INTERNATIONAL INSTITUTE FOR LAND RECLAMATION AND IMPROVEMENT

BIBLIOGRAPHY

9

ANNOTATED BIBLIOGRAPHY ON SURFACE IRRIGATION METHODS

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SURFACE IRRIGATION METHODS

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International Institute for Land Reclamation and Improvement
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Contents

Preface

Large areas of good lands in arid regions cannot be irrigated because of a shortage of suitable water resources. Elsewhere in the world it is becoming more and more obvious that water resources have to be utilized with the utmost care.
As irrigation is the greatest consumer of water, attention must be devoted, above all, to those parts of the irrigation process where the greatest losses occur: this is in the field. Field water application efficiency can be improved in many situations. In general, there are three ways in which this can be achieved:

- a careful selection of the irrigation method most suited to local conditions,
- a proper design of the water application system,
- a good irrigation management, which includes not only the careful determination of the timing and depth of each water application, but also the conscientious supervision of the water application in the field, the actual irrigation.

These considerations, coupled with the fact that surface irrigation is the method most widely applied in the world and has the lowest field water application efficiency, prompted the compilation of this bibliography on various aspects of surface irrigation.

A rational design of the layout of irrigated fields, one easily applicable in practice and adaptable to all situations, is not yet available. Much progress, however, has been made in studies carried out along the various lines of thought on the hydraulics of surface irrigation: the behaviour of a layer of water moving over the land surface in relation to the infiltration characteristics of the soil. Such knowledge is essential for an optimal design.
Efficient water use is widely affected by the maxim that water is cheaper than labour. A great deal of effort has therefore gone into the development of new techniques and new equipment to reduce the care and labour

required for proper surface irrigation, and to prevent unnecessary waste of water. Still, the practical and economic facets of automatic irrigation need further consideration before it can be included as a standard operational procedure of surface irrigation systems.
This bibliography contains selected references to literature on surface irrigation methods, most of it published in the period from 1956 through 1970, under the headings of: general aspects of surface irrigation; methods of surface irrigation; hydraulics of surface irrigation; infiltration in relation to surface irrigation; field water application efficiencies; design of surface irrigation systems; operation of surface irrigation systems, and economics of surface irrigation as related to different irrigation methods.
The classification of the publications under their appropriate headings is often arbitrary, because many publications cover more than one topic. Determining the proper timing and depth of water applications is closely related to evapotranspiration and can be regarded as a separate subject, not included in the bibliography.

In general, the publications have been confined to those written in English, French or German. Journals are abbreviated on the following principle:
Trans. ASAE 9 (1966) 1 : 20-26. 18 refs.
Transactions of the American Society of Agricultural Engineers, volume 9, year 1966, number 1, pages 20-26, number of references 18.

S. Raadsma

General aspects of irrigation, inclusive of surface irrigation

B O O H E R, L. J. / Surface irrigation.
FAO Rome 1967, pp.161. 45 refs.

Practical observations on surface irrigation, covering water supply, soils, land preparation, distribution systems (ditches and pipelines) and ancillary control structures. Various methods of surface irrigation are discussed, together with which method to apply under particular conditions. Guidelines are given for the design of field layouts.

C R I D D L E, W. D. / Irrigation.
Agricultural Engineers' Handbook (C.B.Richey, ed. in chief) McGraw-Hill Book Co., 1961. Chapter 44 : 509-531. 11 refs.

This chapter is a complete textbook on irrigation, dealing concisely with: water supply, water delivery and control, irrigation water requirements, methods of water application, and the application of irrigation water. Included are furrow and border irrigation methods and design.

C R I D D L E, W. D., S. D A V I E S, C. H. P A I R and
D. G. S H O C K L E Y / Methods for evaluating irrigation systems.
Agricultural Handbook No.82. Soil Cons. Service, USDA 1956, pp.24.

Description of field tests of furrow and border irrigation to determine size of stream, length of run and time required to apply water. Field tests for evaluating sprinkler irrigation systems are also described.

Efficiency of water distribution and use on the land.
Reports for discussion on Question 16, V Congress on Irrigation and Drainage, Tokyo, 1963 ICID, New Delhi, India, pp.546.

A collection of 30 reports on hydraulics of surface irrigation, rational methods of defining irrigation efficiency and suggestions

for improving irrigation efficiency.
(The reports are mentioned elsewhere in this bibliography under the names of the author(s)).

H A G A N, R. M., H. R. H A I S E and T. W. E D M I N S T E R (editors) / Irrigation of agricultural lands.
Monograph No.11 Am. Soc. Agronomy, Madison, Wisconsin USA 1964, pp.1180.
Irrigation is dealt with comprehensively by various authors in 62 chapters, classified under the following 13 sections:
I Introduction, historical review and social context of irrigation. II Climatic environment. III Water source for irrigation. IV Selection of land for irrigation. V Soil-water relations. VI Plant-water relations. VII Water-soil-plant relations. VIII Evapotranspiration. IX Predicting irrigation needs. X Irrigation of principal crops. XI Irrigation systems. XII Irrigation management. XIII Water conservation related to irrigation.
A chapter on "Surface irrigation systems" by A.A.Bishop, M.E.Jensen and W.A.Hall is included (p.865-884, 14 refs.).

H O U K, I. E. / Irrigation engineering.
Vol.I Agricultural and hydrological phases. John Wiley & Sons Inc. New York, Chapman & Hall Ltd., London, 1951, pp.521. 39 refs.
A textbook on irrigation with a short description of surface irrigation methods in Chapter 16: Irrigation preparations and procedures.

Instructions and criteria for preparation of irrigation guides.
Section 15, Part I, Engineering Handbook, Far Western States and Territories. USDA Soil Cons. Service, Portland, Oregon, 1957, pp.29. 3 refs
In this paper detailed instructions are presented on how to prepare an irrigation guide, setting forth basic criteria for irrigation system design and irrigation water management. A standard form was developed in the western part of the USA, which can also be used in other areas.

Irrigation advisers'guide.
U.S.Dept. Interior, Bur.Reclam. Washington D.C., 1951, pp.216. 7 refs.

A textbook in six chapters on the practical application of irrigation:I Introduction. II Background information (land, soils, crops). III Project standards (construction of canals and structures, water measuring devices, operation and maintenance). IV Farm development (clearing, levelling). V Frequency and amount of irrigation. VI Methods of irrigation (surface and sprinkling irrigation, guidelines for design).

I S R A E L S E N, O. W. and V. E. H A N S E N / Irrigation principles and practices.
John Wiley & Sons, New York-London, 3rd Ed. 1962, pp.447.

Textbook for students in agronomy and engineering and for non-technical readers, discussing the basic elements of irrigation in agriculture. A description of surface irrigation methods is given in Chapter 14, with 21 refs.

K O V D A, V.A., C. v a n d e n B E R G and R. M. H A G A N (ed)/ International source book on irrigation and drainage of arid lands in relation to salinity and alkalinity.
FAO/UNESCO, Draft ed. 1967, pp.663.

Contains contributions by a great number of specialists in the field of irrigation and drainage. Fourteen chapters on:
I Introduction. II Water and salt balance. III Soils in relation to salinity, irrigation and drainage. IV Hydro-physics of arid and irrigated soils. V Chemistry of saline and alkali soils of arid zones. VI Landscapes in relation to irrigation, drainage and salinity. VII Quality of irrigation water. VIII Water, plant growth and crop irrigation requirements. IX Plants in relation to waterlogging and salinity. X Irrigation systems and management. XI Drainage systems and management. XII Some effects of irrigation and drainage on soils. XIII Reclamation of saline and alkali soils. XIV Design and operational recommendations for the establishment or improvement of irrigation

and drainage projects.

For surface irrigation methods, criteria for selection and design, see pp.410-430.

P O I R E E, M. and Ch. O L L I E R / Irrigation. Les réseaux d'irrigation théorie, technique et économie des arrosages.
Ed. Eyrolles, 3me Edition, Paris 1966, pp.405.

A French textbook, giving a general review of irrigation, divided into four parts:
Part I: Water resources and diversion structures; the layout of irrigation schemes; design of canals and ancillary structures.
Part II: Theory of irrigation; need, timing and depth of water applications, water distribution. Part III: Technique of irrigation; surface and subsurface irrigation, overhead irrigation. Part IV: The economics of irrigation.
A substantial portion of Part III is concerned with surface irrigation systems.

Proceedings of the ARS - SCS Workshop on Hydraulics of Surface Irrigation. Denver, Colorado, Febr. 9-10, 1960, Edit. by M.E.Jensen. ARS 41-43, Oct. 1960, pp.110.

A collection of 14 progress reports and papers on research into design of surface irrigation systems. (Reports are mentioned elsewhere in this bibliography under the names of the author(s).)

Proceedings of the International Conference on Water for Peace, Washington D.C. May 23-31 1967.
Superint. of Doc., Govt.Printing Office, Washington D.C., USA.

Conference, attended by representatives of 92 countries, to discuss the various problems related to the use and development of water.
Vol.I: plenary session speeches, 50 country situation reports.
Vol.II, III, IV: Water supply technology (desalting, weather modification, re-use of water, evaporation control, watershed management, groundwater, pipe design, water quality, water conservat-

ion techniques, pollution control).
Vol.IV: Basic data for Water Programs (Role and development, geo-economic).
Vol.V: Organizing for Water Programs (Int. agencies, govt. agencies, water user agencies, water law and legislation).
Education and Training for Water Programs (need and programs, water user education, int. programs).
Vol.VI, VII, and VIII: Planning and Developing Water Programs (concepts and procedures. systems and analysis, economic considerations, water supply, irrigation, flood control, inland waterway transportation, water quality control, multiple purposes, financing considerations).

Mainly in English with French and Spanish summary.

- Index to "Proceedings on the Int. Conf. Water for Peace", by Giefer G.J. and staff. Report No.20 Archives Ser; Water Resources Centre, Univ. of California, Oct. 1969.
- Goldberg, D. / Modern Irrigation for increased agricultural production. Vol. III : 395-402.
- Garton, J.E. / The relation of improved system design to improved uniformity and efficiency in surface irrigation. Vol. III : 539-541. 8 refs.
- Sanford, H. / Water conservation through improved use procedures. Vol. III : 585-594. 19 refs.
- Merriam, J.L. and G.L.Westesen / Flexibility in water delivery and the need for it to obtain efficient irrigation. Vol. III : 599-608. 2 refs.

T H O R N E, D. W. and H. B. P E T E R S O N / Irrigated soils, their fertility and management.
2nd. Ed. The Blakiston Co. Inc. New York-Toronto, 1954, pp.392, with glossary.

A textbook on irrigation, dealing with soils and fertilizers under irrigation, and soil management for various crops, fruits and vegetables. In Chapter 9: "Planning a farm for irrigation", various

irrigation methods (including those for surface irrigation) are described, together with a basis for selecting appropriate methods and tentative standards for design.

Z I M M E R M A N, J. D. / Irrigation.
John Wiley & Sons Inc. New York-London-Sydney, 1966, pp.516.

A textbook on irrigation. Part I: Irrigation development (basic irrigation development problems, preliminary investigations, water source development). Part II: Modern irrigation methods (evaluation, applications and limitations of surface and sprinkler irrigation methods). Part III: The irrigation network and structures (canals, reservoirs, pipes, structures, pumps). Part IV: Investigations, planning and implementation (an example of an irrigation project).

Methods of surface irrigation

B A R B I E R I, R. / Studio delle techniche irrigue considerate in rapporto all ambiente. (Study of various irrigation techniques considered in relation to environment.)
L'Irrigazione, Bologna 15 (1968) 3 : 14-23. 40 refs.
In Italian with English, French, German summary.

Comparitive experiments between various irrigation methods are rarely conducted as they are complex and onerous. Besides actual parameters for irrigation, many other factors must be considered: type of crop and methods of cultivation, mechanization, water availability, climate, size of farms, etc. The tests should be limited to those methods which can be applied in the area under study. In the south of Italy sprinkler irrigation should be given preference over the traditional methods of surface irrigation.

B E R G , P. H. / Methods of applying irrigation water.
Paper No.3293. Trans.Am.Soc.Civ.Eng. 127 (1962) Part III : 61-74.

