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The Foundation of Permanent Agriculture in Arid Regions

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IRRIGATION SCIENCE

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By ORSON W. ISRAELSEN

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SECOND ANNUAL FACULTY RESEARCH LECTURE

IRRIGATION SCIENCE

The
Foundation of Permanent Agriculture
in
Arid Regions

By
ORSON W. ISRAELSEN
Research Professor of
Irrigation and Drainage

THE FACULTY ASSOCIATION
UTAH STATE AGRICULTURAL COLLEGE
LOGAN UTAH 1943
INTRODUCTORY NOTE

The following lecture by Professor Orson W. Israelsen is the second in a series to be presented annually by a scholar chosen from the resident faculty at Utah State Agricultural College. The occasion expresses one of the broad purposes of the college Faculty Association which is a voluntary association of members of the faculty. The 1943 lecture appears under the Association's auspices as defined in Article II of its Constitution, amended in May 1941:

"The purpose of the Organization shall be ... to encourage intellectual growth and development of its members ... by sponsoring an Annual Faculty Research Lecture ... The lecturer shall be a resident member of the faculty selected by a special committee which is appointed each year for this purpose and which shall take into account in making its selection, the research record of the group and the dignity of the occasion ... The lecture shall be a report of the lecturer's own findings in a field of knowledge ... The Association shall express its interest by printing and distributing copies of the Annual Faculty Research Lecture."

Professor Israelsen was elected by the committee to the second lectureship thus sponsored. On behalf of the men and women of the Association, a group devoted to scholarly quest and to the teaching of truth, we are happy to present Dr. Israelsen's paper: "IRRIGATION SCIENCE—The Foundation of Permanent Agriculture in Arid Regions."

COMMITTEE ON FACULTY RESEARCH
FOREWORD

The engineer, like other scientists, is continuously seeking knowledge and understanding of the universe in which he lives. He is vitally interested in the control and the use of the forces and materials of nature for the benefit of man. He strives for the maximum economy in the use of these forces and materials which is consistent with safety and durability. He abhors waste and he works vigorously to increase efficiency. To the engineer, mastery of the physical obstacles of life is not only a challenge—it is also an opportunity. He knows that full understanding of the physical sciences is vital to his objectives, that the conservation and use of mechanical energy, whether it be in the form of direct solar radiation, or fixed in coal, or in oil, or in a waterfall, or in the water pressure of an artesian aquifer, contributes to his ability to meet the challenge—to embrace the opportunity.

The engineer's educational equipment is a result of centuries of progress in mathematics, physics, chemistry, and other physical sciences. His engineering formulas come from two major sources: reasoning and experiment; they are designated as rational and empirical. Because of the great number of variables encountered in nature it is, in many cases, impractical by reasoning alone, to consider all of them, and therefore the engineer conducts experiments and evaluates certain coefficients for use in his rational formulas.

Irrigation science first makes use of all rational formulas which are applicable; thereafter it depends on experiment. The major motivating objective in the work of the engineer is the application of his knowledge, his formulas, his understanding and his experience to the advancement and welfare of society.

ORSON W. ISRAELSEN

Logan, Utah
Engineering Building
March 10, 1943
ACKNOWLEDGMENTS

The author's work in irrigation science has been inspired and advanced by teachers, research colleagues, and assistants. In his earlier years the motivating influence of the researches, writings, and teachings of Dr. John A. Widtsoe, Dr. Franklin S. Harris, Professor Frank Adams, Professor B. A. Etcheverry, and their associates was especially noteworthy.

Following these years the author's period of more advanced study and organization for research was influenced by the writings and association of many research colleagues in the West. Intimate contact through the years with Dr. Willard Gardner and his students and with Mr. W. W. McLaughlin and members of his staff has been inspiring and stimulating.

During the author's 30 years of teaching and research experience his students and research assistants have contributed greatly toward progress in his work. Several of the author's students and research assistants who have become research colleagues and whose work has been most noteworthy are: T. M. Ashcroft, A. E. Backman, J. E. Christiansen, George D. Clyde, W. D. Criddle, D. K. Fuhriman, R. A. Hales, V. E. Hansen, Karl Harris, I. D. Jerman, Reid Jerman, E. H. Larson, E. O. Larson, A. V. Maxwell, C. H. Milligan, O. W. Monson, E. R. Morgan, H. E. Nielsen, and R. C. Reeve.

In the preparation of this paper the author has used freely data from the research work of many of his colleagues. Space will not permit mention of the names of all to whom he is indebted for assistance.

