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Appendix "A"

[redacted] ABSTRACTS PERTAINING TO

ARID REGIONS

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1970

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INTRODUCTION

The following abstracts were obtained to gain insight into what is now being accomplished in the realm of research of hydrologic and range phenomena in an arid watershed. The abstracts are classified into the following categories: 1) Range Management, 2) Climatology, 3) Rainfall, 4) Water Quality, 5) Drought, 6) Surface Runoff, 7) Soils, 8) Irrigation Development and 9) Salt Accumulation. These categories, when combined, constitute the basis for mathematical models to determine surface runoff, soil moisture content, salt accumulation or a variety of other watershed parameters.

A need exists for mathematical models to successfully predict surface runoff, infiltration, storage, interception, and evaporation in arid or semi-arid watersheds. A watershed model must be developed on the following hypothesis: At every point in the watershed a functional relationship exists between the rate of surface runoff and the hydrologic parameters of topography, temperature, rainfall intensity, time from the beginning of the storm event, and depth of flow. The overall accuracy of the model depends upon the ability of these relationships to describe the respective phenomena.

The previously suggested approach to watershed modeling is possibly too idealized for runoff determination in an underdeveloped country. Many times the data required for a model that includes all aspects affecting runoff will not be available to an investigator. An alternative must then be sought to determine runoff from data that is available. The proposed model given in Appendix A gives excellent results over large watersheds and the only variables needed are: average monthly air temperature, rainfall, and a general knowledge of soil type over the watershed. A program listing, sample output, and validation techniques are also given in Appendix A.

A mathematical model accounting for all runoff parameters as previously mentioned has applications on small watersheds. Functional relationships for each of the following hydrologic components must be specified: rainfall, infiltration, interception, surface retention, and runoff. Functional relationships exist for the previously given components.

Interception - The phenomena of rainfall interception began with Horton (1919). His work was directed toward determining the total volume of water intercepted during a given storm. For direct use in watershed models, however, a relationship for estimating the rate at which rainfall is intercepted throughout a storm even is required. A proposed interception equation might be of the form

$$I = e^{-b\Delta t}$$

where

I = interception rate

b = coefficient characteristic of the vegetative type

Δt = time increment between successive interception amounts

The magnitude of interception storage is usually small and on the order of a few hundredths of a millimeter.

Infiltration - Despite comparatively large efforts devoted to infiltration research over the past few years, no widely accepted model of describing the infiltration process has been developed. Of the empirical equations suggested by various investigators, the one suggested by Holton (1964) seems to be the most appropriate for watershed simulation studies:

$$f = fct + A[(S-F)/T_p]^B$$

where

A,B = coefficients characteristic of a given soil and its antecedent conditions

S = storage potential of the soil (total porosity minus soil moisture).

Runoff - The watershed model is based on the hypothesis that a functional relationship exists between the depth of water and the rate of surface runoff for every point within the watershed. Such relationships would depend upon the general slope of the watershed, the degree of turbulence in the flow, the microrelief, and, in depressional areas, the topography.

Considerable research has been devoted to the development of relationships describing the flow of thin sheets of water over plane surfaces, but the adaptability of these equations to the varied topography of a natural watershed is doubtful.

Manning's equation could be used to determine flow from a watershed.

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where

V = average velocity of flow (cm sec^{-1})

n = roughness coefficient

R = a/p, the cross-sectional area divided by the wetted perimeter (cm)

S = hydraulic gradient.

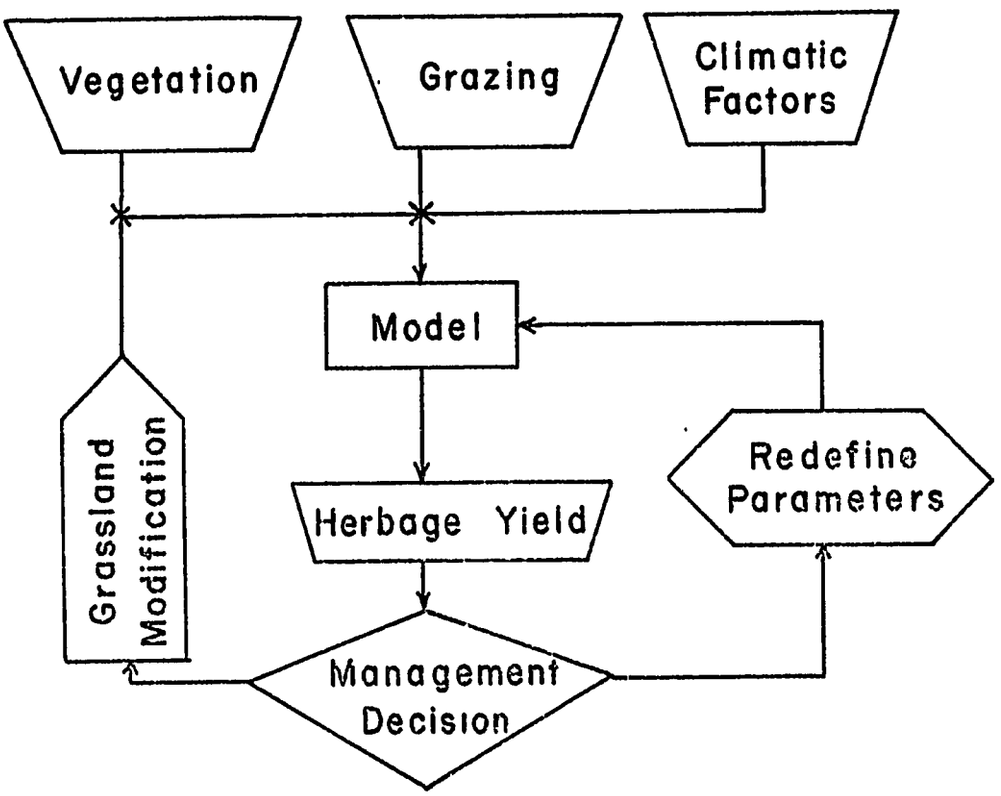
The above equation requires that the watershed's slope be known. This is accomplished by dividing a small watershed into many small areas of known slopes as does the Stanford Model (1966) and the Purdue Model (1968). This type of modeling has a great potential if precise methods can be employed to obtain the necessary variables needed to produce a workable model. Theoretically an investigator could look at each relationship and determine its role in the rainfall-runoff cycle. This is the largest disadvantage of the previously derived model in that several variables are lumped under the title of moisture surplus.

The following abstracts do not individually deal with modeling, but their combination among and between topics will help an investigator to better understand the variables needed in a particular model.

Range Management

Many of todays classical problems regarding grazing, soil fertility, reseeding, range development, and optimum forage type grasses are discussed. These problems are discussed on a global basis whereever semi-arid rangeland occurs, i.e., India, Africa, Australia, United States, New South Wales, Israel, Tanganika, Kenya, and Pakistan. All studies seem to have the same basic ideas in common: 1) economic factors in the improvement of grasslands, 2) grass establishment, 3) effects of rainfall on soil characteristics, and 4) grazing capacity.

Following is a flow diagram of a proposed range management model that includes the above basic ideas plus management decision options. The model does not assume that emperical equations are available for each component, but rather it provides a basis for development. Additional information would have to be available for each component as to method of attack and expected results.



Range Management Model

Ahiya, L.D., and Bhimaya, C.P.
1967, "Germination Studies of Perennial Grass Seeds," Annals of Arid Zone, Vol. 6, No. 2, pp. 146-152.
The economy of arid western Rajasthan, India, is closely linked to the livestock industry which must utilize seriously deteriorating ranges. Successful range management will depend upon successful reseeding of appropriate perennial grasses.