Practical guidelines are given for the design of various surface irrigation systems and three principal methods of conveying water to the farm are described: open ditches, low and high pressure pipelines.

B O N E T T I, F. / Alcune considerazioni sulla irrigazione a sommersione per "bacini" o "rasole". (Some considerations on the submersion method of irrigation by small basins.)
L'Irrigazione, Bologna 13 (1966) 1 : 23-27.
In Italian with English, French, German summary.

Basin irrigation is widely applied in many Mediterranean and Middle Eastern countries. Advantages are: (1) low installation costs on flat plains (slope $< 0.3\%$), (2) smaller losses in comparison with border irrigation on the mainly sandy soils, (3) better penetration into the heavier soils than with border irrigation, (4) fewer water applications. Disadvantages are: (1) limited suitability on land with a

slope 0.3%, (2) high annual labour requirements for maintenance of levees.

B O N E T T I, F. / The irrigation of citrus - A working hypothesis.
L'Irrigazione, Bologna 16 (1969) 4 : 13-29.
In Italian and English.

Various irrigation methods practised on citrus in Cyprus are explained, based on the changes with time of parameters determining irrigation costs.

This methodical approach may prove useful when a choice is being made between different irrigation methods. A complete study will require computer techniques.

B R O W N, L. N. / Irrigation on steep land.
Univ.Calif. Calif.Agr.Exp.Stat.Circ. 509 (1962) 26 pp.

The most suitable irrigation methods for land with a slope of 2% or more are described. For orchards on land with a slope of less than 6-8% furrow irrigation is recommended (square grid planting); on steeper slopes (but less than 20%) row planting with small ditches or sprinkling is advocated. For pasture on land with a slope of 6-8% strip irrigation is advised, and on steeper slopes flooding from ditches along the contours, or sprinkling, is considered best.

C E L E S T R E, P. / Drop irrigation systems.
V Congress ICID, Question 16, Tokyo, 1963 : 542-546.

Describes the drop irrigation system, developed in the early sixties. Initial report on the hydraulic, agronomic and economic aspects of this method.

D A N, Ch. / Surface irrigation in the Beisan area.
V Congress ICID, Question 16, Tokyo, 1963 : 485-507.

The author describes surface irrigation methods and practices in the Beisan-Valley in Israel, and trials to improve these practices, giving special consideration to various soil and agronomic aspects.

D A V I S, S. and F. M. W I L L H I T E / Border-basin irrigation on mountain meadows.
Report no.C-703 from ASAE; Agr.Eng. 44 (1963) 10 : 545.

Description of border and basin irrigation on sloping land for the irrigation of mountain meadows. Selection of the proper system reduces the amount of earthmoving and the initial expenses involved.

D E G A N, A. / Les techniques de l'irrigation. (Irrigation techniques.)
Bas-Rhône Languedoc (1964) 21 : 27-40. 11 refs. In French.

Surface and sprinkler irrigation are described, together with their application requirements and their limitations. The author emphasizes the advantage of a supply system which allows both surface and sprinkler irrigation in the same area.

D E G A N, A. / Considerazioni sulle varie tecniche irrigue. (Considerations on the different techniques of irrigation.)
L'Irrigazione, Bologna 12 (1965) 1 : 5-11. 3 refs.
In Italian with English, French, German summary.

In a report submitted to the FAO-meeting on regional development of Mediterranean countries (Nimes, 1964) the main characteristics of different irrigation methods are described, including the limitations of various techniques. It is maintained that irrigation networks (channels or pipelines) should be "bivalent", i.e. suitable for both surface and overhead irrigation. Pipelines best suited to these requirements can only supply water modules up to 30-40 l/sec, sufficient for most crops and most types of surface irrigation.

D E L I B A L T O V, J. / Die Effektivität der Furchenbewässerung und Beregnung.(The effect of furrow and sprinkler irrigation.)
Inter.Z.Landwirtschaft, Sofia/Berlin 1966, 4 : 413-418.

Sprinkler irrigation is more suitable than furrow irrigation: on steep slopes, on flat land, on land with an irregular surface, with a high percolation rate, with a high groundwater level, and when water is relatively expensive.

Selection of a system should be related to soil conditions, climate, crops and economic criteria.

F I N K E L, H. / Irrigation methods: a study of the comparison between sprinkling and surface flooding in the Huleh Valley.
Technion, Israel Inst.Tech., Haifa, 1957. pp.65. 44 refs.

Two different methods of irrigation, i.e. gravity (border) and sprinkling, and their effect on the crop and soil were studied on experimental fields covered with alfalfa. The general conclusion of this study was that sprinkler irrigation is superior in a number of important respects: yield, infiltration, aeration. With regard to other factors, such as volume-weight, aggregate analysis, salinity and soil temperature, there were no highly significant differences between the two methods.

F I N K E L, H. J. and D. N I R / Criteria for the choice of irrigation method.
Trans. ASAE 3 (1960) 1 : 92-96. 8 refs.

Discussion of seven items influencing the choice of irrigation method: water supply, topography, climate, soils, crops, economics, human factor.

F I N R O C K, D. C. / Plastic levees in rice fields.
World Crops 15 (1963) 1 : 17-18.

Bunds or levees in rice fields, built to ensure a uniform water depth, are usually constructed in situ using soil material. It is shown that black polyethylene film can be used instead. This results in savings in costs of land preparation and harvesting, while yields increase due to better weed control, and more land becomes available for cropping. The most desirable construction is described.

G O L D B E R G, D. and M. S H M U E L I / Drip irrigation - a method used under arid and desert conditions of high water and soil salinity.
Trans. ASAE 13, 1970 (1) : 38-41.

(See also: L'Irrigazione, Bologna 16 (1969) 4 : 5-10; approx. same article in Italian.)

Description of a system for drip irrigation from tubes laid out on the field. Advantages of the system are: increase of yield, production on lands otherwise not suitable for irrigation in view of salinity, shortening of the growing season, and uniform and accurate water distribution, even on land which is not levelled.

G O R Y U N O V, N. S. / Influence of irrigation methods on some soil properties.
Soviet Soil Science (1966) 1 : 14-19. 21 refs.

Field investigations were carried out between 1960-1963 to evaluate irrigation methods (flooding, furrow and overhead). One of the indices studied was soil structure unfavourably affected by flooding and less unfavourably by sprinkling and furrow irrigation. Under optimum soil moisture conditions no negative effect was found. Flooding produced a steady decrease in the amount of water-stable aggregates immediately after the first application. Irrigation affected the micro-aggregate state of the soil, also in layers below the topsoil.

H A L L, W. A. / Functional analysis of levees for border irrigation systems.
Trans. ASAE 7 (1964) 4 : 396-397, 401.

Preliminary analysis of border-levee dimensions is made and a proposal for design is presented, applicable to the "flat ridge" border levee. The design requires an evaluation of the max.slope for erosion tolerance with very shallow flow and of the capillary transmission characteristics of the soil. This is in addition to infiltrometer data, roughness, slope, etc., usually analyzed for design of the checks. Where applicable, considerable improvements in productivity and in ease of farming operations should result.

J E N S E N, M. E. and O. W. H O W E / Operational characteristics of border checks on a sandy soil.

Annual Bull. ICID 1961 : 5-10. 10 refs.

Detailed examples of the water surface profiles, intake opportunity time, uniformity of application, and irrigation application efficiency, using low gradient border checks. These examples illustrate the flexibility required in a surface irrigation system and the effectiveness of low gradient border check irrigation under variable irrigation conditions.

J O N E S, L. D. / Land layout for pasture irrigation.
Res.Div. State Rivers Water Supply Comm. Armidale, Australia, June 1968, pp.12.

An extension booklet designed to assist in planning and executing irrigation layouts on virgin country and to aid in improving existing irrigation layouts. It describes planning and design of the layout of borders, farm supply channels and drains and the execution of land levelling and ditch construction with their appropriate costs.

L A W R E N C E, G. A. / Furrow irrigation.
USDA Soil Cons. Science Serv. Leaflet No.344, 1953, 1960, pp.8.

A description of the furrow irrigation method; its use and limitations, spacing, slope, stream size, length of run, field water supply systems, operation and maintenance.

M A L O S S I, D. / Aspetti ed evoluzione della tecnica degli impiante irrigni consortili. (Aspects and evolution of techniques for collective irrigation systems.)
L'Irrigazione, Bologna 17 (1970) 3 : 5-15.

Elements that brought about the evolution of techniques in collective irrigation systems are discussed: buried pipelines, overhead irrigation, the use of small plastic pipes, etc. Networks of buried supply pipelines may serve both furrow and sprinkler irrigation if stream size is less than 30 l/sec. Comments are given on trickle irrigation.

M A R R, J. C. / The border method of irrigation.
Univ.Cal., Agr.Expt Stat.Circ. 408, 1950, pp.23.
Describes the design and construction of borders, the possible field water supply systems and the irrigation operations.

P A P A D O P O U L O S, J. / Irrigation methods.
In Farm Irrigation, Report training course Eur.Prod.Ag. of OEEC and U.S.For.Op.Ad., Greece, 1954 : 49-57.
In an introductory talk the author describes various irrigation methods and their scope, inclusive of surface irrigation methods.

P A P A D O P O U L O S, G. E. / Irrigation methods used all over the world.
ICID Annual Bull. 1965 : 68-72.
Discussion of information obtained through a questionnaire on preference given to irrigation systems in recently constructed large irrigation projects. Reasons are shown for preferring surface irrigation (saving of initial and operating costs, tradition, suitable topography and soil, adequate water supply, specific crops) and sprinkler irrigation (high application efficiency, no topographical limitations, its adaptability to various types of soil, no loss of water and land in distribution system, facility of operation, maintenance and water application, etc.). Construction costs of projects in various countries are given.

P A S Q U A L I S, T. / Irrigazione a scorrimento su spianata mediante canalette prefabbricate con sfioratore laterale. (Border irrigation in flat areas by means of prefabricated water canals with lateral spillways.)
L'Irrigazione, Bologna 17 (1970) 1/2 : 25-28.
In Italian with English, French, German summary.
From prefabricated concrete canals raised above land surface, water is applied to borders in flat areas under grassland by means of lateral spillways (4.30 m by 0.12 m), rendering field inlets superfluous.

P H E L A N, J. T. and W. D. C R I D D L E / Surface irrigation methods.
"Water", the yearbook of agr. 1955 USDA : 258-266.
A description of various methods of surface irrigation and guidelines for the design of systems, their layout and management.

R A M, M. / Irrigation practices in semi-arid regions.
Tel Aviv, Oct. 1964, pp.48.
Contains three lectures on irrigation, dealing with irrigation efficiency, irrigation methods and salinity. Different methods of surface irrigation are described and criteria for selecting a method are discussed.

R O S S, P. E. and N. P. S W A N S O N / Level irrigation.
Journ. Soil and Water Conservation 12 (1957) 5 : 209-214.
Level irrigation provides an excellent means of controlling of irrigation water, resulting in improved application efficiency and a more uniform water distribution. The system reduces operating costs and has a wide range of applicability. The design of level irrigation systems and of the required distribution systems and basic principles of operation are presented.

S H A H I, H. N. / Surface methods of irrigation.
World Crops 23 (1971) 1 : 12-15. 8 refs.
The various methods of surface irrigation are described. The author points out the advantages and the limitations of the different methods and emphasizes the need to given due attention to the design and the applicability before putting any method into actual use.

S O C H O N, Z. / Possibillities of considerable reduction of total water requirements for flood irrigation by means of utilization of outflowing water within a system.
V Congress ICID, Question 16, Tokyo, 1963 : 338-352. 2 refs.
The author quotes the mathematical interrelation for the determination

of the various components of the water balance of a field when flood irrigation of successive basins is applied. Practical application is illustrated by two examples.

S T A N L E Y, W. R. / Corrugation irrigation.
USDA Soil Cons. Service Leaflet No.343, 1954/1962, pp.8.
Describes the corrugation irrigation method: where it can be applied, the layout and construction, the field water supply system (siphons, spiles), operation and maintenance.