In harmony with the provisions of the constitution of the Faculty Association that the lecture be a report of the lecturer's own findings in a field of knowledge and experience, use has been made of unpublished reports of data collected by the Utah Agricultural Experiment Station in cooperation with the Irrigation Division of the Soil Conservation Service. The author extends gratitude to the officials of these research institutions for permission to use the data, and to all of his associates and assistants who have contributed generously in collecting and interpreting these data. Sincere gratitude is extended also to colleagues for reading the manuscript and giving many helpful suggestions.
IRRIGATION SCIENCE

The Foundation of Permanent Agriculture in Arid Regions

by

Orson W. Israelsen

Irrigation science is of comparatively recent origin, although irrigation has been practiced in arid regions for many centuries.

The science of irrigation concerns in part the relations of irrigation to climate, to soils, to plants, and to man. Intelligent applications of the sciences of mathematics, chemistry, physics, hydraulics, hydrology, and fluid mechanics to the solution of problems of irrigation have contributed greatly to the development of irrigation science. For example, the statement in 1738 by Daniel Bernoulli, an eminent mathematician, that the total energy of unit weight of an ideal moving fluid must remain constant is now the basis for numerous applications in the design of irrigation canals, chutes, pipe lines, pumping plants, and drainage systems. Applications of algebra, geometry, trigonometry, analytical geometry, and of the calculus of Newton to problems of irrigation are now made by all civilized peoples in arid regions with great benefit.

WORLD'S IRRIGATED AREAS

The area of irrigated land in the world is variously estimated to be from 150 to 200 million acres—the maximum estimated area being nearly twice as large as the total land area of Utah and Idaho. Some of the more noteworthy areas of irrigated land, as reported in the Encyclopedia Britannica and by Fortier in Use of Water in Irrigation are as follows: South America, 6 million acres; Africa and Australia, 10 million; the islands of the Pacific, 10 million; North America, 26 million; Europe, 22 million; and Asia, 54 million acres.

IRRIGATION IN THE UNITED STATES

In the United States there are 430,000 irrigated farms, of which 283,000 are in the 17 western states. Twenty-one million acres were provided a water supply by primary irrigation enterprises in 1939, and more than 3½ million acres were provided additional water by supplemental enterprises. In 1940 the primary irrigation enterprises were capable of supplying water to 28 million acres. The 1940 capital investment in irrigation enterprises was more than a billion dollars, of which more than 91 percent was in primary enterprises.
The potential irrigation of new land in the United States, as recently reported by the United States Bureau of Reclamation shows that there are yet 22 million acres susceptible to irrigation, of which 11 million are in the West Coast region, $6\frac{1}{2}$ million in the Intermountain region, and $4\frac{1}{2}$ million in the Great Plains region. Ultimately, though doubtless not for many years, with complete storage of flood waters the United States should irrigate an area nearly as large as the total land surface of Utah, including mountains, valleys, and deserts.

**CLIMATE AND IRRIGATION**

Variations in the average annual precipitation from point to point on the earth make irrigation essential to crop growth in some places and drainage in others. The extent of these variations is most remarkable. For example, in Alaska the annual precipitation ranges from 4.3 inches at Barrow to 150.9 inches at Ketchikan—a ratio of 1 to 35. In Canada, the minimum recorded average annual rainfall is 10.4 inches at Fort Good Hope as compared to 55.5 inches at Halifax. In Mexico, the minimum is 5.7 at La Paz as compared to 63.7 at Vera Cruz. Similar variations may be cited for every country in which measurements have been made.

There are even more remarkable variations in the Hawaiian Islands. For instance, in the West Mauai Region at Lahaina, altitude 50 feet, the annual rainfall is 12 inches, whereas at Puu Kukui, only 5 miles distant, it is 382 inches—nearly 32 times as great.

In the Imperial Valley of California there are four locations where long-time precipitation measurements have been made, of which the average is less than 4 inches annually and in Kern County, the average precipitation is 6 inches, whereas there are ten different measuring stations in the state at which the precipitation exceeds 60 inches annually, or more than 12 times the Imperial Valley precipitation.

In Box Elder County, Utah, a minimum of 4.5 inches is recorded, and a maximum of 40 inches is on record in Salt Lake County. Doubtless, in the higher mountains, unrecorded precipitation exceeds 40 inches annually.

Of great significance to the welfare of man is the variability in precipitation from season to season. It is not unusual in arid regions for the precipitation to drop as much as one-third below normal and then rise one-third or more above normal.

Climatic changes, reflected by cycles of wet years followed by cycles of dry ones; and then dry cycles followed by wet cycles, are vitally important in irrigation.
WATER STORAGE ESSENTIAL TO IRRIGATION

In most irrigated regions the flood flows of rivers occur during periods when there is but little, if any, need for irrigation water; and later when the need for water is greatest during the hot summer months, the flow of rivers is smallest. Storage of water in surface reservoirs during flood periods, and diversion from reservoirs when needed for irrigation are, therefore, essential to satisfactory crop production and to fullest practical utilization of water supplies. Recognition of this need in the United States has resulted in the building of thousands of reservoir dams making reservoirs having capacity for millions of acre-feet of water.

