under rate conditions — subsurface methods. If a sprinkler system is properly designed and used, control and high efficiency in the use of irrigation water presents no real problem. However, if the water is to be applied by surface methods, land preparation and system design become extremely important for good, efficient irrigation.

Criteria for land leveling for each of the various surface methods of applying water are presented in Appendix G. Furthermore, even after the land is properly leveled, there are certain relationships between the influencing factors that must be observed if proper irrigation is to be accomplished. These influencing factors are:

1. Size of irrigation stream
2. Texture and intake rate of soil
3. Slope of land
4. Depth of water to be stored each irrigation
5. Unit area of land to be irrigated with a given stream

The irrigation relationships for furrows and borders are given in Appendices H and I.

Moisture control through irrigation has resulted in benefits extending far beyond the farm. Some of these indirect benefits will be discussed later. However, the direct benefits to the farmer vary widely for several reasons:

1. The amount of irrigation water needed and its cost vary widely from one area to another.
2. Different crops have widely varying returns.
3. Uniformity and efficiency of water application vary widely.
4. The cost of applying water is widely variable.

Needless to say, irrigation pays greatest dividends on high-valued crops in areas where the frequency and duration of droughts during the growing season make it hazardous or impossible to grow such crops

without addition of water. However, in the United States, hay and pasture are the most widely grown of irrigated crops; and yield-returns, because of irrigation, are as varied as the climate over the United States.

The average 1958 crop value per irrigated acre on the Bureau of Reclamation Belle Fourche Project in South Dakota was \$36.⁴ on the Strawberry Project in Utah, \$67 per acre, and \$433 per acre on the Yuma Auxiliary in Arizona. The average per acre crop value on all Reclamation projects is over \$146.

CROP RESPONSE TO IRRIGATION

It is impossible in a manual of this kind to discuss the response of all crops to irrigation in every area of the United States. However, the results of irrigation studies on a few crops in various areas of the country will be discussed.

In Illinois⁵ irrigated pasture produced 1¼ tons per acre per year more dry matter than the nonirrigated field. The animal-carrying capacity was 71 per cent higher on the irrigated field with an average increase of 111 animal-unit days per acre. Rotational grazing and good management practice showed better returns than continuous grazing. (Irrigation scheduling fits in well with rotational grazing.)

Irrigation was effective and necessary in maintaining legumes in pastures. All legumes died on the nonirrigated field. To meet the water requirements of the pasture, about 14 inches of water was applied per season.

A report on pasture response in Mississippi⁶ noted that "irrigated Dallis, Johnson, and Coastal Bermuda grass pastures produced over 300 pounds of beef cattle per acre in the period from July 26 to November of 1954."

A report from Georgia⁷ states: "If a pasture is to be irrigated, an adapted grass such as Coastal Bermuda and Star Millet that will respond to water and fertilizer should be planted on a well-drained soil that has a good moisture holding capacity. It is better to irrigate a small acreage and do a good job than to try to water your entire pasture land. Three to four cows per acre can be carried where a good job of irrigation is done on a high-yielding forage."

⁴1958 *Crop Report and Related Data, Federal Reclamation Projects, Division of Irrigation, Bureau of Reclamation, Department of the Interior, Washington, D. C., August, 1959, pp. 20-27.*

⁵G. E. McKibben, L. E. Gard, R. J. Webb, H. A. Cate, and B. A. Jones, Jr., *Experimental Irrigation of Ladino Clover-Grass Pasture*, Bulletin No. 640, Agricultural Experiment Station, University of Illinois, Urbana, Illinois, March, 1959, p. 27.

⁶Perrin Grissom, W. A. Roney, and Peter Hogg, *Crop Response to Irrigation in the Yazoo-Mississippi Delta*, Bulletin No. 531, Agricultural Experiment Station, Mississippi State University, State College, Mississippi, May, 1955, p. 23.

⁷Willis E. Huston, *Irrigating Georgia Crops*, Bulletin No. 597, Agricultural Extension Service, University of Georgia, Athens, Georgia, January, 1957, p. 17.

Results of irrigation work at the Dairy Experiment Station, Lewisburg, Tennessee,⁸ show the following:

TABLE 3
Income per Acre During Pasture Season
1951-1954

Items	1951	1952	1953	1954	Average
Income* Unirrigated	\$327	\$279	\$262	\$195	\$266
Irrigated	448	389	324	297	364
Profit from Irrigation**	\$121	\$110	\$ 62	\$102	\$ 99

*Income from sale of milk above value of feed consumed at barn and cost of irrigation.

**Difference in gross income from irrigated and unirrigated pasture after subtracting cost of supplemental feed and irrigation.

Another report⁹ states: "It is possible to produce 1,000 pounds of beef gain or milk equivalent per acre on well-managed irrigated pastures in South Texas. Irrigated pastures offer good profits in milk or beef production and the best known method of soil improvement."

Most of the pasture irrigation investigational work in the Western States has been done on water supplies, water requirements, irrigation methods, pasture varieties, fertilization rates, and other agronomic and management practices. The benefits from irrigation have long been recognized. In most areas of the West, without irrigation, there is no production. Thus the economics is simply tied up with the cost of irrigation and the returns that are possible.

The acreage of irrigated cotton in the Southeast has increased rapidly during the last 10 years. Even in the wetter years, cotton is now being irrigated.