S U M A K O V, B. A. / Mechanization and automation of irrigation in the USSR.
Wissenschaftliche Zusch. Humboldt-Uni. Berlin Math.-Naturwiss. Reihe 18 (1969) 4 : 621-627.
In German with English, Russian, French summary.
The technology of surface irrigation (furrow irrigation, distribution pipes, irrigation channels, irrigation machines with flexible pipes, and machines for surface and overhead irrigation) is described in detail, and new developments in overhead irrigation are discussed.

U N C I A N S C H I, L., S. R E N E A and M. B O T Z A N / Contribution à la determination des elements techniques de la méthode d'arrosage par sillons. (Contribution to the establishment of technical elements of furrow irrigation.)
V Congress ICID, Question 16, Tokyo, 1963 : 277-295. 1 ref.
In French with English summary.
The author describes furrow irrigation tests in the Danube Valley. Under normal conditions furrow irrigation ensures a higher productivity than sprinkler irrigation. It was found that a logarithmic relation could be established between furrow length and duration of water application.

Hydraulics of surface irrigation

A S S E E D, M. S. / Horizontal advance of flooding irrigation water in relation to infiltration rate of soil.
Ph.D.Thesis, Iowa St.Univ.Sc.Techn., 1966, pp.240.

Mathematical equations describing the horizontal advance of the irrigation stream over the soil surface are derived and discussed for different types of infiltration equations, corresponding to different known field conditions. The equations are expressed in algebraic forms, easily applicable in irrigation design; they were tested in a laboratory model and showed a good agreement. The results obtained with the model are expressed in dimensionless functions. Theoretical curves for the rate of advance on different soil types, for different antecedent moisture conditions and for different depths of surface water storage are developed and their usefulness is shown with numerical examples.

A S S E E D, M. and D. K I R K H A M / Advance of irrigation water on the soil surface in relation to soil infiltration rate: a mathematical and laboratory model study.
Iowa Agr. & Home Econ.Exp. Station. Iowa State Univ.Sci. & Techn.Res.Bull. 565 (1968) 293-317. 33 refs.

Mathematical equations describing the horizontal advance of an irrigation stream on a soil surface are derived and discussed for different types of infiltration equations, corresponding to different known field conditions. The theory was tested in a laboratory model and comparisons were made between experimental data and theory. The theory enables the depth of infiltration and the maximum distance of advance to be predicted.

B A R T E L S, L. F. / Hydraulic roughness of a flood-irrigated pasture.
Trans. ASAE 3 (1), 1960, 71-72.

Roughness coefficient in Mannings' formula (n) for short and long term

pasture determined in borders was 0.12 and 0.38 resp. under given field conditions of slope, discharge, etc.

B A S S E T T , D. L. and V. E. H A N S E N / The discharge coefficient in the coördinate equation for measuring water flow from horizontal pipes.
Trans. ASAE 7 (1964) 3 : 207-208. 6 refs.

The coördinate method is sometimes used in irrigation trials to measure the inflow if delivered through a horizontal pipe. The authors have conducted an investigation to determine the nature of the coefficient, and certain approximate values are given. Refinements in accuracy will be possible as the given values are now extensively tested.

B A S S E T T, D. L. and E. R. T I N N E Y / Water surface configuration and velocity of advance in hydraulic laboratory tests.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 11-18.

A progress report on a project to establish engineering criteria for the design of low gradient irrigation systems. At the time of presentation the study mainly involved the determination of hydraulic phenomena under controlled laboratory conditions.

B O N D U R A N T, J. A. / Hydraulics of surface irrigation.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 18-20.

A progress report on the study of hydraulics of surface irrigation, a study based on simulation of open channel flow with the use of a Hele-Shaw viscous fluid model.

B O W M A N, C. C. / Manning's equation for shallow flow.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 21.

The paper describes laboratory and field studies on shallow flow of irrigation water. Such flow through vegetation is either turbulent or in a transitional state; through scattered clumps of vegetation it can be a combination of turbulent and laminar flow. A procedure is

described to determine the proper "n" in Manning's formula which can be used for calculating the velocities of shallow water movement over grassy strips.

B O W M A N, C. C. / Dimensional analysis applied to more efficient application of irrigation water.
Trans. ASAE 7 (1964) 3 : 238-239, 242. 10 refs.

Description of an analytical method to derive an equation for calculating the velocity, depth of flow and proper stream size for efficient border irrigation. The application was tested on two cultivated borders. The author points out that more tests must be made with variations in slope, intake rate and densities of growth to determine the best possible value for the constants in the equation.

B O Z O K Y - S Z E S Z I C H, K. / An investigation of the hydraulics of border-flow irrigation with allowance to the change of infiltration in time.
V Congress ICID, Question 16, Tokyo, 1963 : 509-523. 7 refs.

An equation has been derived to determine the rate of advance in border irrigation, taking into account a changing rate of infiltration. An attempt has been made to establish empirical relationships from measured values of parameters with the help of nomograms.

C H E N, C. L. / Surface irrigation using Kinematic-wave method.
Journ.Irr.Drain.Div. (ASCE), 96 (1970) IRI : 39-46. 8 refs.

A mathematical model for one-dimensional unsteady flow in surface irrigation is described. It consists of:

1. the equation of continuity for the surface flow ;
2. the simplified equation of motion, a uniform-flow formula, for the surface flow;
3. the simplified flow equation for the subsurface flow, the infiltration equation for an empirical formula, and appropriately prescribed initial and boundary conditions.

The method (only valid for supercritical flow) is used to solve the model, yielding the general solution that depends on the solution form of the cumulative depth of the subsurface flow at the head ditch. A particular solution for a constant infiltration rate is shown to be compatible with the one obtained from the modified Lewis-Milne equation. Both solutions have been specifically expressed for laminar and turbulent flows.

C H E N, Ch. and V. E. H A N S E N / Theory and characteristics of overland flow.
Trans. ASAE 9 (1966) 1 : 20-26. 18 refs.

A general equation of overland flow is presented and characteristics of the unsteady flow profiles are analyzed. The equation and profiles are compared with those for gradually varied steady flow. The theory presented is shown to apply to a wide range of flow problems. Analysis is being extended in order to obtain a more complete understanding of overland flow.

C H R I S T I A N S E N, J. E., A. A. B I S H O P, F. W. K I E F E R Jr. and Y U - S I F O K / Evaluation of intake rate constant as related to advance of water in surface irrigation.
Trans. ASAE 9 (5) 1966, pp. 671-674. 15 refs.

Based on mathematical analyses, equations are established expressing the relationship between the infiltration function and the rate of advance of the water front in furrow and border irrigation. How the intake rate function can then be calculated is illustrated with examples.

D A V I S, J. R. / Estimating rate of advance for irrigation furrows.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 67-86. 13 refs.

An equation for estimating the rate of advance in furrows is outlined, which showed good results when compared with field observations. Hall's equation, with some modifications, was selected to describe furrow flow because it promised an accurate, simple solution and its

derivation is based on mass conservation. Taken into consideration are infiltration rates and hydraulic roughness parameters, changing with time and season.

D A V I S, J. R. / Estimating rate of advance for irrigation furrows.
Trans. ASAE 4 (1961) 1 : 52-54, 57. 13 refs.
Presents a numerical (mathematical) method to predict the rate of advance for irrigation furrows, checked on results of field tests.

F A R R E L L, D. A. / Analysis of border irrigation.
V Congress ICID, Question 16, Tokyo, 1963 : 59-81. 19 refs.
Surface flow in border check irrigation systems is analyzed mathematically. The method has only been applied in determining the advance of the wave-front and profiles of the water surface during the period of flow, but equations and their solutions relating to recession can be determined by the same method.

F E N Z L, R. H. and J. R. D A V I S / Hydraulic resistance relationships for surface flows in vegetated channels.
Trans. 7 (1964) 1 : 46-51, 55. 17 refs.
Design methods for irrigation borders based on mass conservation principles require the calculation of depth of surface flow, which is influenced by hydraulic resistance. Authors analyzed mathematically the resistance relationships for flow in vegetated channels. The development of completely satisfactory relationships will require systematic evaluation, in particular of soil roughness, plant spacing and its relation to soil roughness, deflection of non-rigid plant elements.

F O K, Y. S. / Analysis of overland flow on a porous bed with applications to the design of surface irrigation systems.
Ph.D.Thesis, Utah St.Univ. 1963, pp.75.
For efficient surface irrigation the length of borders and furrows is determined by characteristics of the advance function, the infiltration

rate, the width, and the ratio of advance time to application time. Mathematical equations have been developed, to predict the advance function based on these characteristics, on the stream size and on the depth of flow at the upper end of borders and furrows. When compared with field data, the equations yielded reliable results. Mathematical equations for the application efficiency and the water distribution have also been succesfully developed.
Design limitations have been suggested according to the conditions studied.

F O K, Y. S. and A. A. B I S H O P / Analysis of water advance in surface irrigation.
Journ.Irr.Drain.Div. 91 (1965) IR1 : 99-116. 10 refs. Discussion : 91 (1965) IR4 : 98-101.
Equations describing the advance in borders and furrows during surface irrigation have been developed and show good results when compared with field data. Empirical equations of water surface profiles on the soil surface and water distribution profiles in the soil are suggested and have proved practical. Methods for computing surface storage and for evaluating the empirical exponent of the advance function have been formulated.

F U K U D A, H. / A theoretical computation of the border flow in irrigation relating to Ostromecki's method.
Annual Bull. 1962 ICID : 27-28. 3 refs.
A theoretical solution of the differential equation developed by Ostromecki is described, proving that results obtained with the equation are practically precise. The solution was successful only if the exponent of the infiltration equation was o.5.

G A R T O N, J. E. and A. L. M I N K / Spatially varied flow in an irrigation distribution ditch.
Trans. ASAE 8 (1965) 4 : 530-531. 2 refs.
A decreasing spatially varied flow occurs in supply ditches where

water is delivered to furrows, etc. As these ditches usually have a slope, the discharge through siphons will decrease in upstream direction of the check unless the head on the siphons is equalized. This study shows that supply ditches constructed as a series of level bays will provide a more uniform water application. Theoretical flow depths in concrete-lined ditches with equal elevation of the water surface at the end of discharge bays have been determined for various spatially varied flows.

H A L L, W. A. / Estimating irrigation border flow.
Agr.Eng. 37 (1956) 4 : 263-265. 3 refs.

A numerical method of predicting the rate of advance of water in a border. The accuracy of results obtained depends on the experimental accuracies with which infiltration data, the puddle factor and surface roughness can be determined.

H A N S E N, V. E. / The importance of hydraulics of surface irrigation.
Journ.Irr.Drain.Div. (ASCE) 84 (1958) IR3, paper 1788, pp.8. 13 refs.

The hydraulic elements involved in surface irrigation are listed and discussed. Relating these hydraulic elements is the key to efficient irrigation, good design and a permanent agriculture.

H A N S E N, V. E. / Mathematical relationships expressing the hydraulics of surface irrigation.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 29-35. 6 refs.

The author describes the progress made in solving the complicated mathematics of the hydraulics of surface irrigation. Seven investigators at Utah State University are working on two approaches to the problem: the hydrodynamic approach, emphasizing the shape of the free water surface, and the direct approach, relating the rate of advance to infiltration rate.

HART, W. E., D. L. BASSETT and T. STRELKOFF / Surface irrigation hydraulics-kinematics.
Journ.Irr.Drain.Div. (ASCE) 94 (1968) IR4 : 419-440. 18 refs.

The study of hydraulics of surface irrigation is separated into kinematic and dynamic approaches. Only the kinematic is considered here, limited primarily to the advance phase. The basic equation applicable in this approach is that of mass conservation or volume balance equation. True solutions of the equation and some that deviate from it are analyzed and compared. Methods of numerically solving the mass-conservation equation are developed and discussed.

HEERMANN, D. F., R. J. WENSTROM and N. A. EVANS / Prediction of flow resistance in furrows from soil roughness.
Trans. ASAE 12 (1969) 4 : 482-485. 6 refs.

Conclusions reached in the laboratory and drawn from statistical procedures, regarding the expression and influence of the roughness coefficient of irrigation furrows, were tested in the field between 1963 and 1965. The empirical relationship between roughness coefficient and roughness height as determined by Kruse et al is applicable in practice. In calculations, the energy gradient can only be replaced by the slope when furrows are longer than about 40 m.