Science Aids in Water Storage. The advancements of the sciences of geology, soil mechanics, concrete construction, thermodynamics, and hydraulics during the past half-century—all grouped herein as irrigation science—have made possible the construction of larger, higher, and safer dams than ever before in the world’s history. For example, the Owyhee Dam in western Oregon is 405 feet above foundation, the recently completed Grand Coulee Dam in Washington is 550 feet high, and the Boulder Dam, now the highest in the world, is 721 feet high.

Irrigation science enables engineers to predict pressures on submerged surfaces, stresses, strengths, and strains of materials in masonry dams before they are built. Thus, it was necessary to design for a horizontal water pressure at the foundation of Boulder Dam, reservoir full, on one square foot of surface of its upstream face of 22 tons, and on one linear foot of the dam with water depth 700 feet above foundation, a horizontal thrust of 7560 tons.

Without knowledge of the sciences of physics, mathematics, and mechanics, and without ability to apply this knowledge in design and construction, these magnificent irrigation storage works could not have been built.

To transmit to future generations these great engineering structures, together with hundreds of similar but smaller ones, with their capacity for water storage, for generating electrical power to do much of the mechanical work of man, to regulate stream flows, to eliminate destructive floods, and to provide ample and reliable water supplies for millions of fertile irrigated acres—this is a privilege in prospect toward which the citizens of a great democracy may look with pleasure. But permanence of storage capacity and usefulness to future generations of these highly valued irrigation reservoirs is by no means assured—permanence depends largely on further development and application of certain phases of irrigation science—that is, the reduction of erosion and the control of silt.
THE SILT PROBLEM

Into hundreds of reservoirs in arid regions, flowing streams carry annually thousands of tons of silt. Reference to a few arid-region reservoirs will illustrate the problem of silt control.

The reservoir storage capacity provided by the Elephant Butte Dam in the Rio Grande in New Mexico when completed in 1916 was 2.64 million acre-feet. Carefully conducted surveys in 1925, after the reservoir had been in use ten years, indicated that 178,000 acre-feet of silt had been deposited in the reservoir, thus reducing its capacity by 6.7 percent, or one-fifteenth. At this rate of silt deposition, the reservoir will have lost one-half of its storage capacity in less than two generations, and all of its capacity in 150 years.

The Roosevelt Dam, constructed in Arizona in 1904, provided storage capacity of 1.37 million acre-feet, of which 7.4 percent was filled with silt in 22 years.

On the Rio Grande, as on the Colorado, a number of other storage sites are available. Ultimately, however, the fact must be faced that these reservoirs may become useless for storage purposes. The people dependent on these rivers may then be reduced to those that can subsist on the areas which the natural summer flow of the river will irrigate.

Therefore, for maximum ultimate storage of water in surface reservoirs silt must first be deposited in reservoirs as low on the stream systems as possible. Upstream storage should be reserved for the future after downstream reservoirs are filled with silt.

More intensive study and intelligent research and application of irrigation science is essential to effect a practical solution of this problem. The menace is real, and unless something constructive is done, civilization in arid regions must eventually decline.

After several years of study, United States Soil Conservation Service engineers conclude that, in broad national view, it appears with unmistakable clearness that exorbitant rates of depletion of reservoir storage by silting are widely prevalent and that the problem of protection of reservoirs from this menace goes hand in hand with that of saving farm and range lands from impairment and destruction by uncontrolled erosion. This broad national view is applicable in other arid regions. For instance, irrigation engineers of India have recently studied rates of reservoir silting and found that their reservoirs are being filled with silt at rates ranging from 1 percent per year to 2.1 percent per year. In other words, Indian reservoirs under present rate of silting will be filled with silt in time periods ranging from 48 to 100 years.
With the aid of irrigation science, much is being done toward direct solution of the silt problem for surface reservoirs; much can be done also by the aid of irrigation science to provide increased and permanent water storage capacity by more extensive and intelligent use of underground storage reservoirs in which there is no silt problem.

**UNDERGROUND WATER STORAGE**

Nearly one-third of California's 5 million acres of irrigated land is provided full water supplies by pumping from underground water. Arizona has 870 irrigation enterprises having pumping plants in wells, and Utah has 173, which provide water for 22 percent and 8 percent, respectively, of the irrigated areas. In many places the natural annual water recharge of underground storage reservoirs is supplemented artificially by spreading spring flood water over the land surfaces of alluvial fans, thus building up the water table and providing ground water supplies for pumping and use during the summer months. Great progress has been made in the use of underground water storage reservoirs, which are inexpensive, have no silt problem, and small evaporation losses, if any.

A major problem which confronts irrigators, administrators, engineers, and the courts in the use of underground water storage for irrigation is the mechanical power problem.