Amiran, D.H.K.
1967, "Symposium on Coastal Deserts [and Changes in Occupance of Arid Areas, Peru, April 3-21, 1967]," Nature and Resources 3(4):11-13.
Reviews of the 36 papers presented at the symposium, lists the areas studied in the field during the northern and southern excursions, and presents the general resolutions proposed by the Arid Zone Commission of the International Geographical Union which organized the symposium with assistance from UNESCO.

Anderson, D.J.
1967, "Studies of structure in plant communities. V: Pattern in Atriplex vesicaria communities in south-eastern Australia," Australian Jour. of Botany 15(3):451-458.
The distribution pattern of A. vesicaria (perennial saltbush) was examined in a number of locations extending from Hay in western New South Wales to Koonamoore Station in South Australia. The populations sampled were from a range of locations exhibiting a variety of topographical, edaphic, and effective rainfall conditions. Pattern varied considerably between sites.

Beatley, J.C.
1967, "Survival of winter annuals in the northern Mohave Desert," Ecology 48(5):745-750.
Following early autumn germination in the Mohave Desert winter annual populations (53 taxa) sampled on 13 plots (total sample size, 16.4 square meters) in 3 drainage basins in southern Nevada, 1963-64, there was 38 percent survival to maturity (plot range 10-63 percent). Death occurred early in the spring, at the time shift from the slow vegetative growth of winter to the beginning of stem elongation. Despite no marked precipitation deficiencies during the 7- to 8-month growing season, mortality apparently resulted from inadequate soil moisture to meet the demands of all seedlings at the point in the life cycle of a manyfold increase in plant volume. Mean percentage survival to maturity of seedlings (58 taxa), sampled on 62 plots (total sample size, 62 square meters) in 7 drainage basins, following spring germination after rains of 3-5.5 inches in March-April 1965, was 60 percent (range by basin, 44-83 percent). Mortality in these populations, whose life cycles were completed in 6-10 weeks could not be attributed to inadequate moisture levels. In most seasons, regardless of precipitation regimes, the majority of seedlings of desert annuals do not survive to maturity.

Condon, R.W.
1968, "Estimation of grazing capacity on arid grazing lands," In G.A. Stewart, ed., Land evaluation, Papers of a CSIRO symposium organized in cooperation with UNESCO 26-31 August 1968, pp. 112-124. Macmillan of Australia.
A method of estimating grazing capacity of arid lands is described. This requires the selection of a standard land class for which the grazing capacity is known, or can be determined with reasonable accuracy; and the establishment of rating scales for the various factors which influence grazing capacity. The most important of these rating scales is average annual rainfall.

Fischer, B.B., Yamada, H., and Pomeroy, C.R.
1967, "Effects of irrigation practices on safflower yield in San Joaquin Valley," Calif. Agr., Vol. 21, No. 11, pp. 6-7.
An experiment was conducted to determine yield responses of safflower to varying amounts of water applied in pre-irrigation and supplemental crop irrigations on Panoche clay loam soil in Fresno county. Fertilization prior to pre-irrigation was uniform. Fifteen pounds of US 10 safflower variety (per acre) were drilled in two rows on each 40 inch bed spaced 20 inches apart. Individual test plots were 24 ft. wide and 600 ft. long replicated five times. Highest yields of safflower were obtained when a medium pre-irrigation of 18 inches and two supplemental 8 inch crop irrigations were applied. When approximately the same total amount of water was applied in one pre-irrigation or in a pre-irrigation and one supplemental crop irrigation the yields were significantly lower. This study suggested that maximum safflower yields (on Panoche clay loam soil) depend on readily available soil moisture in the top 4 ft. of soil during bud and flowering periods.

Frost, K.R., and Hamilton, Louis
1965, "Basin forming and reseeding of rangeland," Trans. Amer. Soc. Agr. Eng., Vol. 8, No. 2, pp. 202-203, 207.
Improvement of semidesert ranges through reseeding is usually unsuccessful because of poor soil moisture conditions. Three mechanical systems for improving success of semidesert ranges were developed and evaluated. The systems were: forming and seeding fan-shaped basins, basin-forming on knifed rangeland and seeding in pits formed by a pitting disk. Sloping fan-shaped basins were a practical device for collecting rainfall for range grass seeding if the soils were suitable. Such basins were formed at a low cost with a tractor and blade designed for this purpose. Moisture penetration of 30 inches in medium soils was possible with four or five high-intensity storms of less than one-half inch each and totaling two inches. Appropriate basins were pressed into loose knifed rangeland by a blister roller.

Holmes, J.W. and Watson, C.L.
1967, "The water budget of irrigated pasture land near Murray Bridge, South Australia," Agr. Meteorol., Vol. 4, No. 3, pp. 177-188.
The measurement of water efficiency on an irrigation district basis was often inaccurate because of inadequate control of factors that occur in arid climates. The purpose of the experiment was to measure components of the water balance which included rainfall, amount of irrigation, evaporation, surface and underground drainage. Techniques of measurement yielded a standard error of about 10% of the total water inventory. The evaporation, measured with the help of small lysimeters, was strongly correlated with measured net radiation. Three formulae for estimating evaporation, based on large weighable lysimeters, were tried. By suitable choice of the coefficient for introducing the effect of the drying power of the air into the formula, it was possible to obtain a close estimate of evaporation. The correlation was no better than the correlation between evaporation and net radiation.

Kincaid, David R. and Williams, Gerald
1966, "Rainfall effects on soil surface characteristics following range improvement treatments," J. Range Manage., Vol. 19, No. 6, pp. 346-351.
The principle objective of this study is to investigate changes in soil surface resulting from one summer's rainy season following brush removal, pitting, seeding and a combination of these treatments. The study area was within Walnut Gulch Experimental Watershed, Tombstone, Arizona. Average annual precipitation is approximately 14 inches, of which 60% falls during convectional thunderstorms in July, August and September. The soil is a gravelly sandy loam. One season's data on surface runoff showed little correlation between runoff and treatment. Reduced runoff seemed to be related to pitting treatment in the earlier summer storms, but later in summer pitting was related to increased runoff. Response varied from statistically nonsignificant changes in untreated, seeded, and cleared and seeded plots to statistically highly significant changes in plots of the other treatments. At the end of the summer rains, seeding alone, and in all combinations of treatments, was accompanied by statistically significant decrease in litter. Generally the lower half of the plots underwent more erosion than the upper half. Crown cover appeared to have a greater effect in reducing rainsite runoff than did soil treatments.

Lange, O.L.
1965, "The heat resistance of plants, its determination and variability," Arid Zone Research 25. UNESCO, Paris, pp. 399-405.

In the arid zones of the world, the heat resistance of plants has a special ecological significance. Its determination is necessary to understand relationships existing between plants and their surroundings and to investigate the possibility of their existence in different localities. The fundamental considerations to be taken into account when measuring heat resistance are given. Since heat damage to a plant depends directly upon the time of heating, the period of heating must be accurately defined. For determination of heat injury, besides measurement of metabolic activities like respiration or photosynthesis, there exists a number of cytological criteria which should be used with care. Within a certain limit, characteristic for each species, heat tolerance can show variations within the same organism, depending upon exogenous or endogenous factors. The heat resistance of plants must be known in order to determine their ability to survive in hot arid climates.