KRUGER, W. E. and D. L. BASSETT / Unsteady flow of water over a porous bed having constant infiltration.
Trans. ASAE 8 (1) 1965, pp.60-62.

A theoretical approach, describing the unsteady state partial surface flow by two partial differential equations, solved numerically. Shape of surface profiles and velocity of advance can be prescribed.

KRUSE, E. G. / Hydraulics of subcritical flow in small, rough channels.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 87-89. 6 refs.

The hydraulics of flow in rough channels similar to irrigation furrows were studied experimentally in a laboratory model. The data obtained

were used to determine the variation of resistance coefficient (Manning's "n") with depth of flow for a given boundary condition.

K R U S E, E. G. / The hydraulics of small rough irrigation channels. V Congress ICID, Question 16, Tokyo, 1963 : 161-176. 12 refs.

Laboratory studies of flow resistance in small rough channels similar to irrigation furrows and borders have shown that transition from laminar to turbulent flows occur at Reynolds number between 400 and 700. The effect of channel shape on flow resistance is negligible compared with the effect of the boundary roughness. The standard deviation of the boundary elevation measurements is sufficient to predict the flow resistance coefficient, but could be improved if roughness, shape and spacing could be measured adequately.

K R U S E, E. G., C. W. H U N T L E Y and A. R. R O B I N S O N / Flow resistance in simulated irrigation borders and furrows. Conserv.Res.Rep. No.3 ARS USDA, 1965, pp.56. 23 refs.

Rate of advance is governed by intake rate, resistance, and discharge rate into channels. The factors affecting flow resistance are difficult to evaluate largely owing to non-uniformity of roughness characteristics, wide ranges of discharge rate and size of roughness elements. Flow hydraulics were studied in a laboratory model and an analysis of experimental results led to equations for the resistance coefficient for rough, laminar flow and for turbulent, hydraulically rough flows with errors small enough to allow practical application. Larger errors would result from estimates of a single value for Manning's "n" for all discharges. Both, laminar and turbulent flows can occur when conditions are similar to those of surface irrigation systems; critical Reynolds numbers range between 500 and 700.

L A L, R. and A. C. P A N D Y A / Furrow irrigation with decreasing inflow rate.
Journ.Irr.Drain.Div. (ASCE) 96 (1970) IR4 : 451-460. 11 refs.

A mathematical model has been developed to provide the method by

which the inflow stream size into a furrow should be reduced stepwise in accordance with the infiltration characteristics of the soil, so as to eliminate runoff losses and to keep the deep percolation losses to a minimum. The total irrigation time is divided into equal intervals of advance time. An equation to determine inflow rates during subsequent time intervals has been developed and graphs to simplify calculations are presented.Practical application of the method is illustrated by an example.

L E S Z C Z Y N S K I, B. / Increase of water volume on the surface in border strip irrigation.
Trans. ASAE 9 (1966) 6 : 857, 859. 7 refs.

In research work on irrigation of borders with a variable infiltration rate it is usually assumed that the constant advance of a waterfront is accompanied by a constant increase of water volume stored on the surface. The author proves from the equation describing this assumption that for a value of 2/3 for the universal coefficient of proportionality it is necessary to assume the constancy of Froude number.

L E W I S, M. R. and W. E. M I L N E / Analysis of border irrigation.
Agr.Eng. 19 (1938) 6 : 267-272. 5 refs.

Based on mathematical analysis of border irrigation, a formula has been developed for the rate of advance in relation to stream size, width and length of the border strip, a variable rate of infiltration, and a constant depth of the water on the surface. Solutions obtained with this formula fit rather well with results of field observations.

M Y E R S, L. E. jr. / Flow regimes in surface irrigation.
Agr.Eng. 40 (1959) 11 : 676-677, 682-683. 7 refs.

Discussion of flow hydraulics in pipes and channels is presented. Equations to characterize surface irrigation flow have been developed and appear valid. Means of applying such equations in practice are still lacking.

N O R U M, D. I. and D. M. G R A Y / Infiltration equations from rate-of-advance data.
Journ.Irr.Drain.Div. (ASCE) 96 (1970) IR2 : 111-119. 13 refs.

Description of a method by which infiltration equations can be determined from rate of advance data by means of curve-matching techniques. Curves were obtained with solutions of the Lewis-Milne border irrigation equation, plotted in dimensionless form on log-paper. If sufficient data are available the technique can be extended to determine the average depth of flow on the surface.

O S T R O M E C K I, J. / Method of computing the border flow irrigation system.
Wiadomosci - IMUZ II (1962) 4, pp.151.
In Polish with English summary.
(For summary of method see also: ICID Annual Bull. 1960 : 73-77. 11 refs.)

A critical analysis of known and applied methods of border flow irrigation is given. A formula is developed for the rate of advance, based on the shape of the advancing water layer and on the infiltration rate. The formula has been checked in the field.

P H I L I P, J. R. and D. A. F A R R E L L / General solution of the infiltration-advance problem in irrigation hydraulics.
Journ.Geophys. Research 69 (1964) 4 : 621-631. 23 refs.

The paper presents a mathematical analysis of the infiltration-advance problem, resulting in a solution of the Lewis-Milne equation, and discusses the interdependence of advance and infiltration. The results are relevant not only to border check irrigation but also to other methods of surface irrigation. The equation is valid only if advance is a monotonic increasing function of time. Advance can be solved for various forms of the infiltration equation, and the inverse problem, deducing infiltration from observed advance and water depth, is considered. Formal solutions for various problems are given as well as the graphical presentation of the solutions of some appropriate dimensionless forms.

S C H R E I B E R, D. L. and D. L. B A S S E T T / Hydraulic description of recession of shallow flow over a porous bed.
Trans. ASAE 10 (1) 1967, pp.54-56. 6 refs.

Describes the shallow, unsteady receding flow over a porous bed with constant infiltration, by means of two partial differential equations, integrated numerically. Solutions were tested in the laboratory. A general application in irrigation system design is suggested.

S H U L L, H. / Furrow hydraulics study at the southwestern Irrigation Field Station.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct. 1960 : 55-62. 5 refs.

This report presents the field procedures followed in obtaining measurements of the infiltration in irrigated furrows. It offers a rational approach to the development of a rate-of-advance equation and mentions some of the problems encountered in developing an equation by this method.

S W A N S O N, N. P. / Hydraulic characteristics of surface runoff from simulated rainfall on irrigation furrows.
Proc. ARS-SCS, Hydra. of Surface Irr. ARS 41-43, Oct.1960 : 90-102. 1 ref.

A progress report of a study planned specifically to determine the maximum furrow grades permissible without excessive erosion, and the limitations on design of irrigation systems as influenced by erosion hazards due to rainfall. It discusses the equipment used in field research techniques, the results of flow velocity, furrow detention, runoff, erosion and time of concentration.

S W E E T E N, Jr. J. M., J. E. G A R T O N and A. L. M I N K / Hydraulic roughness of an irrigation channel with decreasing spatially varied flow.
Trans. ASAE 12, (1969) (4) : 466-470. 6 refs.

Decreasing spatially varied flow occurs when water is withdrawn from distribution channels by siphons. Roughness values of a horizontal

concrete-lined channel were determined in experiments and used to calculate the siphon-tube discharge variations. In practice, these discharges are much more affected by differences in tube outlet elevation than by the rise or descent of water surface profiles.

T H O R N T O N, J. F. / Summary of hydraulics of furrow irrigation studies in Missouri.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 63-66.

The effects of roughness and channel shape on rate of advance, intake rate and flow hydraulics were studied on precisely graded plots with 0.25 percent slope and triangular and flatbottomed furrows. In further studies emphasis will be placed on securing additional data from models.

T H O R N T O N, J. F. / Characteristics of flow in irrigation furrows.
Ph.D.Thesis, Univ. Missouri 1963, pp.146.

The purpose of this study was to investigate the characteristics of flow in irrigation furrows, as influenced by roughness, slope and rate of flow, in a hydraulic flume with trapezoidal and triangular furrow shapes. Tests were run with different degrees of roughness, varying rates of flow and various side slopes, with and without infiltration simulation. Results were analyzed to determine the relationship between roughness coefficient, velocity and depth of flow, hydraulic radius and Reynolds number. It was found that the roughness coefficient decreased when one or more of the four mentioned variables increased, and was higher for trapezoidal than for triangular furrows under similar conditions of flow, slope, etc. The Reynolds number and the infiltration rate were higher for the triangular furrows than for the trapezoidal furrows.

See also: Thornton, J.F. and R.P.Beasley / Characteristics of flow in trapezoidal and triangular irrigation furrows.
Bull. Missouri Agr.Exp.St. 855, March 1964, pp.36. 8 refs.

T H O R N T O N, J. F. and R. P. B E A S L E Y / Characteristics of flow in trapezoidal and triangular irrigation furrows.
Univ. Missouri Coll.Agr.Exp.St.Res.Bull. No.855 (1964), 36 pp.

Description of laboratory tests with two furrow models in which the tractive force and Reynolds number were compared under various flow conditions. The infiltration rate from both types of furrows can be determined from the water depth, the sedimentation, the ratio of the wetted perimeter and the furrow width at waterlevel.

V L A D I M I R E S C U, I. / Formules rationelles pour le calcul hydraulique des longs sillons d'irrigation. (Rational formulae for the hydraulic computation of long irrigation furrows.)
V Congress ICID, Question 16, Tokyo, 1963 : 259-276. 3 refs.
In French with English summary.

Mathematical analysis of the balance equation has resulted in a solution for the length covered by the stream as related to stream size and time. Additional formulae are given for the average depth at the upper end of furrows with different cross-sections and the mean width of the water infiltration pattern. The formulae are used to determine the optimum length of furrows and borders, open and closed at the end, as related to stream size (partially cut back), application depth and time of application. A numerical example is given to illustrate the relatively simple calculations. Accurate values of parameters have to be determined, which requires further investigation.

W I L K E, O. and E. T. S M E R D O N / A solution of the irrigation advance problem.
Journ.Irr.Drain.Div. (ASCE) 91 (1965) IR3 : 23-34. 9 refs. Discussion by C.L.Chen in 92 (1966) IR2 : 97-101.

Presents dimensionless curves that provide a direct and accurate solution of the irrigation advance problem for furrow and border irrigation, when infiltration satisfies the equation $y=kt^a$
Relations between stream size and position of the advancing front can quickly be determined by this method. Predicted positions of advancing

Infiltration in relation to surface irrigation

B I S H O P, A. A. / Relation of intake rate to length of run in surface irrigation.
Trans. ASCE 127 (1962) PIII : 282-293. 6 refs.
Also in Journ.Irr.Drain.Div. (ASCE) 87 (1961) : 23-29.
Describes the relationship between the intake rate of the soil, the length of run and the amount of water lost below the root zone through deep percolation. A nomograph is included from which the percentage of loss by deep percolation can be estimated for soils having different intake characteristics.

B O N D U R A N T, J. A. / Developing a furrow infiltrometer.
Agr.Eng. 38 (8) 1957, 602-604. 8 refs.
Description of infiltrometer for measuring infiltration in situ in a furrow.

B O U W E R, H. / Infiltration patterns for surface irrigation.
Agr.Eng. 38 (9) 1957, p.662-664, 676. 6 refs.
A numerical solution to determine the infiltration patterns for border and furrow irrigation systems from relatively easy-to-take field measurements.

B O U W E R, H. / A study of final infiltration rates from cylinder infiltrometers and irrigation furrows with an electrical resistance network.
Trans. Vol.I, 7th Int. Congress Soil Sc. Madison, Wisc. USA 1960, VI 6 : 448-456. 11 refs.
Describes results of analogue studies with a graded network on soil infiltration capacities. Field intake rates increased with the width of the furrow stream, but only up to a width equal to approximately one-half the row spacing. At that point the field intake rate was

already very nearly the saturated conductivity, which is the intake rate that would be reached under complete inundation. The relationship between cylinder and furrow infiltration performance appeared to be governed by a number of factors, which reduces the usefulness of cylinder infiltrometer data for predicting furrow intake behaviour and makes standardization of techniques difficult.