Areas which are provided irrigation water from flowing wells are favored by nature's furnishing the mechanical power. Other areas may be provided irrigation by lifting water only a few feet at a nominal cost for power, whereas still other areas require high-lift pumping at excessive power costs.

Power costs for obtaining underground water for irrigation are increased when the volumes of water taken annually from ground water sources continually exceed the volumes added.

To obtain maximum use of underground storage reservoirs, pumping is essential. Reservoirs kept full continuously have no value in irrigation. Artesian aquifers, for example, are valueless for irrigation storage purposes if the public upholds the contention that maximum natural pressure heads must be maintained to provide mechanical power for lifting water to the surface for culinary and stock-watering purposes. Moreover, water under pressure in artesian aquifers generates mechanical power which is frequently harmful to overlying land by causing a continuous, though slow, movement of water up through the overlying clay soils to the land surface, and thus maintaining waterlogged and alkali conditions.

Application of science to efficient generation, transmission, and utilization of hydroelectric and steam mechanical power are gratifying, but there is urgent need for the use of more science in the design
of irrigation wells to reduce the friction and thus reduce mechanical power required to make water flow in the aquifer to the wells.

The basic equations for flow of fluids, the energy equation of Bernoulli (1738), the capillary tube velocity equation of Poiseuille (1840), the soil-water flow equation of Darcy (1852), and other fundamental physical and mathematical concepts and equations constitute rational bases for the advancement and use of science toward the solution of the irrigation pumping mechanical power problem.

The fact that underground water reservoirs usually are close to irrigated lands, thus avoiding the necessity for long, expensive water-dissipating canals, justifies special efforts in the application of irrigation science toward solution of underground water storage problems.

Intelligent ground water legislation, based on the needs of arid regions and on sound doctrines of water rights, together with wise court decisions protecting public interests and encouraging fair replacements of water sources, are essential to a realization of the great possibilities ahead in the application of irrigation science to the efficient use of ground water reservoirs.

CONVEYANCE OF IRRIGATION WATER

Most irrigation canals are constructed in soil materials which vary greatly in texture, structure, and permeability. Water losses through seepage in canal systems range from 15 percent to 60 percent, or more, of the volume of water taken into the canals. Using an estimate of 25 percent average losses from all canals, then nearly 20 million acre-feet of water—a volume which if spread over Utah's irrigated land would cover it to a depth of 17 feet—seeps out of United States' irrigation canals annually.

These seepage losses may be helpful provided recharge of underground reservoirs is needed. For instance, in the Central Valley of California, pumping of water for irrigation has lowered the ground water supplies to such an extent that seepage losses, which recharge ground water supplies and thus decrease pumping costs, are helpful and not harmful.

In some places the water lost by canals is quickly returned to natural stream channels from which it may again be diverted for beneficial use; in other places it is permanently lost by flowing underground to desert regions; in still other places, where there is no pumping of ground water for irrigation, the seepage from canals causes a general rise of the ground water and injury to vast areas of arable land owing to concentration of alkali.

The water commissioner for the Snake River Valley, Idaho, recently estimated the total seepage losses from the valley canal sys-
tems as 2 million acre-feet annually, of which one-half was considered permanently lost—the equivalent money loss to Idaho farmers being about 1.5 million dollars.

In Utah probably 2 million acre-feet of water—enough to cover our irrigated land to a depth of 20 inches—having a value of 3 million dollars, are permanently lost annually owing to seepage from canals.

Utah Canal Lining Studies. The Utah Agricultural Experiment Station in cooperation with the Irrigation Division of the Soil Conservation Service, assisted financially by the Work Projects Administration, Millard County and irrigation companies, made a study of canal seepage losses and low-cost canal lining in the Delta Area, Utah, during the past three years under the author’s leadership.

In eight experimental canals, seepage losses during the season of 1940 ranged from 2.1 to 8.6 percent per mile. Two of these canal sections have since been lined with a layer of clay three inches thick after being compacted. Water losses from the lined canals are thus far negligible. A 4000-foot length of canal lining, having a surface area of 128,000 square feet, during the first season saved 4.2 cubic feet per second or 1500 acre-feet in a 6-month season, having a value of more than $2000 or two-fifths of the cost of lining.

There is great opportunity for development and application of irrigation science to research in lining of irrigation canals with low-cost natural materials. The Utah cooperative irrigation studies are being expanded with a view to reducing losses and providing more fully the actual water needs of soils and crops.

IRRIGATION WATER REQUIREMENTS

The expression “irrigation water requirements” as used herein, is defined as the volume of water needed by the irrigation project or by the irrigator for satisfactory crop production. It includes reasonable and unavoidable losses which are beyond control and also the volumes of water consumed by the crops. For areas to which all water supplies are provided from surface diversions—not from direct use of ground water—the water requirements are greater than the water consumed. If, however, crops consume large volumes of ground water from unmeasured sources, then irrigation water requirements may be less than the water consumed.