Muirhead, W.A. and Jones, R.M.
1966, "Species trials in the semi-arid southwest of New South Wales Part II - Native shrub trials in the Hay district," J. of the Soil Cons. Serv. of N.S.W., Vol. 22, No. 3, pp. 138-146.

After the drought years ending in the 1940's there were many scalds (claypans) in the arid Hay district (9-14 inches of annual rainfall) of southwest New South Wales. The soils were generally clays or clay loams of high salinity, extremely low infiltration, high exchangeable sodium and a marked instability to wetting, resulting in a characteristic sealed and slaked surface. The sowing into a plowed scald treatment consisted of two trials: complete plowing and saltbush trials and the sowing into reclaimed scald. The seven complete plowing trials were complete failures as far as scald reclamation was concerned. Under all sowing conditions on scald and reclaimed scald, perennial saltbush has been the outstanding species, and on areas where all the sown species died, it gave the best persistence. The saltbushes' positive attributes were relatively reliable establishment, vigorous growth, persistence both in ungrazed and grazed conditions, spread by seed and ease with which seeds could be collected.

Orshan, G., Gavish, U., and Borovic, I.
1968, "Use of vegetation as an indicator for soil properties under desert conditions," Negev Institute for Arid Zone Research, Beer Sheva. 50 p.

The report discusses the root systems in sandy deserts as related to soil properties. Thirteen leading species were excavated and described. These are classified in 3 types. Soil moisture was measured at 2 locations in the Negev desert during the summer of 1966 and its use by plants discussed. The effect of sand cover and irrigation on the competition between leading desert psamophytes was examined.

Owens, M.A. and Brzostowski, H.W.
1967, "Grass establishment under semi-arid conditions in Central Tanganyika," Tropical Agr. (Trinidad), Vol. 44, No. 4, pp. 275-291.

Cenchrus ciliaris L. has been the grass most widely used at Kongwa in establishment work. Rainfall, averaging just over 21 inches per year, can be very erratic. It is confined almost entirely to a four month period extending from mid-December to mid-April. From the aspects of both evenness of distribution and seed economy, drilling has been more satisfactory than broadcasting. From strip planting observations it seemed that the most valuable perennial grass species employed were incapable of satisfactory natural spreading. The pelleting of seed adversely affected germination in laboratory tests while in the field trial, more than three times as many C. ciliaris plants were counted on plots where unpelleted seed was sown than where pelleted seed was used. In exploring the possibilities of sowing C. ciliaris in the dry season, a very satisfactory establishment was obtained in two years out of three when seed was sown about two months before the onset of rains.

Perry, R.A.
1968, "Australia's arid rangelands," Annals of Arid Zone 7(2): 244-249.
The boundaries of Australia's arid rangelands are delimited and a comparison made of features of arid Australia and other arid parts of the world. The cattle and sheep industries, and their effect on rangeland resources, are described. The climate-land-vegetation-animal ecosystem, and the program of rangeland research are outlined briefly.

Pratt, D.J.
1968, "Rangeland development in Kenya," Annals of Arid Zone, Vol. 7, No. 2, pp. 179-208.
In arid and semi-arid grazing regions of Africa increased population and demand for food has placed tremendous pressure on the land. The author proposed to develop planning and management programs based on careful studies of the ecology, sociology, land tenure, and natural resources of the area.

Rader, L.
1966, "Economic factors in the improvement of arid and semi-arid grasslands," Proc. 9th Int. Grassland Congr., Vol. 2, pp. 1593-1597.
Range improvement and management practices can be used to increase productivity of arid and semi-arid grazing lands. An analysis of factors influencing costs and returns from range improvement, using removal of sagebrush as an example, suggests that actual costs of improvement are related to the method of improvement,

site conditions and size of the area improved. Sagebrush grows in areas where precipitation is low and where there are large fluctuations in annual rainfall with frequent and often prolonged droughts. With removal of sagebrush, more water becomes available for the growth of grass. This in turn will increase range carrying capacity and result in increased livestock production. Examples of three possible situations and two levels of improvement costs are given. They illustrate that improvement of sagebrush ranges may be profitable on better sites and that relatively small investments may be justified on sites where potential capacity is low.

Rzedowski, J.
1966, "Vegetacion del Estado de San Luis Potosi," Instituto de Investigaciones de Zonas Deserticas, Contribucion 20. 291 p.
A reprint from Acta Cientifica Potosina (Universidad Autonoma de San Luis Potosi). Includes bibliography (pp. 281-291), and an index of scientific names (pp. 248-280). Particular sections devoted to desert vegetation cover "mezquital extra desertico, matorral desertico microfilo, and matorral desertico rosetofilo."

Shamsoutdinov, I. Sh.
1967, "The improvement of desert ranges in Uzbekistan," Proc. 10th Int. Grassland Congr., pp. 960-962.
The planting of black saksaul shelter belts in sagebrush-ephemer deserts together with the establishment of fall-winter ranges in foothill deserts and cultivation of fodder crops, without irrigation, to provide feed on ranges in winter are ways that are used to conserve moisture on desert ranges. Black saksaul shelter belts act as windbreaks and snow accumulators. The nearby humidity level is increased and as a result a milder and more stable microclimate is created which promotes normal growth and development of range plants.

Snead, Rodman E., and Tasnif, Mohammad
1966, "Vegetation types in the Las Bela region of West Pakistan," Ecology, Vol. 47, No. 3, pp. 494-499.
The vegetation of the Las Bela region of West Pakistan with an annual rainfall of 5 to 9 inches consists of scattered xerophytic shrubs and trees. Indicator species were identified on six different landform regions in the area, and by identifying their morphology on aerial photographs, the different environments were determined before the field work was done. The density of the plants, shading and aerial distribution of the vegetation were the main methods used to identify the plant species.

Verstappen, H. Th.
1966, "Land forms, water and land use west of the Indus Plain," Nature and Resources, Vol. 2, No. 3, pp. 6-8.
Due to wide range in lithological conditions and in annual rainfall, there is great variety in hydrological characteristics of various drainage basins. Moderate intensity and fairly reliable winter rains fall in river basins of limestone which may have an average superficial run-off of only 5%. Summer rains, which are erratic and fall in heavy showers, are found in areas of shale and mudstone which may yield run-off of 70-90%. Gravel fans are important in obtaining ground and surface water for irrigation. Temporary dams were built in the river bed to divert flood water for field irrigation. Climatic changes of the past, through the hydrological and geomorphological changes which it produced, still influence distribution of agricultural activities in the plain. The survey carried out in the Porali Plain revealed complex relations between geomorphology, ground- and surface-water conditions and agricultural land use in the dry mountainous areas west of the Indus Valley.

Visser, W.C.
1965, "The moisture consumption of plants described as a hydrological phenomenon," In B. Slavik, ed., Symposium on water stress in plants, 1st, Prague, 1963, pp. 257-265.
The way in which real evapotranspiration depends on the evaporative capacity of the atmosphere, the soil moisture content and the density and distribution of the root system, can be described by an equation based on the formula of Darcy. This formula enables one to elucidate the influence of environmental factors on evapotranspiration and the influence of moisture extraction by the plant on the shape of the moisture profile. It is also possible to calculate a number of evaporation parameters, which consist of soil, plant and site constants with a definite physical meaning. The plant activity constant may be computed by inserting the soil constants in the complex evaporation parameters.