B O U W E R, H. / Infiltration of water into nonuniform soil.
Journ.Irr.Drain.Div. (ASCE) 95 (1969) IR4 : 451-462. 11 refs.

Presents a simplified procedure for calculating infiltration of water into soil of nonuniform water content or nonuniform hydraulic conductivity, or both. The procedure (based on the Green and Ampt model of piston flow) is applied to calculate infiltration-time relationships for flood irrigation of a coarse and a fine textured soil, and to evaluate the effect of nonuniform inundation time on irrigation efficiency. Large differences in inundation time can be allowed in practice without greatly affecting the irrigation efficiencies, particularly if the hydraulic conductivity of the soil decreases with depth. Parameters required for the procedure can easily be measured in the field.

C O L L I N S, H. G. and R. B. C A M P B E L L / Water infiltration in Hawaiian sugarcane furrows.
Journ.Irr.Drain.Div. (ASCE) 93 (1967) IR4 : 81-96. 11 refs.

A basic requirement in developing criteria for design and regulation of the amount and uniformity of water application is an infiltration equation that describes separately the effects of flow retardance from sugarcane growing in the furrow, the inflow rate, and the furrow slope, shape and spacing as related to time. A regression analysis of infiltration equations developed from 200 inflow-outflow measurements resulted in a quadratic polynomical equation regarding slope, inflow rate, sugarcane age, and time to infiltration. This equation was reduced to parabolic form to simplify comparison and use; the latter equation is limited to sugarcane furrows in the most common soils

(Molokai series) or soils with similar characteristics.

C O R E Y, G. L. and D. W. F I T Z S I M M O N S / Infiltration patterns from irrigation furrows.
Idaho Agr.Expt.St.Res.Bull. 59, 1962, pp.16.

Describes the theory and procedures for studying unsaturated flow from irrigation furrows with the aid of an electric analogue. The wetted Perimeter of a furrow is an important variable when the quantity of water that discharges from it into the soil is considered. The use of the hydraulic radius as a variable appeared to have no greater significance.

Data and analysis are still limited as the study is being continued to determine the effects of furrow spacing, soil types and soil variability within the profile.

D A V I S, J. R. and A. W. F R Y / Measurement of infiltration rates in irrigated furrows.
Trans. ASAE 6 (1963) 4 : 318-319. 10 refs.

Infiltration measurements in irrigated furrows were made with cylinder infiltrometers, blocked-furrow infiltrometers, inflow-outflow measurements and a volume-balance equation based on the rate of advance of the water front. The four methods gave different results on different types of soil (sealing effect); best results were obtained with the last two methods.

F I N K E L, H. J. and D. N I R / Determining infiltration rates in an irrigation border.
Journ. of Geophysical Research, 65 (1960) 7 : 2125-2131. 11 refs.

From field data gathered during border irrigation tests, it is possible to determine graphically not only the rates of advance and recession but also the infiltration rate as dependent on time. This method is also suitable for furrow irrigation tests. A description of the field tests and the simple graphical construction is presented.

F O K, Y. S. and V. E. H A N S E N / One-dimensional infiltration into homogeneous soil.
Journ.Irr.Drain.Div. (ASCE) 92 (1966) IR3 : 35-47. 6 refs.

Semi-logarithmic equations of infiltration rate and accumulative infiltration related to the soil properties and infiltration time are developed. Graphical solutions for these equations are presented in two coaxial charts and examples of applications are given. The validity of such empirical exponental equations is examined. It is recommended that the time interval during which the empirical expression is valid, should not be exceeded in practice.

F O K, Y. S. / Infiltration equation in exponential forms.
Journ.Irr.Drain.Div. (ASCE) 93 (1967) IR4 : 125-135. 13 refs.

Empirical infiltration equations have always been expressed in power or exponential forms. For practical application this is very suitable, but its physical significance needs exploration. Four accumulative equations and rates of infiltration for four typical time periods in exponential form are developed, from which the effect of individual soil properties could be observed. Good agreement was obtained between the equations and empirical data collected from different sources.

F O K, Y. S. / One-dimensional infiltration into layered soils.
Journ.Irr.Drain.Div. (ASCE) 96 (1970) IR2 : 121-129. 4 refs.

An algebraic equation to describe one-dimensional infiltration into layered soil is also applicable to a homogeneous soil if the soil profile is regarded as being one layer. The effect of soil properties on the infiltration process is readily observable in this equation. The validity of the equation has been examined, using published data of infiltration into two-layered soil profiles, and showed good agreement.

G R O V E R, B. L. and C. W. H O T C H K I S S / An electric point gauge and tube orifice plates for measuring flow rates in furrow

irrigation.
Proc. Soil Sci.Soc. of America 27 (1963) 5 : 584-586. 6 refs.
Describes an electric point gauge and orifice tube plate with tubes of various diameters and discusses its application. The equipment is particularly useful in evaluating intake rates in furrow irrigation.

H A I S E, H. R., W. W. D O N N A N, J. T. P H E L A N, L. F. L A W H O N and D. G. S H O C K L E Y / The use of cylinder infiltrometers to determine the intake characteristics of irrigated soils.
Agr.Res.Serv. & Soil Con.Ser., USDA, ARS 41-7, May 1956, pp.10.
Describes the equipment used in measuring the intake rates of soils, and its application; also discusses the computation of the intake rates from test data.

S H O C K L E Y, D. C., J. T. P H E L A N, L. F. L A W H O N, H. B. H A I S E, W. V. D O N N A N and L. E. M Y E R S / A method for determining intake characteristics of irrigation furrows.
USDA Agr.Res.Ser. and Soil Con.Ser. ARS 41-31, April 1959, pp.10.
A description is presented of field tests carried out to determine the infiltration rate in irrigated furrows from inflow-outflow measurements.

S H U L L, H. / An inflow-advance-storage method for determining infiltration in irrigated furrows.
Soil Science 98 (1964) 3 : 192-196. 9 refs.
Presents a numerical analysis of the infiltration in an irrigated furrow, based on the inflow, the storage in the furrow and the rate of advance data. The resulting infiltration equation should be more accurate than equations derived from infiltrometers or inflow-outflow data under certain conditions.

S M E R D O N, E. T. and C. M. H O H N / Relationships between the rate of advance and intake rate in furrow irrigation.
Tec.Agr.Expt.Sta. MP - 509, 1961, pp.11.

Field research data were used to evaluate analytically determined relationships between infiltration and the rate of advance in irrigated furrows. The relationships presented are valid for all soil types. A method is given for determining the infiltration rate by taking measurements on a furrow being irrigated. Results compare better with actual infiltration than when the infiltration rate is determined by furrow infiltrometers.

T A L M A, T. / Infiltration from semi-circular furrows in the field.
Australian Journ. Soil Res. 7 (1969) 3 : 277-284. 4 refs.

Field data have been used to check the applicability of a recently proposed theory on infiltration from semi-circular furrows; the theoretical solutions adequately describe cumulative infiltration. In most soils gravity effects were pronounced. Some factors of relevance to furrow irrigation are discussed, as is the estimation of final infiltration rates from short furrow tests.

V A N 't W O U D T, B. D. / Infiltration behaviour under furrow and sprinkler irrigation.
Agr.Eng. 38 (5) 1957, 310-311, 319. 3 refs.

Tests showed that the advance of the wet front appeared to be the same under either furrow or sprinkler irrigation. Influence of cracks on the wetting pattern is discussed.

W U, I. and A. A. B I S H O P / Graphic relation of intake, length-of-run and time.
Journ.Irr.Drain.Div. Proc. ASCE 96 (1970) IR3 : 233-240. 8 refs.

Accumulated infiltration of surface irrigation expressed as a function of length of run and time depends on the advance function of stream and infiltration characteristics of the soil, both of which can be expressed as power functions.

This paper presents a simple graphical method of determining accumulated infiltration in border or furrow irrigation from field data (rate of advance and of recession, of total irrigation time), showing the

estimated infiltration pattern at any given time during irrigation. The technique is simple and can be used to evaluate an irrigation system by determining the distribution efficiency and the application efficiency from the infiltration pattern.

Field water application efficiencies

B A L O G H, J. / Irrigation efficiency with surface irrigation in Hungary.
V Congress ICID, Question 16, Tokyo, 1963 : 319-327. 4 refs.

Results of three years of investigations on the water household of various surface irrigation methods are reported. It was concluded that the technology of the method determined the lower limit of each irrigation water quantity, rather than the soil type, water requirement, etc. Flooding and border irrigation nearly always caused a rise of the groundwater table, furrow irrigation only when larger quantities were supplied.

B O U W E R, H. / Salt balance, irrigation efficiency and drainage design.
Journ.Irr.Drain.Div. (ASCE) 95 (1969) IR1 : 153-170. 27 refs.

A simplified procedure is given to predict additional irrigation water requirements to maintain the salt balance in the rootzone. Key factor is the leaching efficiency (ranging from 0.2 to 0.6 for fine and coarse textured soils respectively), which was accurately predicted with the procedure for known leaching requirements in three regions. In defining irrigation efficiency, distinction is made between an efficiency of water utilization and of water application. In conclusion, a calculation method for the design of a drainage system to avoid high water tables is given.

B U S C H, C. D., W. G. M A T L O C K and M. M. F O G E L / Utilization of water resources in a coastal groundwater basin. Part I: Evaluation of irrigation efficiency.
Journ.Soil and Water Conservation 21 (1966) 5 : 163-166.

The authors describe the evaluation of current surface irrigation practices and analyze the irrigation efficiency on a coastal plain in Mexico. Recommendations are made in the field of irrigation manage-

ment and layout to reduce the high water losses.

C U R R I E, J. A., J. W. W O L F E and L. R. S W A R N E R / Irrigation efficiency, consumptive use and certain soil characteristics of the North Unit of the Deschutes Irrigation Project, Oregon. Agr.Exp.Stat., Oregon State Col., Corvallis.Misc. Paper 72, 1959, pp.29.

Field investigations on 22 farm fields showed that 39% of the water applied was stored for consumptive use, 46% was lost as surface runoff and the remainder was presumed lost to deep percolation. Overall farm irrigation efficiency studies on six farms was 40%. A supplementary study compared the irrigation efficiency of the border strip method and of the corrugation method throughout the three-year study. The values for each year were 60, 88 and 94% on the borders and 47, 55 and 73% on the corrugations. Results indicate that under certain conditions a change in irrigation method could save water.

E R I E, L. J. / Management: a key to irrigation efficiency. Journ.Irr.Drain.Div. (ASCE) 94 (1968) IR3 : 285, 293. 10 refs.

Nearly 42% of the water delivered to irrigated farms is not beneficially used by plants: part of it is absolute waste that could be avoided by proper management. Various cultural practices, irrigation systems and consumptive use data are discussed in relation to efficiency and water conservation.

F U J I O K A, Y. / Suggestions for improving irrigation efficiency. V Congress ICID, Question 16, Tokyo, 1963 : 115-130. 3 refs.

The author suggests various methods for improving irrigation efficiency in submergence irrigation (continuous basin irrigation of rice): shallow waterdepth, restriction of excess percolation with imported clay and bentonite, and re-use of irrigation water.

H A L L, W. A. / Performance parameters of irrigation systems. Trans. ASAE 3 (1960) 1 : 75-76, 81. 1 ref.

A philosophy on the evaluation of farm irrigation systems, using the

following defined parameters: application efficiency, system application efficiency, ideal system application efficiency, operational efficiency, season application efficiency, uniformity function, uniformity coefficiency and economic irrigation efficiency. Adoption of such parameters will result in improvement of design and operation of irrigation systems.

H A N S E N, V. D. / New concepts in irrigation efficiency.
Trans. ASAE 3 (1960) 1 : 55-57, 61. 10 refs.

Additional aspects of irrigation efficiency (water storage efficiency, water distribution efficiency, consumptive use efficiency) are described, necessary for more precise evaluation of irrigation practices.

J E N S E N, M. E. / Evaluating irrigation efficiency.
Journ.Irr.Drain.Div. 93 (1967) IR1 : 83-98. 11 refs.