The fear of drought and resulting crop failures, together with the large crops produced by adequate irrigation during the pioneer days of the West, stimulated early irrigators to use water lavishly. They seemed to feel that crop production was in direct proportion to the volume of water applied; therefore they applied annually irrigation water far in excess of that actually needed. Irrigation scientists foresaw the need for dependable knowledge as to the amounts
of water consumed by well-irrigated crops and conducted numerous studies of irrigation-water requirements. In these pioneering irrigation studies, the research of the Utah Agricultural Experiment Station, in cooperation with the U. S. Department of Agriculture, during the early years of the present century made real contributions toward establishment of experimental relations between amounts of water used by crops and resulting yields. It was found that mountain area crops use from 1.5 to 2.0 feet depth of water annually.

CONSUMPTIVE USE OF WATER

In a basic sense the consumptive use of water is defined as the amount absorbed by the crop and transpired or used directly in building plant tissue, together with the amount evaporated.

During the growing season water is transpired and evaporated. It is thus "consumed" from cropland, natural vegetation land, bare land, and water surfaces. The seasonal or annual water consumption depends on the crop, the temperature, humidity, wind, and other factors, and varies considerably. The integration method of estimating consumptive use is explained by example. Assume, for instance, a 1000-acre valley in which all of the land is cropped; 600 acres to alfalfa and 400 to small grains, and assume that the alfalfa consumes 2 acre-feet of water each season and the grains 1 acre-foot. The total water consumed would then be $600 \times 2 + 400 \times 1$, which equals 1600 acre-feet. Each valley has many different water-consuming areas and the integration method necessitates measuring all of the areas and the amounts of water consumed on each area.

Another method of estimating valley consumptive use is to measure the inflow and outflow. Water inflow to a valley includes surface streams, subsurface ground water flow, upward ground water flow resulting from pressure, and precipitation. Water outflow includes surface and subsurface flow and lowering of the ground water table. The inflow minus the outflow is considered as the amount consumed and is therefore designated the "consumptive use."

On many western streams the consumptive use of water in the higher valleys decreases the amounts available for irrigation in the lower ones. For example, the extent of the irrigated area and the consumptive use of water in Utah, Wasatch, and Summit Counties on the lands provided irrigation water by the Provo and Spanish Fork Rivers, influences the amounts of water annually available for lands in Salt Lake County irrigated from Jordan River. Likewise the consumptive use of water in Garfield and Piute Counties from the Sevier River headwaters influences the amounts available to irrigators in Sevier County; and the use in Sevier Valley and in San
Pitch River Area and in all of the higher valleys influences the amounts available to the large area of arable land in the Delta Area of Millard County.

Excessive diversions of water by irrigation companies of the higher valleys, large water conveyance losses and copious water applications to farms during early season when there is plenty of water contribute to the rise of ground water in the lower lands, and in some areas to growth of low-value water-loving plants, high evaporation losses, excessive valley consumptive use, and decreased annual water supplies for the farms in the lower valleys. However, this apparent disadvantage to the lower valleys frequently is generously compensated by a delayed return flow of water to creeks and rivers for diversion and use during the hot summer days.

From 1924 to 1928, as a member of the Committee on Irrigation, American Society of Civil Engineers, the author assumed responsibility for the development of a report on the consumptive use of water, including basic analyses, appropriate equations, methods of evaluating consumptive use, and a resume and analyses of experimental data. In this report, which was published in the Proceedings of the Society of April, 1928, and in its Transactions of 1930, seven basic rational equations for analyses of consumptive use were proposed. These equations include the effect on consumptive use of the available heat, evaporation, soil moisture, the crop, and the yield, together with relations between consumptive use of water on the farm, the irrigation project, and the irrigated valley. The available experimental data on irrigation from Utah, Idaho, Oregon, Colorado, and Alberta, Canada, were analyzed in terms of the basic consumptive use equations.

In the Sevier Valley, Utah, the author found in 1927, as a result of a study of 22 years’ record, that an increase in gross water diversions from the river of 1000 acre-feet increased the valley consumptive use from 300 to 400 acre-feet.

In 1936, the author made a study of consumptive use of water in the Rio Grande Joint Investigations conducted by the Division of Irrigation for the National Resources Planning Board in Colorado, New Mexico, and Texas. The integration method and the inflow-outflow method were applied to measuring consumptive use in the 77,000-acre Mesilla Valley of New Mexico for a period of record of 17 years. The average valley consumptive use as found by the inflow-outflow method was 2.75 acre-feet per acre per year, and by the integration method it was 2.74.

Thus far, in the solution of Utah’s complex water right problems, and in the conservation and use of its water resources, the applications of the basic concepts and equations of consumptive use have been few. Comprehensive and long-time studies of consumptive use
of water on all of the upper valleys of the major river systems in the West are urgently needed. The results of these studies will be of great value as the demand for complete and efficient use of all the water of these rivers increases.