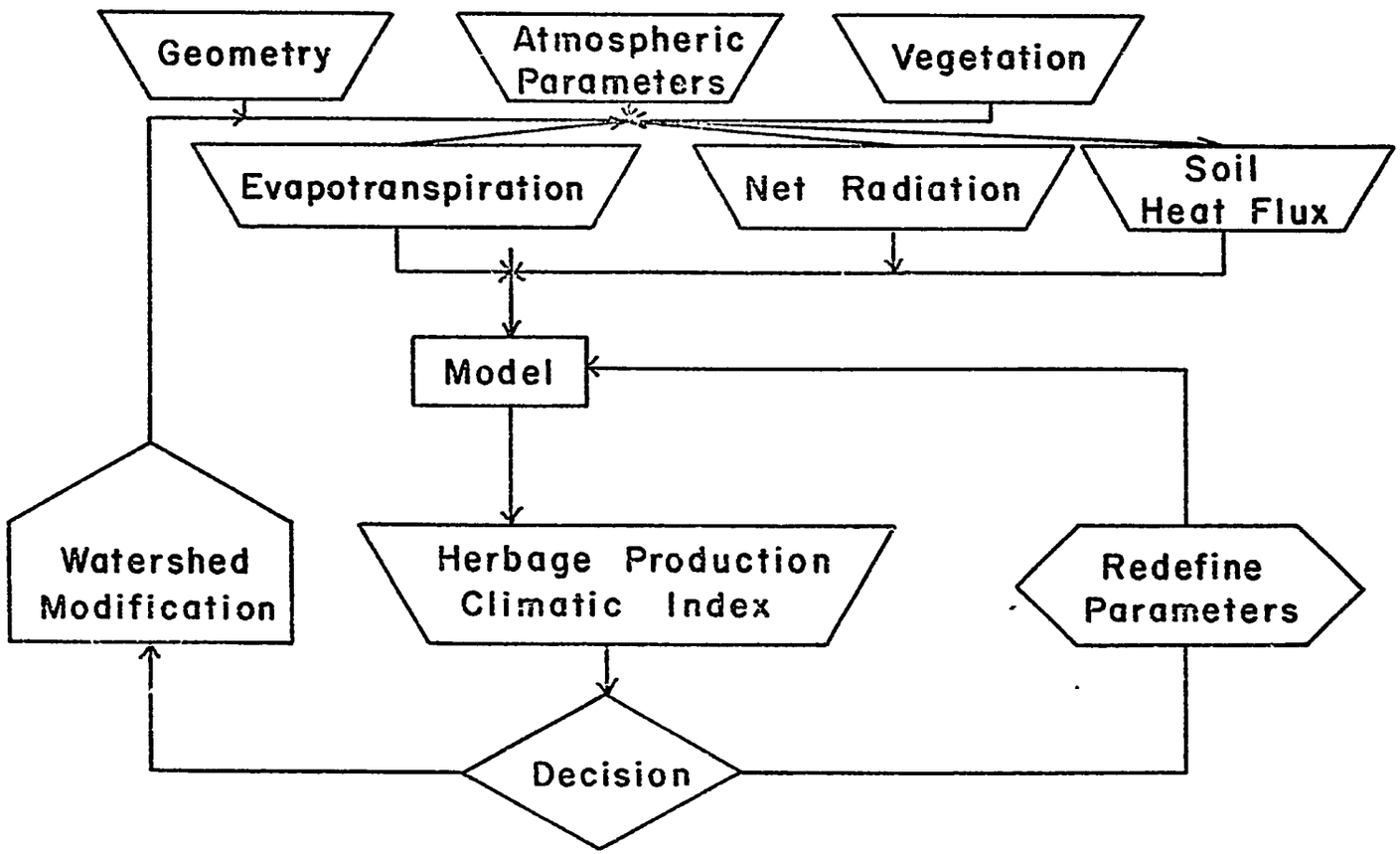
Walter, H.
1967, "Das Pampaproblem in vergleichend okologischer Betrachtung und seine Losung (Problem of the pampa in comparative ecological observation and its solution)," Erdkunde 21(3): 181-203.
The problem of the origin and the nature of the vegetation of the pampas is examined with particular reference to the prevailing moisture regime. Indications are that potential evaporation exceeds mean annual precipitation. The pampa has a climate similar to a weak semi-arid type in which aridity increases from NE to SW. The original pampa vegetation was formed by grassland associations which in the NE were very rich in species and became poorer towards the SW.

Climatology

The climatology of an area defines its role as a humid, semi-arid or arid region, and the following abstracts include climatological data for many world-wide arid regions.

Amount of rainfall ususally classifies a region as arid or not. Many references are abstracted giving world-wide rainfall data. With more emphasis being placed on dynamic energy and water budget type models, information about transpiration effects of plant cover, radiation, and heat flux into the soil and air must be known.

Climatic indexes of growth can be developed for an area based on the available energy for evapotranspiration. Hence climatological parameters could become indicators of herbage production on semi-arid or arid watersheds.



Watershed Management Using Climatic Parameters

Australia, Commonwealth Scientific and Industrial Research Organization, Division of Meteorological Physics

1966, Annual Report, 1965-66. Australia, CSIRO, Division of Meteorological Physics, Melbourne. 24 p.

States the objectives of the organization and provides brief summaries of its activities in the following areas: dynamic and snyoptic meteorology, upper atmosphere studies, micrometeorology and evaporation, agricultural meteorology, radiation, etc. In addition to outlining activities and listing publications, names of the staff are provided.

Baier, W.

1967, "Recent advancements in the use of standard climatic data for estimating soil moisture," Annals of Arid Zone, Vol. 6, No. 1, pp. 1-21.

This paper reviews advances in technique to estimate soil moisture and crop response from standard climatic data. This technique is of particular importance in arid and semi-arid zones, where soil moisture is of particular importance.

Blackwell, M.J. and Tyldesley, J.B.

1968, "Measurement of natural evaporation: comparison of gravimetric and aerodynamic methods," UNESCO, Arid Zone Research, Vol. 25, pp. 141-148.

Aerodynamic and energy balance methods of measuring natural evaporation from land surfaces were compared. The modern weighing lysimeter was used in the experiment to determine relative merits of the two methods for evaluating water losses. Suggestions were made for extending their use in arid regions. The aerodynamic method can be modified for more general application by including an empirical correction for stability, and this was recommended particularly for arid zone studies. The energy balance approach could also be modified by allowing for variation of eddy diffusivities for heat and water vapor at large negative Richardson numbers. Both methods were exacting in instrumental techniques, and it may be necessary to combine some aspects of both when horizontal gradients of temperature and humidity are no longer small. This is likely to be the case in normally arid areas, near the boundary of irrigated crops, when the influence of small scale advection is likely to be significant.

Boyko, H.

1967, "Some new methods in ecological climatography and ecological hydrology," Biometeorology 2(2):924-930.

A number of new methods are presented, as well as examples of practical applications: a vegetation map of the Huleh region in Israel; examples of quantitative indications of groundwater fluctuations in oases by investigating the vegetation cover; and an example showing the determination of the yearly water influx into these oases of Wadi Araba, as a basis for recognizing the in potential for settlements and land use in general without endangering the natural equilibrium; plant sociological records showing the erratic features of desert climate and the various adaptations of plant species to this important "Factor of Erratics."

Bryson, A.B., and Baerreis, D.A.
1967, "Possibilities of major climatic modification and their implications: northwest India, a case for study," American Meteorological Society, Bull. 48(3):136-142.
On the basis of field observations and theoretical studies it is believed that the dense pall of local dust over northwestern India and West Pakistan is a significant factor in the development of subsidence over the desert. Archeological evidence derived from the northern portion of the desert within India suggests a pattern of intermittent occupation with the role of man being important in making the desert. As man has made the desert, so through surface stabilization can he reduce the dust and consequently modify the subsidence and precipitation patterns in the region. The social consequences of such climatic modification are briefly considered.