The evaluation of irrigation efficiency requires the delineation of necessary and beneficial water uses in irrigation projects, uniform evaluation procedures, and acceptable standards for comparative purposes. Above-mentioned water uses are defined, together with practical and economical methods for evaluating irrigation efficiency. Examples are presented to illustrate the probable accuracy of various measurements used in evaluation.

Discussion on this paper by M.A.Gill and H.F.Blaney, (Journ.Irr.Drain. Div. 93 (1967) IR4 : 149-153. 8 refs.)

Blaney refers to field and farm irrigation efficiency research on 75 locations in New Mexico with following results (based on different soil groups): farm supply ditch loss 5-15%, surface runoff loss 5-25%, deep percolation loss 10-35%, field irrigation efficiency 60-75%, farm irrigation efficiency 45-60%.

For closure of discussion and errata see: J.Ir.Dr.Dv. 95 (1969) IR1 : 213-214.

J E N S E N, M. E., L. R. S W A R N E R and J. T. P H E L A N / Improving irrigation efficiencies.
Mon. 11 Am.Soc.Agr.: Irrigation of agricultural lands, 1967 : 1120-1142. 23 refs.

Defines irrigation efficiency terms, describing factors affecting irrigation efficiencies, discusses measurement and calculation procedures and suggests methods to improve farm water conveyance and application efficiencies.

K E L L E R, J. / Effect of irrigation mehtod on water conservation.
Journ.Irr.Drain.Div. Proc. ASCE 91 (1965) IR2 : 61-72. 20 refs.

Irrigation efficiencies are discussed for various methods of irrigation (surface and overhead) and average values are given. The conclusion is reached that farm-irrigation efficiency depends on management and facilities rather than on irrigation methods. Operational efficiency increases as more water control and management are provided for in the system and preference should be given to irrigation system planning on a regional rather than a farm basis, as the economic efficiency is independent of the farm-irrigation efficiency, particularly when the user's limiting resource is land.

K O R V E N, H. C. / Border ditch and border dike irrigation.
Trans. ASAE 5 (1) 1962, pp.192-196. 14 refs.

The uniformity of water application is depicted by plotting the measured soil moisture storage on a map of the irrigated area ("topographic method"). The influence of the head and of the soil moisture content at the time of irrigation on the water application efficiency and its uniformity were determined in border ditch and border dike irrigation trials.

K R U S E, E. G., P. E. S C H L E U S E N E R, W. E. S E L B Y and B. R. S O M E R H O L D E R / Sprinkler and furrow irrigation efficiencies.
Agr.Eng. 1962 Nov., pp.636-639, 647. 19 refs.

Comparison of efficiencies of sprinkler and furrow irrigation under conditions suitable for irrigation by either methods. Tests performed during a period of three years showed an average application efficiency of 82.5 and 74.4% resp. With proper design and operation both methods can supply water to the rootzone at a high level of efficiency.

METELERKAMP, H. R. R. / Irrigation efficiency under surface irrigation on the alluvial soils of the Sabi Valley.
Rhodesia Agr.Journ. 62 (1965) 3 : 64-68, 72.

A description is given of field trials to determine influence of landscape, stream size and cultural practices on the irrigation efficiency. Optimum stream flows and cultivation practices (flat, ridged, furrows) are given for maize and cotton on steep and flat slopes and different lengths of run (0.01-0.1 curves per foot width). The correct time of cutback and turn-off is of great importance in preventing waste of water. Planting should be done as soon after land preparation irrigation as possible.

MARTINS, C. A. and A. L. DOS SANTOS / Irrigation efficiency in Sorraia and Sado Valley irrigation schemes.
V Congress ICID, Question 16, Tokyo, 1963 : 297-309. 4 refs.

In this paper methods used in estimating irrigation efficiency are presented, and the influence of various conditions (irrigation method, soil, stream size, area to be irrigated and irrigation's skill) on efficiency are analyzed. One example is presented to illustrate the method of determining the best dimensions of a border strip as used in Portugal.

OLIVIER, H. / Efficiency of water distribution and use on the land.
V Congress ICID, Question 16, Tokyo, 1963 : 35-58.

All aspects of irrigation efficiency are broadly discussed. Some thoughts are expressed on the improvement of water application in practice.

P A I R, C. H. / Effects of irrigation methods and system management on water application efficiency.
V Congress ICID, Question 16, Tokyo, 1963 : 145-159. 9 refs.

The author defines field-water application efficiency and describes the factors affecting efficiency. The paper summarizes a study made to compare field-water application efficiencies of the furrow, border, contour border and sprinkler methods of irrigation. The contour border gave the highest efficiency for greater depths of water application, whereas the sprinkling method gave the highest efficiency for shallow depths.

P A I R, C. H. / A comparison of water application efficiencies obtained under various methods of applying irrigation water.
Proc. Alaskan Sci.Conf. 14 (1964) : 125-126.

A field-water application efficiency study with various methods of irrigation on alfalfa and hard fescue grass crop grown on 3 to 5% slopes showed an efficiency on the downslope furrow method of 40%, on the downslope border of 47%, on the contour border of 66% and on the sprinkling method of 61% (average figures). Maximum water application efficiency requires water control equipment, proper land preparation, correct irrigation system design and proper management of the system.

P O H J A K A S, K. / Measuring irrigation water losses through border dykes.
Canad.Agr.Eng. 7 (1965) 1 : 28-29.

In border dike irrigation systems, some of the irrigation water is lost through and below dikes. A sampling program was designed and conducted to provide data for calculating border losses from the gravimetric soil moisture determinations.
Losses turned out to be higher when soil moisture content was higher prior to irrigation, and when greater depths of water were applied. Data on the magnitude of water losses on various types of soil are presented.

S I M E O N O V, D. / The water distribution in the soil under border and sprinkler irrigation.
Rastenievudni nauki, Sofija 3 (1966) 8 : 37-44. 6 refs.
(In Bulgarian with Russian and English summ.)

Irrigation trials on an acid brown forest soil showed that the water distribution in the soil under border irrigation was far from uniform. To obtain sufficient information samples should be taken with 7 to 8 repetitions from the topsoil (0-40 cm) and 10 to 13 from the subsoil. Sprinkler irrigation gave a more uniform distribution and an average soil moisture value can be obtained from 4 to 6 repetitions.

S M E R D O N, E. T. / Subsurface water distribution in surface irrigation.
Journ.Irr.Drain.Div. (ASCE), 89 (1963) IR1 : 1-15. 10 refs. Discussion: 89 (1963) IR3 : 91-95. 6 refs.

Experimental data on subsurface water distribution in furrows show that the uniformity of water distribution is greatly dependent on the manner in which the infiltration rate changes with time after initial wetting and on the time required for the wetting front to traverse the run. Equations are developed describing the subsurface water distribution in terms of three dimensionless ratios, one each for time quantities, distances along runs and water application quantities.

S M E R D O N, E. T. and L. J. G L A S S / Surface irrigation water distribution efficiency related to soil infiltration.
Trans. ASAE 8 (1) 1965, pp.76-78, 82. 6 refs.

The water distribution related by a rational equation to three-dimensionless ratios, representing time factors (advance: application), distance covered and water application amounts. Water distribution efficiency graphically related to the infiltration function and the time factor is useful in design and evaluation of an irrigation system.

S O M E R H A L D E R, B. R. / Comparing efficiencies in irrigation water application.
Agr.Eng. 39 (1958) 3 : 156-159. 17 refs.

A study of field-water application efficiencies on alfalfa plots from 1952-54 showed a mean efficiency of 84% for sprinkler irrigation and 72% for surface irrigation (lower due to greater amount of surface runoff). The quantity of water stored in the rootzone was not affected by the method of irrigation.

S T A M M E R S, W. N. / Investigation on the improvement of irrigation practices in the Umatilla Project.
Agr.Exp.Station, Oregon State Univ., Corvallis. Special Report 166, 1963, pp.33. 4 refs.

Irrigation efficiencies in the area studied ranged from 20 to 30%. Irrigation practices were improved, among other things, by described methods of determination of design irrigation streams for border and furrow irrigation on sandy soils. Efficient irrigation methods were demonstrated but appeared to be of little value unless a definite economic benefit could be shown to the farmers.

T A M H A N E, R. V. / Identification for problems faced in the field management of irrigation supplies and measures to be adopted for maximisation of production from available resources of water.
Centr.Board Irr. and Power, Symposium Irr. Water Management, New Delhi Nov. 1967, pp.4.

Low irrigation efficiency is partly due to changes in infiltration rate throughout the irrigation season and from year to year. The irrigation system should therefore be rather flexible. Large stream sizes are suggested for soils with a high intake rate and smaller streams for soils with a low intake rate.

V A N 't W O U D T, B. D. / Irrigating from flat-grade, compacted furrows.
Annual Bulletin ICID, 1967 : 91-96. 5 refs.

Experimental work was carried out to improve the irrigation efficiency in furrow irrigation on two types of soil with a high infiltration rate by means of compaction. The application of pressure for shaping and partially sealing furrows looks promising but further research is needed on mechanics and persistence of compaction.

W I L L A R D S O N, L. S. / What is irrigation efficiency?
Irr.Eng. & Maint. (USA), April 1960 : 13-14, 18.

Defines various terms used in describing irrigation efficiency.

W I L L A R D S O N, L. S. and A. A. B I S H O P / Analysis of surface irrigation application efficiency.
Journ.Irr.Drain.Div. (ASCE) 93 (1967) IR2 : 21-36. 4 refs.

Design of surface irrigation can be improved if the interrelationships of design parameters of infiltration and advance are understood. Two analyses are presented, showing the effect of advance time and infiltration rate on water application efficiencies: (1) treats runoff as a constant proportion of the inflow, (2) computes runoff and deep percolation losses from advance and infiltration variables. Both analyses show that surface irrigation water application efficiencies above 60% are easily attainable under reasonable design and operation conditions. Low efficiencies can be attributed primarily to over-irrigation.

Design of surface irrigation systems

B I S H O P, A. A. / Irrigation of sloping lands, report to the Government of Japan.
FAO Report No.1396, Rome 1961, pp.59. 23 refs.

In this report various methods for upland irrigation (sloping land) are discussed, and the planning and design of a furrow irrigation system are presented in detail. Although special reference is made to the Aiche Project Area in Japan, the report may serve as an example for planning upland irrigation.

B I S H O P, A. A., M. E. J E N S E N and W. A. H A L L / Surface irrigation systems.
Mon. 11 Am.Soc.Agr.: Irrigation of agricultural lands, 1967 : 865-884. 14 refs.

Description of various methods of surface irrigation with adaptations, limitations and advantages. Principles for design of irrigated borders and furrows are presented.

B O N D U R A N T, J. A. / Design of recirculating irrigation systems.
Trans. ASAE 12 (1969) 2 : 195-198, 201. 3 refs.

Re-use of irrigation runoff water, particularly in furrow irrigation, may be more economical than the effort required to accomplish efficient irrigation with the smallest amount of runoff. A method for determining rates and amount of runoff and time and size of a cutback stream is presented. The system required for re-use (collecting-storage-pumping-piping) is described, and different factors affecting total costs are discussed. Finally, a design example is given.

B O N E T T I, F. / Un metodo teorico-practico per la determinazione delle portate unitarie nell'irrigazione a solchi e a spianate.
(A theoretical-practical method to determine unit delivery rates when irrigating by furrows and by strips.)

L'Irrigazione, Bologna 16 (1969) 1 : 5-11. 21 refs.
In Italian with English summary.

A new formula is proposed to determine the unit flow in furrow and border irrigation.

D A V I S, J. R. / Concepts on design of border irrigation systems.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 36-44. 6 refs.

Three methods of design of border systems are discussed: (1) a design based on the objective of 100% irrigation efficiency, (2) a modification of the first method, sacrificing some efficiency (Hall, 1960, making use of the volume balance method), (3) a design based upon achieving maximum economic returns from the border system, disregarding irrigation efficiencies as such. The basis upon which the design is evaluated must be clearly understood.

F O K, Y. S. and A. A. B I S H O P / Expressing irrigation efficiency in terms of application time, intake and water advance constants.
Trans. ASAE 12 (1969) 4 : 438-442. 11 refs.