Knowledge gained in scientific study of the consumptive use of water by basic crops constitutes a reliable guide as to the minimum volume of water that each farmer need receive at the farm when it is applied most efficiently with resulting negligible losses by surface runoff and percolation below the crop root zone.

WATER-APPLICATION EFFICIENCIES

Deep, well-drained farm soils provide plant nutrients and available water in the capillary form and therefore are in reality reservoirs for irrigation water.

Intelligent use of soil capillary reservoirs in irrigation agriculture contributes to conservation of soils and of water supplies and thus to the permanence of agriculture in arid regions.

During the years 1913 to 1915 the author assisted the irrigation research workers of the University of California in a study of irrigation practices on many typical farms. After publication of the official report of these studies, he assembled technical experimental data and prepared a paper entitled, "Studies on capacities of soils for irrigation water," which was published in the Journal of Agricultural Research of April 1, 1918. An elementary rational equation presented first in this paper 25 years ago, showing how to convert soil moisture percentages to inches depth of water in given depths of soil, has since been widely used. These early California studies concerning capacities of soils for irrigation water, together with later Utah studies, constitute a guide to irrigators helping them to store large percentages of their irrigation water in their soils, thus attaining efficient water application. The need for efficient application of water at each irrigation seems apparent from the fact that each of the 283,000 irrigated farms in the 17 western states is irrigated several times during the crop-growing season—probably five times as an average.

There is an urgent need for more scientific information as to how to distribute irrigation water uniformly over land surfaces of farms, and thus cause reasonably uniform depth of percolation into the soil; how to reduce if not prevent surface runoff losses on irrigation farms and yet moisten the soil adequately; how to avoid excessive deep-percolation losses at one end or the other of long sloping strips of land; how to balance the size of stream, length of irrigation run, and width of land strip, with the rate of percolation of water
into the soil; and finally, how to moisten fully the soil root zone at each irrigation with a minimum of water losses and thus attain high water-application efficiencies.

Analyses of relations between the size of irrigation stream, depth of irrigation water flowing over the land, the length of irrigation run, width of land covered with water at one time, and the soil permeability; by use of calculus, are presented in the author's book, entitled, *Irrigation Principles and Practices*, published by John Wiley and Sons in 1932. More experimental measurements of variations in permeabilities of irrigated soils will add greatly to the practical value of these mathematical analyses in which it was of necessity assumed that for each soil the permeability did not change during the time of irrigation.

The Utah Agricultural Experiment Station, in cooperation with the Irrigation Division, Soil Conservation Service, conducted detailed irrigation studies in Utah and Salt Lake Counties during 1937 to 1941 in which studies of water-application efficiencies were made under ordinary farm practices. These studies conducted under the author's leadership were made on 14 farms—some at the higher elevations near the mountains; some of medium elevation; and some in the lower, more level parts of the valley. A resume of the results of this research, as yet unpublished, shows that less than 50 percent of the water received by the farmers was stored in their root zone soils. The average water-application efficiency for the higher lands was 38 percent; for the lands of medium elevation, 44 percent; and for the low lands, 34 percent.

The author's water-application efficiency studies show that low efficiencies are obtained because some farmers use obsolete irrigation systems and attempt to irrigate rough irregular land surfaces, and thus they apply excessive depths of water in single irrigations. It was found that low efficiencies accompany abundant water supplies and that losses occur when irrigation water is applied to soils that already have plenty of moisture. Soils of shallow depth are difficult to irrigate efficiently and much water is lost by penetration through the shallow layers into underlying gravels. A dominant factor in water-application efficiencies is the permeability of the soil which varies between wide limits. Highly permeable soils, and likewise, soils of low permeability are hard to irrigate efficiently. It is even more difficult to irrigate efficiently soils which vary greatly in permeability from place to place in the field. Low time-rates of water application on highly permeable soils of shallow depth usually result in the application of excessive depths of water, large deep-percolation losses, and low water-application efficiencies.

The author's studies of capacities of soils for irrigation water show that average loam soil may retain from 1.0 to 1.5 inches of irri-
igation water per foot depth of soil. Thus, a 4-foot-depth loam soil, which has no available moisture, may absorb and retain in capillary form, not more than 6 inches of irrigation water without deep-percolation loss of water from the soil zone of major root development. The findings of irrigation science concerning the capacities of soils for irrigation water constitute a contribution of vital importance toward the efficient application of water to soils.

Every irrigation farmer knows that he cannot put a gallon of water into a quart cup, but unknowingly, many try to put 4 acre-inches of water into a soil which has capacity for only 1 acre-inch. Unfortunately, the excess 3 acre-inches flow away by deep percolation.