Butzer, K.W., and Twidale, C.R.
1966, "Deserts in the past," In E.S. Hills, ed., Arid Lands: a geographic appraisal, pp. 127-144. Methuen, London.
Discussions of criteria of climatic change in the recent past including lacustrine conditions, river terraces, palynology, sediment and fossil soils, dendrochronology, and archaeology are followed by an examination of effects of small climatic changes. The changes in the Lake Bonneville and Lake Lahonton basins in the southwestern U.S. are cited as cases of substantial physiographic changes caused by small climatic changes. In discussing the pluvial periods of the Quaternary, the authors state that between the last interglacial and the last glacial, the sequence recorded in the Sahara and on the Mediterranean borderlands seems to be: warm, comparatively dry; warm, comparatively moist; cool, comparatively moist; and cold, comparatively dry. The terra rossas of the Mediterranean Basin are cited as evidence in support of warm pluvials. The blown sands in many parts of southern and central Africa are some of the limited evidence in support of interpluvial phases drier than today. An attempt to reconstruct the rainfall distribution for ca. 5000-2350 B.C. on the basis of archaeologically recorded zoological evidence is shown on a map of eastern and central Sahara. Contemporary climatic trends are shown by isolines of precipitation anomalies. With the unique exception of the American Southwest and northern Mexico, the records indicate a declining rainfall between about 1910 and 1940. A forecast of general amelioration of moisture conditions in lower latitudes during 1950-1970 (Willet, 1951) was made on the basis of expected sunspot developments, which failed to materialize. The authors conclude that, until the comparatively minor but ecologically important fluctuations within the general circulation of the atmosphere are explained, no useful suggestions as to the future trend of the "dynamique" of arid zone climates can be offered.

Chatterjee, S.P.
1966, "Progress in climatology in India," Tokyo Jour. of Climatology 3(1):30-35.
A brief summary of progress in climatology in India. After noting that rainfall measurements were taken in India as early as the 4th Cent. B.C., it is indicated that India's climatology in its different aspects has been studied by meteorologists, geographers, agriculturists, etc. Work done in the following areas are pointed out: surface climatology, upper air climatology, weather and climate, rainfall and runoff, climatic types and climatic changes.

Christiansen, Jerald E.
1968, "Pan evaporation and evapotranspiration from climatic data," J. Irrig. and Drainage Div (ASCE), Vol.94, No.IR 2, Proc. Paper 5988.
A formula was developed at Utah State University for estimating pan evaporation from extraterrestrial radiation and climatic data. This formula utilizes climatic data of the type most readily available. Tables are presented to simplify the application of the formula where electronic computers are not used. Three formulas for estimating evapotranspiration for several agricultural crops using as the principal parameters either extraterrestrial radiation, pan evaporation or measured incident radiation, together with climatic data were also presented. The planning and design of irrigation systems in arid regions requires, at the outset, an estimate of water requirements which this formula can help to supply.

Cluff, C. Brent
1967, "Rafts: A new way to control evaporation;" Crops and Soils Magazine, Vol. 20, No. 2, pp. 7-9.
Loss of water from small ponds is a serious problem in arid climates. The solution is to cover the water and to avoid raising the water temperature at the same time since warm water evaporates faster. One of the most promising methods for reducing evaporation on small reservoirs is by floating covers or rafts. Small rafts - 8 by 8 feet - have several advantages. Directions are given on how the rancher can use the raft to conserve the water in his stock tanks. Different materials used in raft construction and their economic advantages are discussed. A brief note on the use of monolayers to control evaporation on large ponds is given.

Cocheme, J.

1967, "Agroclimatology of the Sudano-Sahelian zone," World Meteorological Organization, Bulletin 16(4): 201-209.

Survey of climatic resources extends from the Atlantic coast to the border of the Sudan and includes parts of Senegal, Mauritania, Mali, Upper Volta, Ghana, Togo, Dahomey, Niger, Nigeria, Cameroon and Chad (map of this area is included). The northern and southern limits are that of settled cultivation and of a climate which can no longer be called semi-arid. The survey showed the most promise of an increase in agricultural production. The weather and seasons of the area are determined by the northern tropical anticyclonic belt and the equatorial convergence and by the movements of these 2 systems. A general description of the climate, soils, vegetation and agriculture, continues on through rainfall, evapotranspiration (computed with Penman's formula for 35 places in or near the area), and the water budgets (deficit, surplus, and runoff). "Humid," "Intermediate," "Moist" and "Preparatory" periods of water availability are defined and shown in a diagram. Discussions of heat and light and of crops are included.

Cocheme, J. Franquin, P.

1967, "Agroclimatology survey of a semi-arid area in Africa south of the Sahara," World Meteorological Organization, Technical Note 86. 136 p.

An area with a semiarid climate of summer rains in Africa south of the Sahara is delineated and its soils and vegetation briefly discussed. A simple model of the atmospheric circulation illustrates the origins of its tropical climate with a long dry northern winter and summer rains. Characteristics of the rainfall pattern in the area are discussed. Comparisons of yield with climatic factors of rainfall and availability of water periods showed that, where there was a marked relation, the regression tended to be curvilinear, with yield dropping off whenever values of the climatic variables exceeded an optimum range, as well as when they fell short of it. Information on yields and the timing of biological events needed for comparisons of agronomic and climatic variables is even scarcer than meteorological information. The type of data required is described in the report. A consideration of the information gathered by the survey and its scale suggest that, once agroclimatic characterization of places from which sufficient data are available has been worked out, great caution must be exercised in extrapolating this information to delineate agroclimatic sub-regions for agricultural planning and development. Regions with climates similar to that of the area surveyed are found on both sides of the Equator and in all continents, but none are as wide. Outside Africa, the most important homologous areas are in the northwest of the Indian sub-continent and in the north of Australia. Followup action recommended includes the periodical publication of agroclimatic information enlarged and reviewed up to date and the holding of a technical meeting jointly by the international agencies concerned and agronomists and meteorologists from the survey area, in addition to the initiation of more detailed studies of smaller areas and the building of energy and water-balance models more specific to selected crops and localities. English, French, Russian and Spanish summaries xi-xviii.

Covey, Winton Guy, Jr.
1965 "Studies of the drying of bare ground," Texas A & M University, Ph.D. dissertation, pp. 1-102.

The studies reported were an attempt at a synthesis - an effort to see the thermal and moisture processes in the drying of bare ground as a unified set of natural phenomena. Livington's concept of evaporativity (the weather factors influencing evaporation rate) was analyzed together with the complementary concept of evaporability, the concepts concerning the Buckingham effect and the second stage of drying. The question of the validity and utility of the concepts of limiting factor, rate-limiting process and activation energy in the study of evaporation from soil was examined. Vapor movement upward at the surface went with heat flow into the soil. The complex concept of evaporativity was shown to be necessary, useful and unavoidable in the consideration of the evaporation of water from soil. The general law had been proposed that an increase in evaporativity gave an increase in the rate of evaporation from soil. The "Buckingham effect" had been shown to occur in the drying of bare ground; this name was proposed for the increased resistance to further drying which is caused by a rapid initial rate of evaporation from a moist soil.

Cluff, R.W. and Thompson, T.H.
1967, "A comparison of methods of estimating potential evapotranspiration from climatological data in arid and subhumid environments," U.S. Geological Survey, Water-Supply Paper 1839-M.