Mathematical expressions are developed for the application efficiency and the distribution efficiency in surface irrigation and tested on field experimental data. The application efficiency depends on the infiltration, on the water advance and on the ratio of the intake time to the water advance time. The larger this ratio, which is the easiest factor to operate, the higher the efficiency. A higher ratio is ensured if the length of run is properly designed. A method to determine the maximum length of run is indicated.

G R A Y, D. M. and M. A H M E D / Rotational approach applied to the design of border dike systems.
Canad.Agr.Eng. 7 (1965) 1 : 30-33, 44.

The authors demonstrate the application of a rational approach, based on the conservation of mass, to the analysis and design of border dike irrigation systems. Theoretical expressions were developed to evaluate soil intake rate characteristics from measurements of inflow, rate of

advance and the time-rate of accumulation of surface storage. These expressions were used to calculate average depths of water applied. When tested in the field, the results were in close agreement with applied depths, determined by soil moisture measurements.

H A L L, W. A. / Design of irrigation border checks.
Agr.Eng. 41 (1960) 7 : 439-442. 3 refs.
A method to design a border (optimum length, rate of inflow and water application) based on the infiltration characteristics of the soil and on the predicted rate of advance is presented.

J E N S E N, M. E. and O. W. H O W E / Performance and design of border checks on a sandy soil.
Trans. ASAE 8 (1965) 1 : 141-145. 11 refs.
Results are presented of field studies on low-gradient border checks with various crops. High water application efficiencies (80-95%) were obtained when rate of application was 1/3 to 1/5 of average intake rate. Procedures for estimating total slope for max. efficiency and uniformity are developed.

K A T H E I N, Z. F. / Organization and demonstration of furrow method of irrigation.
V Congress ICID, Question 16, Tokyo, 1963 : 311-317.
The paper presents a guide to the instructor on how to approach a demonstration of the furrow method of irrigation under field conditions. Actual evaluation problems are not dealt with but a description is given of the tests and of the suitable irrigation equipment.

K R I V O V J A Z, S. and C. M A T E V / Op redeljane elementite na technikata na polivane pro brazdi. (Technical factors determining furrow irrigation.)
SelsKostopanska nauka, Sofija 2 (8) 1963, 3/4 : 316-324. 5 refs.
Different factors to be considered in furrow irrigation are described:

depth of application, rate of advance, stream size, length of run, time of irrigation. Based on field trials these factors have been correlated in a nomograph for various types of soil and different land slopes.

L A W H O N, L. F. / Attempts at improvement of design procedures for border irrigation.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 7-10.

Formulas used to design border irrigation systems are presented. The procedures are still empirical in nature but may approach rational solutions, provided the assumptions on which they are based can be proved.

L E S Z C Z Y N S K I, B. / The stream advance function in border flow irrigations.
Zeszyty naukowe Szkoly głównej Gospodarstwa wiejskiego w Warszawie, Melioracje rolne 1965, 6 : 73-85. 14 refs.
In polish with Russian and English summ.

The influence of the stream size on the design of surface irrigation is determined on the basis of theoretical considerations, assuming a constant stream flow and no interference by the groundwater level on the infiltration. Solutions are given for a constant infiltration rate and a changing infiltration rate. Examples of the calculations are given; results are compared with those obtained according to the Ostromecki method and show a rather good agreement.

L E S Z C Z Y N S K I, B. / Solving the differential equation for slowly changing unsteady water motion in conditions of border strip irrigation.
Arch.Hydrotechn. 14 (1967) 3 : 393-426.
In Polish with Russian and English summ.

Knowledge of the relationship between time and advance of the water-front is necessary for the design of borders. If the infiltration is assumed to be constant, the ratio of the horizontal velocities at various locations in the vertical profile of the flow depends only on

the distance of these locations to the land surface. The volume balance equation leads to the Volterra's integral equation, having one solution in the form of advance stream function only.

L I T T L E, W. C. / The design of furrow irrigation systems.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 103-110.
9 refs.

A procedure is presented to design a furrow irrigation system, a procedure depending upon empirically derived relationships. Hence, the result is no better than the field data obtained. More studies must be performed in order to determine its validity (conclusions were only derived from one year's data), and flow characteristics in furrows should be determined.

M O O R E, S. D. / Flood irrigation design.
Journ.Agr. South Australia 67 (1964) 9 : 280-287 and 67 (1964) 10 : 316-321. 1 ref.

Descriptions of various surface irrigation methods with guidelines for design based on practical experience: border irrigation, furrow irrigation, wild flooding, and ancillary structures.

O S H I M A, K. / Hydraulic consideration of furrow irrigation in Japan.
V Congress ICID, Question 16, Tokyo, 1963 : 89-97.

A description is given of an intake rate test and a furrow stream test carried out in the field to determine the optimum furrow length. The author presents the characteristics of upland field regions which govern the irrigation methods practised.

P H E L A N, J. T. / Design procedures and research needs for the furrow method of irrigation.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 45-54.

Current procedures for the design of furrows for irrigation are discussed. Maximum and minimum allowable slopes are considered in

view of flow velocity of runoff caused by rainfall. Recommended corrugation spacings are given. The author points out that the research need cannot fully be met until the basic relationship between the various factors involved in furrow irrigation is solved.

R A W I T Z, K. / Surface irrigation research in Israel.
V Congress ICID, Question 16, Tokyo, 1963 : 1-12. 13 refs.

Furrow irrigation is the most important method of surface irrigation in Israel. Field experiments are required before recommendations for furrow design can be made, as a fully satisfactory method of predicting the rate of advance is still lacking. A description is given of such experiments, a graphical method of presenting results is suggested, and a new index of uniformity of water distribution is presented.

S H O C K L E Y, D. G. / Present procedures and major problems in border irrigation design.
Proc. ARS-SCS, Hydr. of Surface Irr. ARS 41-43, Oct.1960 : 1-6. 1 ref.

A description is given of border designs, based on the unit-stream concept, assuming that irrigation streams are proportional to border strip area and that rates of advance are in direct proportion to stream size. It is an empirical approach as the basic hydraulic characteristics of surface irrigation flows are not yet sufficiently known.

S H O C K L E Y, D. G., H. J. W O O D W A R D and J. T. P H E L A N / A quasi-rational method of border-irrigation design.
Trans. ASAE, 7 (1964) 4 : 420-423, 426. 7 refs.

For the graded border method an attempt is made to adjust stream size to intake characteristics of soil, land slope and area to be covered. This should provide a nearly uniform intake opportunity time at all points along the border. A rational design method requires knowledge of intake characteristics, rate of advance and of recession. Since

hydraulic characteristics have not been adequately determined, a design method based on certain assumptions has been developed. Four important design limitations are mentioned, and two examples of the design procedure are given.

W U, I. and T. L I A N G / Optimal design of furrow length of surface irrigation.
Journ.Irr.Drain.Div. Proc. ASCE 96 (1970) IR3 : 319-331. 12 refs.

The design of furrow length can be optimized by analyzing overall irrigation system costs when infiltration intensity, advance function and other pertinent facts are known. Computer programs were coded to obtain optimal solutions; cost data in programs can be adjusted. The gentle slope of the curves of cost functions leaves the designer limited freedom in choosing a suitable furrow length without incurring extremely high costs.

Results showed that the irrigation application efficiency is a function of furrow length. Comparison was made between ordinary systems and cutback systems. The method can also be used to determine border length.

Operation of surface irrigation systems

B O G A R D I, I. / Hydraulic problems in lay-flat irrigation.
Hidrologiail Közlöng 44 (1964) 1 : 1-8.
In Hungarian.

Lay-flat irrigation method using soft plastic hoses with circular openings at certain intervals is described. The hydraulic problems - particularly pressure and discharge distribution - are discussed. The method facilitates operation of irrigation systems.

B O N D U R A N T, J. A. and A. S. H U M P H E R Y S / Surface irrigation through automatic control.
Agr.Eng. 43 (1962) 1 : 20-21, 35. 4 refs.

An automatically operated surface irrigation system requires: 1. properly prepared fields, 2. sensing and/or timing devices to turn on the inflow and to shut it off when irrigation is completed, 3. distribution system with automatically controlled mechanized gates. Existing possibilities for meeting these requirements are discussed. A description is given of proper field lay-outs and of an automatically operated (mechanized) check gate.

B O W M A N, C. C. / Semi-automation of irrigation.
VII Congress ICID, Mexico-City 1969, Question 24 : 271-275. 10 refs.
ICID, New Delhi.

The demand for water and the lack of good labor for irrigation has made it necessary to develop efficient automatic systems for the application of water. A description is given of a semi-automatic irrigation system, utilizing pressure-operated gates in conjunction with a series of portable water depth sensing transmitters and a portable receiver as controls. The system is designed for all surface irrigation methods where the water flows in a definite channel. The radio control system as described can also be used in conjunction

with sprinkler systems.

C U R T I S, T. H. / Changing irrigation sets by the clock.
Irr.Eng.Maint. 10 (1960) 12 : 14-15.
Describes a clock system attached to a common canvas dam, which converts it into an automatically operated dam. Also describes an automatic border outlet dropgate and other types of automatic check gates which can be released by a timer. Automatic controls of this type are best suited where border irrigation is used.

F I S C H B A C K, P. and H. W I T T M U S S / Automatic irrigation is here.
Crops and Soils 19 (1966) 2 : 9-10.
Description of an automatic furrow irrigation system with pumps, buried pipelines, and hydrants with air-inflated rubber valves. The system is controlled by tensiometers, placed at various locations in the field. The surface runoff is automatically pumped back into the system.
(See also Wittmuss)

G A R T O N, J. E. / Automation of cutback furrow irrigation.
Ph.D.Thesis, Univ. of Missouri, 1964, pp.97.
The purpose of this study was to develop an automatic cutback irrigation system for furrow irrigation which would reduce labor requirements and improve irrigation efficiency. An extensive series of tests with short, level tubes of various diameters and lengths, having cannopy inlets, was carried out to establish the flow under different heads. A relationship between the various items was established. Design procedures for practical cutback systems were developed with single and double cutbacks.

G A R T O N, J. E. / Designing an automatic cutback furrow irrigation system.
Oklahoma Agr.Exp. Station Bull. B-651, Oct. 1966.

Shows how to design a supply ditch with a number of bays, separated by check dams, from which a large initial furrow stream is provided, and watering is continued with a cutback furrow stream for a certain time period.
The labor saved is expected to pay for the system in less than its useful life.

G A R T O N, J. E., R. P. B E A S L E Y and A. D. B A R E F O O T / Automation of cutback furrow irrigation.
Agr.Eng. 45 (1964) 6 : 328-329.

A concrete-lined farm supply ditch is divided by check dams into a number of bays. The level furrow-outlet tubes in each bay are installed at a specific pre-determined height. By manually or automatically closing and opening the check dams, water is supplied to the furrows of one bay at a high initial inflow, which flow is cut back when the check to the next dam is opened up.

H A I S E, H. R. and E. G. K R U S E / Automation of surface irrigation systems.
Journ.Irr.Drain.Div. (ASCE) 95 (1969) IR4 : 503-516. 9 refs.

Two systems for automating surface irrigation are described. One uses pneumatic valves remotely controlled by tone telemetry to open and close turnouts at timed intervals. The other uses water-powered cylinders activated by float valves to operate center pivot gates. The automatic components can be adapted to various methods of surface irrigation and to supply by open ditches or buried pipelines.

H A I S E, H. R., E. G. K R U S E and L. E R I-E / Automatic surface irrigation.
Agr.Eng. 50 (1969) 4 : 212-216. 5 refs.

Description, with drawings and photographs, of hydraulically operated check gates and turnout pipes for automatic irrigation of 4 ha citrus, reducing labor and conserving water. Pressure is obtained from a pump driven by a water wheel in the supply ditch. The water pressure is

conveyed by a P.V.C. pipeline to valves in the structures. The system is thought to be ready for commercial production.

H A I S E, H. R. and P. L. W H I T N E Y / Hydraulically operated gates for automatic surface irrigation.
Trans. ASAE 10 (1967) 5 : 639-642. 4 refs.