EROSION CONTROL ON IRRIGATED LANDS

Water-application efficiencies in irrigation are closely related to the problems of erosion control on irrigated lands. To prevent erosion during irrigation it is essential to apply water in small streams and make it run in directions along the land having small slopes. Erosion control is usually most difficult on loose friable soils of high permeability and shallow depth. In order to attain high water-application efficiencies on soils of this type, it is essential to use large irrigation streams and run the water quickly over the land.

Therefore, the irrigation conditions which favor erosion control contribute to low water-application efficiencies, and, conversely, the irrigation conditions which tend toward high water-application efficiencies tend also to cause excessive erosion during irrigation.

During the past three years, under the author’s leadership, the Utah Agricultural Experiment Station in cooperation with the Soil Conservation Service, has conducted field studies of erosion during irrigation with special reference to the effects of slope of furrow and size of streams.

**Cache County Studies.** In Cache Valley on the loam soils of the South Logan Experimental Farm it was found in 1940 that on a 0.5 percent slope with a stream of 5.8 gallons per minute, in the irrigation—seven times annually, in one-hour periods—of row crops in furrows of 240 feet spaced 20 inches apart, it would require 1320 years to remove the upper seven inches of soil by erosion. Making the slope six times as large, with the same stream would remove seven inches of soil in only twenty-three years. A stream of 16 gallons per minute on a furrow slope of 3 percent in the first hour removed soil at the rate of 0.74 inches annually, thus requiring only nine and one-half years to remove seven inches. Erosion of this magnitude by irrigation is positively adverse to the perpetuation of permanent agriculture in arid regions.
To assure permanence of soil productivity by control of erosion resulting from irrigation on the Cache County soils studied, and also to provide for efficient use of water by prevention of excessive deep percolation, it is essential to strive continuously to coordinate irrigation practices to attain erosion control and also efficient water application.

Salt Lake County Studies. During 1941 and 1942 field erosion studies were continued on light granular sandy soils of the new Utah State Prison Farm.

The weights of soil eroded in one hour from each of 10 furrows were measured first with an inlet stream of 15 gallons per minute and later with streams of 20, 25, and 30 gallons per minute. The slopes of the furrows before the erosion tests ranged from 0.35 to 6.07 percent. The weights of soil eroded in one hour from the furrow of maximum slope were 484, 796, 1142, and 1811 pounds, respectively, for each of the four streams, which are equivalent to depths of erosion of 1.1, 1.8, 2.5, and 4.0 inches per irrigation season of 10 irrigations, each of one-hour duration, from a one-acre plot having 80 furrows spaced 2.5 feet apart.

Erosion of 100 pounds per hour from one furrow, under the irrigation conditions stated, is equivalent to 0.22 inch depth per irrigation season. Four of the furrows have slopes of 1.2 percent or less. Erosion from the furrow having a slope of 1.2 percent was 3, 48, 65, and 151 pounds per hour, respectively, for each of the four streams. With a stream of 15 gallons per minute the erosion exceeded 100 pounds per hour in four of ten furrows; with 20 gallons per minute in six of the ten; and with 30 gallons per minute, it exceeded 100 pounds per hour in eight of the ten furrows.

The 1942 erosion studies show that for furrows of 200 feet or less on deep, open, porous, coarse-textured soils of high permeability, like the soil on the Utah State Prison Farm experimental plots, furrow slopes should not exceed 2 percent, and the size of stream should not be greater than 15 gallons per minute. Irrigation thus practiced on these soils with short furrows to prevent excessive deep percolation losses will contribute to soil and water conservation and to the permanence of agriculture under irrigation.

IRRIGATION AND ALKALI

In arid regions under irrigation, excess alkali has caused abandonment of millions of acres which were once productive and has reduced crop production on other millions.

The San Joaquin, Sacramento, and Imperial Valleys of California; the Great Basin, including a large part of Utah and Nevada; the Colorado River watershed, comprising parts of Wyoming, Utah,
Colorado, Arizona, and California; the Rio Grande area, including parts of New Mexico and Texas; parts of the Columbia River Basin; and the Great Plains area east of the Rocky Mountains, all contain significant areas of land now nonproductive because of alkali.

Certain areas in Africa, Australia, Asia, Canada, India, and Mexico are only partly productive or sterile because of the presence of alkali.

*American Studies of Alkali.* The problems of alkali under irrigation have been studied by American scientists for many years and almost every alkali research worker has found that seepage from canals and over-irrigation caused a rise of water table in the lower-land areas with resulting movement of alkali salts to the soil surface, water evaporation, concentration of alkali, and land injury.