Comparison of potential evapotranspiration computed from climatological data of six empirical methods was made of 25 sites with a wide range of climatic conditions. This was done in the arid and subhumid parts of Arizona, California and Nevada over a calendar year and a 6 month period from May through October. The methods used were the Thornthwaite, Weather Bureau (a modification of the Penman method), Lowry-Johnson, Hamon, Blaney-Criddle and Lane. Lack of sufficient climatological data limited some methods to certain areas. Only the Weather Bureau method gave estimates that correlated with the adjusted pan evaporation where its use was possible. Low results were obtained with the Thornthwaite, Lowry-Johnson, and Hamon. Results with the Lane method agreed with pan evaporation at one site but were high at others. One data group was eliminated since adjusted pan evaporation in an arid environment was not a satisfactory standard to test the reliability of the methods. The most practical method was the Blaney-Criddle which agreed $\pm$ 22 percent with adjusted pan evaporation.

Daniels, F.
1967, "Direct use of the sun's energy," American Scientist: 55 pp. 15-45.
Solar radiation can be used for cooking, heating, water, heating buildings, cooling buildings, refrigeration, drying and distilling drinking water from saltwater. Special opportunities exist in some of the rapidly developing countries situated not too far from the equator where sunlight is abundant. Here, solar radiation would take the place of electricity and coal as a supplier of energy. Added research is needed to lower the cost to a feasible level first.

Davenport, D. C., Hudson, J.P.
1967, "Local advection over crops and fallow. 2: Meteorological observations and Penman estimates along a 17 kilometer transect in the Sudan Gezira," Agricultural Meteorology 4(6): 405-414.
Daily measurements of maximum and minimum temperature, wind velocity, and vapor pressure were made at windward and leeward edges of selected cotton fields, interspersed amongst uncropped fields, in the Sudan Gezira. Mean temperature, vapor pressure deficit and wind run were lower at the leeward than windward edges of the cotton. At comparable windward sites, wind run per day and mean daily temperature decreased as the downward distance from the most windward edge of the 17-km transect increased. Values of evaporation, calculated by the Penman formula from meteorological data at various sites, were reduced by the presence of upwind stretches of cotton. Negative Bowen ratios indicated that advective conditions existed.

Davies, J.A.
1967, "Global radiation and reflection coefficients at Azraq in Jordan," Archiv fur Meteorologie, Geophysik und Bioklimatologie, ser B. 15(4):376-384.
Measurements of incoming and reflected global radiation at Azraq in the Jordan desert during April and May, 1966 permitted the calculation of coefficients of atmospheric transmission and ground surface reflection. The transmission coefficient varied between 0.706 and 0.777 and showed an afternoon maximum. A slightly higher value (0.808) was obtained from the regression of daily amounts of global reduction against the daily duration of sunshine. The regression gave estimates of solar radiation that were similar to values taken from Budyko's heat balance atlas. Average reflection coefficients for green vegetation were in good agreement with the value of 0.25 suggested by Monteith. Most surfaces, except for basalt, showed a marked dependence of reflection upon solar elevation. Absorbed global radiation was calculated for different surfaces in the area and estimates of the net radiation and potential evapotranspiration were made.

Decker, W.L.
1967, "Potential evapotranspiration in humid and arid climates," In Conference on Evapotranspiration and Its Role in Water Management, Chicago, 1966, Proceedings, p. 23-26.
This paper evaluates the concept of potential evapotranspiration and its relationship to various climatic conditions. Attempts at measuring potential evapotranspiration from a growing plant canopy are valid only when water is abundant and unlimited in the soil profile. Estimations of evapotranspiration potential from mean temperature and energy budget data are discussed. In semi-arid and arid regions the actual evapotranspiration is determined by the amount of precipitation. Analysis shows that use of a method for estimating potential evapotranspiration based on the mean temperature will result in no great difference between the moist and dry climates at similar latitudes and elevation. Movement toward warmer and cooler climates results in rapid changes of potential evapotranspiration. When high levels of soil moisture are maintained through irrigation, the actual evapotranspiration is nearly equal to the potential evapotranspiration. Potential evapotranspiration is discussed in relation to irrigation problems.

Deryagin, B.V., Zakhavayeva, N.N., and Lopatina, A.M.
1966, "Study of water evaporation from soils," Soviet Soil Sci. Vol. 2, pp. 147-150.
Studies were made of water evaporation from quartz sand with varying degrees of dispersion. Film from a solution in a hexane of aliphatic acid or alcohol was applied to the surface of sand which had been wetted with water. The sample was put in thermostat and at a specific temperature and air moisture, water was evaporated from the soil. Evaporation of water from soil decreased whenever the soil surface was coated with films of aliphatic acids of different molecular weight. As length of the molecular chain decreased, evaporation rate decreased. Similar results were obtained with alcohol films. Coatings from a solution of myristic acid in a hexane produced more significant decrease in water evaporation than pure hexane. A film of aliphatic acid was effective. Water evaporation was decreased by two-thirds when hydrophobic coatings of polysiloxane liquids (ethylpolysiloxane, methylpolysiloxane, isobutylpolysiloxane) were applied to the soil surface. Soils to which coatings of surface-active and hydrophobizing substances (polysiloxane liquids) were applied, lost their capacity to be saturated by the liquid after repeated wetting (after drying).

Dieleman, P.J.
1963, "Reclamation of salt affected soils in Iraq," International Institute for Land Reclamation and Improvement, Wageningen, Soil Hydrological and Agricultural Studies. 175 p.

Fitzpatrick, Eugene A.
1968, "An appraisal of advection contributions to observed evaporation in Australia using an empirical approximation of Penman's potential evaporation," J. Hydrol (Amsterdam). Vol. 6. No. 1, pp. 69-94.

A method was developed for obtaining an approximation of Penman's potential evaporation using data obtained in field studies of growth and water-use characteristics of cotton at Kununurra, Western Australia. Using daily data, a distinctive linear relationship between the weighted vapor pressure deficit and Penman evaporation was identified for periods with low advection. Reasonable close approximations of Penman's potential evaporation over periods of 10 days or longer could be made solely from temperature and vapor pressure data over a wide range of climatic environments in Australia. A regional appraisal of advective contributions to the observed or estimated rates of tank evaporation using energy balance considerations was difficult in Australia because of the paucity of radiation (or sunshine) and evaporation measurements over large parts of the continent.

Fitzpatrick, E.A. and Stern, W.R.
1966, "Estimates of potential evaporation using alternative data in Penman's formula," Agr. Meteorol., Vol. 3, pp. 225-239.

At Kununurra, Western Australia which has an environment with a wide seasonal range of radiation and vapor-pressure deficit, the energy and aerodynamic components of Penman's evaporation formula were calculated daily for a year. Reference values for the aerodynamic component were calculated from wet-and dry-bulb temperatures and windspeed using a relationship defined by Penman. Total radiation and relative duration of sunshine were found to be effective alternative sources of data for the energy component. Daily Piche and tank evaporimeter data were found to be satisfactory alternatives to the aerodynamic component. The minimal instrumentation needed to determine potential evaporation was a net radiometer, Piche evaporimeter and maximum and minimum thermometers provided a suitable relation between the Piche and aerodynamic component existed. The use of inappropriate constants in the Penman formula was probably a greater source of error when determining potential evaporation than the deficiencies inherent in a particular type of instrument, e.g., a sunshine recorder.