Inefficient use of water in surface irrigation is partly caused by high labor costs and inexpensive water. Requirements for automation are mentioned and a description is given of laboratory developments in the application of water to furrows, border strips or level basins by means of remotely controlled field gates. The gates can be operated by hydraulic or pneumatic valves, requiring a pressure line. The system is being tested in the field.

H A I S E, H. R., E. G. K R U S E and N. A. D I M I C K / Pneumatic valves for automation of irrigation systems.
USDA Agr.Res.Serv. 41-104, July 1965, pp.21

Several models of a pneumatic nylon-reinforced valve for use in underground pipeline or ditch distribution systems are described. The system includes (1) a pneumatic closure (2) a three-way solenoid valve to regulate the inflow and outflow of air, (3) a source of air pressure to the valves and (4) a centrally located remote control system with timing by radio or carried by wire.

H O W E, O. W. and D. F. H E E R M A N N / Efficient border irrigation design and operation.
Trans. ASAE 13 (1970) (1) : 126-130. 6 refs.

Three border irrigation systems on different soil types were studied to determine design and operation criteria for the most efficient application. In practice, the uniformity coefficient appeared to be independent of stream size (within the range 0.03-0.12 cfs) and of slope, though best results were obtained on low gradients. The critical variable for an efficient water application was the cut-off time.

Operation, not design, proved to be the key to efficient irrigation.

H U M P H E R Y S, A. S. / Control structures for automatic surface irrigation systems.
Trans. ASAE 10 (1) 1967, pp.21-23, 27; also: Agr.Eng. 48 (1967) 6 : 338-340 (abridged).

Description, photographs and sketches of automatically operated checks (flexible canvas dams and rigid metal gates with float-actuated timers) in lined and unlined irrigation supply ditches.

H U M P H E R Y S, A. S. / Automatic mechanical irrigation gates.
VII Congress ICID Mexico City 1969, Question 24. 2 refs.

Two general classes of gates are described: fully automatic, operating on the energy of flowing water, and semi-automatic, requiring resetting or moving at each irrigation. Types of gates tested were: center-of-pressure check gate, sinking float border turnout gate used in combination with a check gate, float-operated check gate, drop gate. Schematic drawings and descriptions of automatic and semi-automatic border irrigation systems are given.

H U M P H E R Y S, A. S. / Mechanical structures for farm irrigation.
Journ.Irr.Drain.Div. (ASCE) 95 (1969) IR4 : 463-479. 3 refs.

Mechanical, automatic irrigation structures like check gates, drop gates, metal apron gates and water level control checks, in lined and unlined farm supply ditches are being developed to improve surface irrigation methods and systems.

H U M P H E R Y S, A. S. and C. W. L A U R I T Z E N / Hydraulic and geometrical relationships of lay-flat irrigation tubing.
USDA, Agr.Res.Serv.Tech.Bull. 1309, 1964, pp.38.

Lay-flat tubing, made of butyl rubber or plastic, can be used to replace farm supply ditches, thus simplifying the water distribution. In this paper the hydraulic design of such a system is presented. The cross-sectional area of tubing, 4 to 16 inches in diameter, for

different degrees of tubing roundness was determined and is given in table form; the discharge for irrigation tubing of different diameters and degrees of roundness as related to head loss is presented in diagrams.

L A L, R. / Increasing efficiency of furrow irrigation with a variable discharge.
Journ. Institution Engineers (India) 48 (1967) 3 (Part Cl 2, Sp) : 771-783. 5 refs.

Analyses water losses due to deep percolation and runoff in furrow irrigation and presents a method of reducing these losses by varying the stream size. A dimensionless graph is included to estimate the percentage variation in inflow with time.

L O B B, W. R. and A. D. H A L L / Automatic irrigation.
New Zealand J.Agric. 106 (1964) 4 : 318-319.

Description of an automatically (time) operated canvas check and ditch outlet.

P A I R, C. H. / Automation near in irrigation.
Agr.Eng. 42 (1961) 11 : 608-610, 621.

Defines requirements for automation in irrigation.

R A M, M. / Surface irrigation.
Israel Nat.Com. ICID Tel-Aviv 1962, pp.28. 7 refs.
See also: V Congress ICID, Question 16, Tokyo, 1963 : 465-483.

A discussion on surface irrigation: methods, hydraulics and the uniform distribution of water. How a high degree of efficiency can be attained in furrow irrigation by means of stream regulation is analyzed and a mathematical solution to the problem, based on logical approach, is presented.

S A K K A S, J. G. and W. E. H A R T / Irrigating with cutback furrow streams.
Journ.Irr.Drain.Div. (ASCE) 94 (1968) IR1 : 91-96. 3 refs.

Cutback of inflow is generally recommended in furrow irrigation to provide an equal intake-opportunity time and uniform water distribution along the run. Tests were conducted in which irrigation was started in a variable number of furrows at the beginning of successive time intervals. A mathematical analysis of the variation is presented, as well as tables showing the number of furrows started at the beginning of each time interval and being irrigated during such an interval. In this way the available quantity of water can be distributed correctly and the required number of siphons (if used) can be estimated.

(See continuation of tables and discussions: J. 95 (1969) IR4 : 591-594.)

V Y R L E V, I. / Mechanisierung und Automatisierung der Berieselung. (Mechanized and automatic irrigation.)
Internat.Z.Landwirtsch., Sofia/Berlin, 1964, 2 : 239-242.

The labor productivity in irrigation can be increased from 0.6-0.8 ha to 10.15 ha/shift by mechanization and automation of the supply system, especially for longer furrows (300-400 m). By means of a simple pneumatic valve, 20 to 30 siphons can be put to work at one time. Flexible pipe is used, which can be laid out and rolled up mechanically. Border irrigation can be automated by using buried pipes with remotely controlled taps. Electric devices are used in furrow irrigation to indicate when the water has reached the end of the furrows.

V Y R L E V, I. und P. P E T R O V / Wasserentnahme aus offenen Gräben bei der Furchenbewässerung. (Water application from open ditches for furrow irrigation.)
Int.Z.Landwirtsch. (Sofia-Berlin) (1969) 5 : 577-581.

The advantages of the use of siphons above spiles or closed-type

take-out boxes and pipes are discussed. Proper water application with siphons is possible when the water level in the ditch is 30 cm above land surface. Siphons are time-saving compared with fixed outlets.

W A T S C H K O V, G. und W. W A S I L J E V / Eine produktive Methode der Berieselung. (An economic method of water supply in irrigation.) Internat.Zeitschr.Landwirtsch., Sofia/Berlin, 1965, 3 : 311-314.

Based on experience gained in Russia, the smallest supply ditches in newly developed irrigated areas in Bulgaria were given a capacity of 100-200 l/sec. Water is supplied to the furrows through T-shaped or -shaped of 6-10 m (total weight 5-10 kg). The last section has outlets every 60-75 cm, each with a piece of plastic pipe 50-80 cm long, leading to a furrow. One man can handle 8 to 12 such distributary sets in one shift, irrigating about 5 ha.

W I T T M U S S, H. and P. F I S C H B A C H / Automatic surface irrigation system is here.
Univ. Nebraska, Coll.Agr., Agr.Exp.Stat. 13 (1966) 2 : 12-14.

Description of an automatic surface irrigation system with (1) adequate water, (2) supply through pipes to the fields, (3) pneumatic valves in the pipeline system, (4) control of the need for and the advance of water application by means of tensiometers, (5) an electronic device to operate pumps and valves according to signals received from the tensiometers,(6) collectors and a pumping system for re-use of surface runoff. The system is being tested in the field.

Z O N E V, I. und Ch. C H R I S T O V / Mechanisierung und Bewässerung in Hanglagen. (Mechanization and irrigation of sloping lands) Intern.Z.Landwirtsch. Sofia-Berlin, 1964, 3 : 357-360.

A system developed by the Inst. Hydrotechnik und Melioration in Sofia to irrigate sloping lands, consists of (1) a reservoir at a higher elevation, (2) buried pipelines or open supply ditches, (3) canvas

hoses with openings in one or two directions. Possibilities for automation are considered.

Economics of surface irrigation

H U G H E S, Wm.F. / Some considerations in the evaluation of irrigation systems.
Oklahoma Current Farm Ec. Special Report 37 (1964) 3 : 60-66.

Discusses some of the more salient considerations and the nature and type of costs associated with or induced by irrigation. Irrigation is a longtime undertaking; for supplementary purposes installation costs might be too high to be profitable. Practices are not the same in arid, humid or sub-humid conditions and various conditions require specific considerations. Items mentioned are: economics of scale regarding size of development, crops in view of water need and yield, use of irrigation facilities, labor, various costs involved.

P A U L S, D. E. and B. D. P A R R I S H / Comparison of sprinkler and surface irrigation methods, 1956 and 1957.
Wash.Agr.Expt.Sta., Sta.Cir. 367, 1960, pp.6.

Costs involved in sprinkler and surface irrigation in the Columbia Basin Project for 1956 and 1957 are compared. Sprinkler-irrigated farms used less water per unit of area; the yields were higher in 1957 but lower in 1956 than those in surface irrigated areas. Total costs per acre on sprinkler-irrigated farms were US $ 21.68 in 1956 and US $ 17.4- in 1957; on surface irrigated farms the respective costs were US $ 10.20 and US $ 7.53.

M O R H A U S, G. H. / Sprinkling or irrigation.
Neth.Journ.Agr.Sc. 10 (1962) 2 : 101-108. 1 ref.

Discussion of criteria which have to be considered when the economics of overhead and surface irrigation are compared. Examples of calculations are given to show whether sprinkling is profitable or not.

S T E V E N S, M. D. / Sprinkler and gravity irrigation - investment and water requirements, operating costs, and labor inputs.
Wyo.Agr.Expt.Sta.Bull. 378, 1961, pp.32.

Sprinkler and surface irrigation were compared as to their physical characteristics, investment costs, operating costs, labor requirements, and water requirements. The farm survey method was applied in conducting the study, which took place in 1957. Time-and-motion studies were used when determining labor requirements.

S T R O N G, D. C. / Economic evaluation of alternative facilities for surface and sprinkler irrigation in Utah.
Agr.Exp-.St.,Utah St.Univ., Bull. 433, 1962, pp.47. 4 refs.

In this study the relative feasibility was determined of surface versus sprinkler irrigation under different physical and economic conditions. Facilities evaluated included field water supply systems (lined and unlined ditches, gated pipe, portable versus permanent main lines), alternative sources of power, etc. For each of these facilities, irrigation design specifications were determined in different groups of uniform slopes, of soil texture and of farm sizes.

V O L P I, M. / Costo della manodopera addetta alla distribuzione dell'acqua sul terreno in rapporto al corpo d'acqua ed al metodo irriguo. (Labor cost in irrigation in relation to stream size and irrigation method.)
Irrigazione, Bologna 13 (1966) 4 : 16-27.
In Italian with English, French, German summary.

Field studies were made of labor costs under various methods of irrigation and with a stream size varying between 10 and 50 l/sec. Labor costs in surface irrigation increase roughly in proportion to decreasing stream size, while in overhead irrigation these costs remain nearly constant for flows above 16-18 l/sec.

W I T T I G, H. G. / Die Bewässerungskosten und ihre Finanzierung.
(Costs and financing of irrigation.)
Z.Bewässerungswirtsch., Frankfurt/M 3 (1968) 1 : 16-23. 11 refs.

A survey was made of costs involved in surface and overhead irrigation on 25 farms in Italy between 1955 and 1960, representative also for Spain, Greece, Turkey. Installation costs amounted to about US $ 820/net ha for surface irrigation (fixed annual costs 8-10%) and to about US $ 550/net ha for sprinkling (fixed annual costs 10-12%). Total annual costs range from US $ 90 - US $ 150. Expenditure is heavily subsidized by the Government.

Glossaries, terminology

Irrigation systems and distribution of irrigation waters.
Multilingual technical dictionary on irrigation and drainage.
ICID New Delhi, India, 1967 : 458-492.

Standard notations of technical terms commonly used in irrigation and drainage.
Annual Report ICID 1969 : 117-135.

W I N T E R, E. J. (ed) / A glossary of terms used in irrigation.
Scient.Hort. 16 (1962'63) : 87-95.
Description of various terms used in irrigation; compiled in England.

Price $ 2.00

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