The United States Department of Agriculture maintains at Riverside, California, a Regional Laboratory for the purpose of conducting basic research looking toward the solution of the alkali problem. From each of the eleven western agricultural experiment stations a collaborator acts as a technical adviser to the director and staff of the laboratory. As one of the collaborators, the author has attended the five annual meetings at Riverside, 1938 to 1942 inclusive, and has noted substantial progress in research relating to the salinity problem. Special equipment has been developed and gradually improved by this laboratory for the measurement of hydraulic energy of water at representative points both in saturated and in unsaturated soils, thus making possible the use of rational equations for measuring the direction and rate of flow of water in soils.

*The Alkali Problem in Other Lands.* The control of alkali is of vital concern to all arid-region countries. In the Murray Valley Irrigation Area of Australia, the development of excessive salinity has become one of the most important problems. Salt troubles were met a few years after settlement in 1887, and since that time the affected areas steadily increased until the installation of a comprehensive drainage scheme in 1936-1937. Some more recent settlements have been adversely affected to the extent of precipitating a major crisis.

"Brak," or alkali in South Africa is considered a curse to the irrigation farmer, and has been the cause of much trouble. Reclamation there is considered impossible without a complete system of underdrainage.

The Central Board of Irrigation of India, in 1931, by resolution recorded the opinion that reclamation of waterlogged and alkaline soils was definitely possible by lowering the subsoil water table except where a hard pan and impermeable crust had formed.

Eight years later, the Board resolved that the provisional opinion recorded in 1931 regarding the reclamation of alkaline soil by lowering the water table is open to considerable doubt in view of the result of research work since carried out.
These examples, and similar ones that might be cited in other arid region countries, support the conclusion that to solve the problems of alkali control in the interest of permanent agriculture in arid regions demands not only intelligent application of the facts of irrigation science by irrigation administrators and managers, but also continued and enlarged research of irrigation scientists.

PERMANENT AGRICULTURE IN ARID REGIONS

Great progress must yet be made in the advancement and application of irrigation science in order to maintain permanent civilizations in arid regions. The basic relations of irrigation to climate need to be clarified and more fully used; persistent efforts toward the solution of water storage and silt problems are essential; and more intelligent and widespread use of underground water storage is necessary. The phases of irrigation science relating to efficient conveyance of water and to its application to farms with a minimum of waste of water and injury to soils thus far have been given less attention by public research agencies than their importance to the permanence of profitable agriculture warrant. The science of irrigation water requirements of crops on different soils as related to permanence of agriculture is now more clearly understood than in the early years, partly because of its fuller development, but also because of the gratifying progress in the advancement of scientific methods of estimating and measuring the consumptive use of water as influenced by irrigation practices.

An awakening of the American public to the fact that permanence of agriculture in arid regions depends vitally on more complete development of irrigation science in relation to erosion control on irrigated lands, and in relation to the solution of the alkali problem by more intelligent irrigation and drainage practices is evident. Outstanding scientific research concerning these problems has been initiated in recent years by the Bureau of Reclamation of the United States Department of the Interior and by the Soil Conservation Service and the Bureau of Plant Industry, Soils, and Agricultural Engineering of the Department of Agriculture in cooperation with the Western Agricultural Experiment Stations. A complete understanding of the inter-relations of soils, water, plants, and soil moisture, and of the influence of these relations on intelligent irrigation practices, so essential to the reduction of water losses, to the prevention of waste of water and plant food, and to the perpetuation of a permanently profitable irrigation agriculture, is the major objective of systematic irrigation and drainage research now being conducted by all of these public agencies.

The challenge of perpetuating agriculture and civilization in arid regions confronts both statesmen and scientists—the way to meet it...
is clear. They must continue and enlarge the development of the sciences and their applications to agriculture. They must allot liberal proportions of their funds, their intelligence, and their energies to studies of permanence of water storage structures to methods of water conveyance, application, and use that will assure perpetuation of soil productivity, prevention of erosion, and mastery of the alkali problem. Wise use and preservation of natural resources, guided by science in all of its branches, will insure the perpetuation of civilization insofar as its material needs are concerned.

Now, on this memorable day, March 10, 1943, in commemorating the establishment, the growth, and the achievements of this great educational and research institution, it is fitting to think seriously concerning the fact that perpetuation of agriculture and of civilization in arid regions depends vitally on further development of irrigation science and on more general understanding of its value, and more widespread and intelligent application of its principles in order to solve the complex problems of irrigation, drainage, and plant growth under irrigation, and thus to conserve and use the abundant productivity of arid-region soils and the water supplies for the perpetual well-being of civilized man.
SOME PUBLICATIONS BY ORSON W. ISRAELEN

INDIVIDUAL AUTHORITYSHIP

20. Combating the drought. A series of thirty-seven 500-word articles in the Deseret News. (June to October, 1934.)
21. Irrigation objectives. A series of ten 2,000-word articles concerning important topics in irrigation practice in the Utah Farmer. (April to October, 1935.)
SOME PUBLICATIONS BY ORSON W. ISRAELSEN

JOINT AUTHORSHIP