Fitzpatrick, E.O., Slatyer, R.O., Krishman, A.I.
1967, "Incidence and duration of periods of plant growth in central Australia as estimated from climatic data," Agr. Meteorol. Vol. 4, No. 6, pp. 389-404.

To gain information on rainfall effectiveness, since it dominates the growth of forage throughout the year, water balance models employing total rainfall and potential evaporation over 5-day intervals were developed to estimate periods of plant growth in arid central Australia. Of 2 basic models developed, 1 expressed a relationship between an empirical measure of growth stage and the ratio of expected evapotranspiration in the absence of water stress to the potential evaporation. The other related the ratio of actual to expected evapotranspiration and the estimated soil water storage, under conditions of restricted soil water supply. A program prepared for the CDC 3600 computer was used to analyze the data. The seasonal rainfall pattern shows a summer maximum; however, the probability of soil water availability was highest in winter. The effectiveness of summer rains is greatly diminished by potential evaporation rates. The seasonal pattern of growth expectancy parallels that for soil water storage; however, at no station does the probability of a growth period commencing in any one month exceed 0.60 and this occurs only in Dec. and Jan. The results may be of practical value in suggesting grazing practices in harmony with the basic climatic factors setting the pattern of growth.

Fox, M.J.
1968, "A technique to determine evaporation from dry stream beds," Journal of Applied Meteorology 7(4): 697-701.

A technique is described to determine 24-hour streambed evaporation subject to the constraints that it be inexpensive, uncomplicated, and accurate to within plus or minus 20 percent. Using maximum thermometers, a totalizing anemometer, and pans filled with dry sand, evaporation is predicted. The results of statistical evaluation of the prediction equation on the experimental data gives an average percentage error of 13 percent and a standard error of 0.88mm. Using this technique, it was determined that evaporation is not important in the annual hydrological balance of a stream bed.

Gale, J. and Poljakoff-Mayber, A.
1965, "Antitranspirants as a research tool for the study of the effects of water stress on plant behavior," UNESCO Arid Zone Research, Vol. 25, pp. 269-274.
One aspect of the study of anti-transpirants is their direct and indirect effect on plant water stress. Evidence that anti-transpirant sprays actually decrease plant water stress has been obtained from experiments in which stomata of treated plants have been found to remain open wider and for longer periods than those of non-treated plants. Increased relative turgidity of treated plants is additional balance of plants. Anti-transpirants have been shown to modify growth and development of plants in the field in a manner which closely resembles the effect of reduced moisture stress obtained by irrigation. In addition to their potentialities as reducers of irrigation water expenditure in arid climates, anti-transpirants may prove to be a versatile research tool for water stress studies if their numerous side effects are taken into account.

Gates, David M. Alderfer, Ronald and Taylor.
1968, "Leaf temperatures of desert plants," Sci. Vol. 159, No. 3818, pp. 994-995.
The leaf temperatures of many plants of semiarid regions are very near air temperature. A new pistol-grip infrared radiometer was used to measure the leaf temperature of 7 plant species. The leaf temperatures of all plants except Opuntia were within 2 or 3 degrees of air temperature. The blade temperatures of Opuntia were 10 to 16 degrees above air temperature. Theoretical justification for the observation was given based on an energy budget analysis. The energy budget for a plant leaf was programmed for computer analysis for any given value of radiation absorbed, air temperature, wind speed, relative humidity, leaf size and diffusion resistance. The leaf temperature has a direct effect on the transpiration rate of plants in arid climates.

Garcia, R.V.
1967, "Global atmospheric research programme," World Meteorological Organization, Bulletin 16(4):212-218.
Progress since the publication of Bjerknes' 1904 paper is traced to the experiments utilized by Smagorinsky and his team in reproducing many of the characteristics of the hydrological cycle in the atmosphere. The author states that the Global Atmospheric Research Program (GARP) may be considered as a point of convergence of numerical weather forecasting, which has to satisfy the operational needs of the weather services, and of numerical simulation of the general circulation of the atmosphere, which is a research tool. It is asserted that GARP "is an attempt to perfect further the dynamic models used in the numerical simulation of the general circulation and to replace the arbitrary initial conditions by actual values of the atmospheric variables, at a given moment, in order to predict the future behavior of the air motion systems and mass fields." A summary of the first published (1967) report of the 1967 GARP study conference is presented. The report "will undoubtedly be in many respects a standard text of reference for many years to come." The stated final goal of GARP is "to conduct global experiments aimed at determining the extent to which knowledge available in the 1970's will permit the understanding and prediction of atmospheric behavior." In the next to last session of this article, "GARP goals: criticisms and answers," the author states that the understanding of the physical processes involved in the general circulation of the atmosphere is, in its own right, a scientific problem which would need no other justification. In the last section, the author quotes the following from the report: '"To be ready with an initial global observation experiment by 1973, it will be necessary to have a complete specification of all requirements formulated in 1968." '

Gol'tsberg, I.A., ed.
1969, "Microclimate of the USSR," Israel Program for Scientific Translations, Jerusalem, Israel. 240 p.
The authors discuss some results and methods of research work carried out by the Main Geophysical Observatory in evaluating quantitative indexes of the microclimate in different regions of the USSR, obtained on the basis of a climatologic analysis of expendition data.

Green, C.R.
1962, "Probabilities of temperature occurrence in Arizona and New Mexico (Arizona Climate-Supplement 1)," University of Arizona, Tucson, Institute of Atmospheric Physics. Various paging. Map.

Grieve, B.J. and Went, F.W.
1965, "An electric hygrometer apparatus for measuring water-vapour loss from plants in the field," UNESCO Arid Zone Research, Vol. 25, pp. 247-257.
The sensing hygrometer apparatus described makes possible instantaneous determination of water-vapor loss using leaves intact on the plant. A better estimation of over-all daily water-vapor loss was possible since the speed of use allows numerous observations to be made on selected leaves in the course of a day. It is inherent in the electric hygrometer sensing method that the moving stream of air around the enclosed leaves disturbed the vapor shells or boundary layers. For field studies of water vapor loss involving comparison of rates in a number of character plants at a given station there were a number of advantages in the use of the electric hygrometer method over the cut and weigh method.

Hanks, R.J., Gardner, H.R., and Fairbourn, M.L.
1967, "Evaporation of water from soils as influenced by drying with wind or radiation," Soil Sci. Soc. of Amer. Vol. 31, No. 5, pp. 593-598.
Evaporation of water directly from the soil accounts for loss of a large part of the precipitation received in arid parts of the world. A study was done to determine relative importance of temperature gradients in evaporation of water from soil. Water was evaporated from soils using wind and radiative drying that would produce different temperature gradients of various magnitudes and directions. When soils were compared for periods, absolute magnitude of the slope of the water content profile was greater at the bottom of the column for silt loam than for loamy sand or sand. The reverse was true near the soil surface. Temperature profiles for the three soils were similar and data from radiated columns showed an increase in temperature with depth from 0.5 to about 6 cm at 1 day and then a decrease with depth below 6 cm. Evaporation for the second day until the end of the run was 1.22, 0.91 and 1.41 times higher for wind than for radiation treatment of silt loam, loamy sand and sand soils respectively.

Iranian Oil Operating Companies, Air Services
1968, Annual Weather Bulletin, 39 p. Mostly charts and tables. Mimeog., looseleaf.
Contains yearly weather summaries for each of 8 of the companies' 10 stations: tables of averages and extremes and of frequency distribution of meteorological elements (temperature, rainfall, RH, wind, etc.) and their monthly and yearly values; and climatological graphs, wind roses, and wind direction frequency charts. A map showing the locations of the weather stations, a list of the instruments used, and a table of coordinates, elevations, and index numbers of the stations precede the tabulated material. The technical work of the companies is supervised by a meteorologist from International Meteorological Consultant Services, London. The instruments and observing procedures are in accordance with International and Iranian practices and regulations.