South Carolina¹⁰ shows cotton irrigation returns as follows:

TABLE 4
Average Increases in Yields and Returns from Irrigation
of Five-Acre Cotton Contest Demonstrations — 1956

Fields	Average Yield		Lint Increase		Seed Increase		Cost Per Acre, Two Irrigations and Seed)		Increase Per Acre Over Irrigation Cost (Lint and Seed)
	Per Acre	Lbs.	Per Acre	Lbs.	Per Acre	Lbs.	Per Acre	Lbs.	
Nonirrigated	593								
Irrigated	861		268		490		\$30.00		\$70.50

⁸A. G. Van Horn, W. M. Whitaker, R. H. Lush, and John R. Carreker, *Irrigation of Pastures for Dairy Cows*, Bulletin No. 248, Agricultural Experiment Station, University of Tennessee, Knoxville 16, Tennessee, June, 1956, p. 11.

⁹E. M. Trew and Carl S. Hoveland, *Irrigated Pastures for South Texas*, Bulletin B-819, Agricultural Experiment Station, Texas A. and M. College, College Station, Texas, p. 3.

¹⁰Clemson Extension Cotton Committee, *Cotton Irrigation in South Carolina*, Information Leaflet, Extension Service, Clemson Agricultural College, Clemson, South Carolina, May, 1957, p. 4.

Increases in yield at the Sandhill, South Carolina Branch Station for 1954-55 were 733 and 450 pounds respectively in favor of irrigation. Carreker¹¹ shows the results of irrigating cotton at Watkinsville, Georgia, and Auburn, Alabama, in the following table:

TABLE 5
Seed Cotton Yields With and Without Irrigation

Treatment	Pounds Per Acre			
<i>Georgia</i>	1949	1950	1951	1952
Without Irrigation	1155	1087	2165	742
With Irrigation	1286	1430	2538	2534
<i>Alabama</i>				
Without Irrigation	1328		1449	2200
With Irrigation	1953		2538	2200

Grisson, et al.,¹² report on cotton irrigation as follows: "On sandy loam soils, during the 1952-54 periods, irrigation increased the yield of cotton an average of approximately 750 pounds of seed cotton per acre . . ."

Work of Phillips, Curtis, and Lytle¹³ is summarized below:

TABLE 6
Lbs. Seed Cotton Per Acre 1958

Plants Per Hill*	1957		1958	
	Available Moisture**	0%	Available Moisture**	25%
1	1137	1870	1849	1240
3	1088	1937	1821	1013
6	1120	1950	1631	1040
				1882
				1897

*Plant spacings 12 inches apart in drill
1 plant per hill = 13,068 plants per acre
3 plants per hill = 39,204 plants per acre
6 plants per hill = 78,408 plants per acre

** 0% - plots were not irrigated
25% - irrigated when soil contained 25% available moisture
50% - irrigated when soil contained 50% available moisture

A report by Gattis and Deere¹⁴ shows effects of irrigation on cotton yields in Arkansas:

- ¹¹John R. Carreker, "Cotton Irrigation," *Plant Food Journal*, Vol. VIII, No. 4, 1954, p. 7.
¹²*Crop Response to Irrigation*, p. 12.
¹³Sherman A. Phillips and William F. Lytle, "More Cotton with Irrigation," *Louisiana Agriculture*, Vol. 3, No. 3, Agricultural Experiment Station, Louisiana State University and Agricultural and Mechanical College, Baton Rouge, Louisiana, Spring, 1950, p. 12.
¹⁴James L. Gattis and Runyan Deere, *Cotton Irrigation for Arkansas*, Circular No. 477, Agricultural Extension Service, University of Arkansas, Little Rock, Arkansas, June, 1956, p. 7.

TABLE 7
Water-Yield Relationship for Cotton at Marianna, Arkansas

Year	No. Times Irrigated	Month	Depth of Water Applied Inches	Rainfall Inches	Yield		Increase in Seed Cotton %
					Irrig. Fields Lbs.	Non-Irrig. Fields Lbs.	
1950	2	1-July	3	22	1842	1557	21.5
		1-Aug.					
1951	2	1-July	2	21	2073	1766	17.0
		1-Aug.					
1952	4	2-July	8	11	2701	1604	69.0
		2-Aug.					
1953	7	2-June	12.9	26*	2383	1822	30.0
		2-July					
1954	5	1-June	11	14	2589	1394	86.0
		3-July					
Average	4		7.9	18.9	2318	1629	42.0

*Twenty inches occurred in April and May.

A study in Oklahoma¹⁵ was conducted on irrigation with cotton, and the results follow:

TABLE 8
Effect of Various Water Treatments on Cotton Yields Oklahoma 1954-1958

Water Treatment	Cotton Yields in 500-Pound Bales per Acre*	
	1954	1958
W ₁ **	.15	.34
W ₂	.48	.65
W ₃	.82	1.16
W ₄	1.39	2.11
W ₅		1.70

*No results were obtained in 1955 due to inadequate stand
**W₁ - No irrigation
W₂ - Irrigation after the plants definitely wilted at 4 p.m. for one week before each irrigation
W₃ - Irrigation 24 hours after the plants wilted at 4 p.m.
W₄ - The soil moisture constantly maintained at 17 per cent of soil moisture in the zone 6-12 inches below the soil surface
W₅ - Soil moisture maintained above 18 per cent

Similar results have been shown in other cotton-growing states. Yield responses to irrigation become greater as one moves toward the arid areas of the Southwest.

¹⁵James E. Garton and A. D. Barefoot, *Irrigation Experiments at Altus and El Reno, Oklahoma, Progress Report 1954-1958*, Bulletin B-534, Agricultural Experiment Station, Oklahoma State University, Stillwater, Oklahoma, July, 1959, pp. 4, 6, and 7.