Jackson, R.J.
1967, "The effect of slope, aspect and albedo on potential evapotranspiration from hillslopes and catchments," J. of Hydrol. (New Zealand), Vol. 6, No. 2, pp. 60-69.
Use of a radiant energy balance appropriate to slope, aspect and albedo of a hillslope or catchment, in estimation of potential evapotranspiration of Penman's method, was illustrated for horizontal surfaces and slopes of 10, 20, 30 and 40 degrees facing north, south, east or west and having albedos of 0.1 and 0.25. The energy-balance approach to estimation of evaporation, which is based on the principle of the conservation of energy, was discussed, using equations. Included also were solar radiation on slopes, net radiation and potential evaportranspiration. For a region with average annual rainfall of 50 to 55 inches, the data implied a considerable variation in potential annual surplus available for stream flow according to characteristics of a hill slope or a catchment area. For any particular combination of slope and aspect there was a 20% decrease in potential evaportranspiration as a result of change in albedo which occurred to a greater extent in the summer months. Slope and aspect had their greatest influence on potential evaporation at the equinox. Methods described in the study could be used to measure evapotranspiration from hillslopes and catchments in arid parts of the world.

Kuzkov, A.A.
1967, "Sushchestvuet li problema usykhaniia Azii (Is there a problem of desiccation of Asis?)?" Akademiia Nauk SSSR, Izvestiia, Ser. Geogr. 4:152-155. (Full translation in Soviet Geography: Review and Translation 9(1):47-54.
On the basis of an extensive review of the literature the author examines the problem of the desiccation of the deserts of Asia in historical times. The discussion includes the hypothesis and evidence for climatic fluctuation and "progressive aridization of climate," retreat of the glaciers, intensification of the process of sand blowing, progressive reduction in the areas of lakes, salinification of soils, and nature of human economic activity in desert regions. The author concludes that it is improper to regard the processes of "desiccation of the territory of the Asiatic deserts" apart from climatic variation.

Lahiri, A.N.
1966, "Role of antitranspirants with special reference to water turn-over in arid plants," Annals of Arid Zone, Vol. 5, No. 1, pp. 97-104.
Water loss by transpiration under desertic conditions is a serious problem because of the great bulk that is lost to the atmosphere. A review of various antitranspirants with particular reference to water turn-over in arid plants is given. The requirements for a successful antitranspirant are listed. The effect of antitranspirants on photosynthesis were discussed. It was suggested that plant antitranspirants have a great possibility for moisture conservation in arid and semi-arid areas where native plants commonly transpire at a very fast rate until low soil moisture reduces the rate of transpiration.

Lawson, G.W. and Jenik, J.
1967, "Observations on microclimate and vegetation inter-relationships on the Accra Plains (Ghana)," J. of Ecology, Vol. 55, No. 3, pp. 773-785.
Measurements of microclimate and transpiration during a complete 24 hour period were carried out on the Accra Plains during the dry season (December 1965 to April 1966). Seven microclimatological stations were set up in a characteristic tree, shrub clump and the surrounding grassland. Hourly records of soil and air temperature, evaporative power of the air, relative humidity, wind speed and wind direction showed marked variations in space and time. The prevailing south-westerly wind effects an ecological differentiation around the clump. The grasses and shrubs on the windward side showed xerophytic features compared with the mesophytic condition of those on the lee of the clump.

Lebedev, An.n
1968, "Klimaticheskii spravochnik Afriki, Chast' I, Temperatura vozdukha, osadki (Climatological reference work on Africa. I: Air temperatures, precipitation)," Gidrometeoizdat, Leningrad. 480 p.
This volume contains very detailed information on the air temperature and precipitation for Africa. Together with the mean values, it includes the probability values of the main meteorological elements. The technique of computation of the climatic characteristics is also discussed. The publication is intended for designing institutions. It will also be of interest to meteorological specialists, students, and teachers of meteorology in higher schools. Russian and English summaries.

Lebedev, A.N.
1967, "Klimaticheskii spravochnik Afriki, Chast' II, veter, otnositel' naia vlazhnost' vozdukha, oblachnost', tumany, grozy i aeroklimaticheskie kharakteristiki (Climatological reference work on Africa. II: Wind, relative atmospheric humidity, cloudiness, fog, thunderstorms and aeroclimatological characteristics)," Gidrometeoizdat, Leningrad. 259 p.
Contains all the principal parameters of wind speed and direction, relative humidity of atmosphere, cloud cover, fog, and thunderstorms. In addition to the mean values of these parameters, values are given also of these elements for different probabilities. The distribution of morning and daily atmospheric moisture is described also by mean square deviations and coefficients of variation. Data are also given on the mean monthly atmospheric temperature at the 850, 700, 500, 300, 200, 150, and 100 mb isobaric surfaces; the mean monthly height of the isotherms of 0 and -- 10 degrees C; the mean monthly moisture content (kilograms per cubic meter) in a column of air below the 500 mb surface; the mean monthly specific atmospheric humidity at the 850, 700, and 500 mb isobaric surface; the mean monthly atmospheric relative humidity (percent) at the 850, 700, and 500 mb isobaric surfaces; the mean monthly height of the isobaric surfaces and the wind characteristics at the 850, 700, 500, 300, 200, 150, and 100 mb surfaces. Lists of the stations from which the data were obtained are given. Russian and English summaries.

Lebedev, A.N.
1967, "Klimaty Afriki (Climates of Africa)," Gidrometeoizdat, Leningrad. 486 p.
This monograph is concerned with the genesis of climates of Africa, the spatial and time features of meteorological elements, beginning with a technique for compilation of monograms, computation and mapping out of climatic parameters. The remaining 9 chapters discuss the following: radiation factors of climate, circulation factors of climate, general characteristics of the climates of Africa, the thermal regime, regime of the relative humidity of the air, cloudiness regime, atmospheric precipitation, wind regime, and the climate of the free atmosphere and the moistening regime. It serves as a manual for those working in designing and research institutions and also those in production organizations dealing with the climate of Africa. English translation of Authors' abstract and table of contents.

Liakopoulos, Aristides
1966, "Theoretical prediction of evaporation losses from groundwater," Water Resources Res., Vol. 2, No. 2, pp. 227-240.
The physical problem of the capillary rise case invetigated theoretically in the study considered a uniform soil 2 meters deep. The soil was initially saturated with water without any excess water on its surface, from which evaporation could take place at a variable rate. The aim was to predict theoretically the evaporation rate, the water distribution, and the pressure distribution of the water at any level of the soil mass over a period of time. The physical problem was reduced to its equivalent mathematical model in terms of a partial differential equation together with its initial and boundary conditions. 18 equations were used to explain evaporation losses. As the intensity of evaporation increased, the loss of water (evaporation rate) increased but as the evaporation proceeded, the rate decreased and became lower than when evaporation proceeded at the lower intensity. Evaporation losses from groundwater can be predicted adequately by solving the diffusion-type equation of water conduction in soils with given initial and boundary conditions. The procedure for the numerous calculations required for numerical integration was programmed in Fortran.

MacRitchie, F.
1969, "Evaporation retarded by monolayers," Science 163(3870): 929-931.
The reduction in the steady-state rate of evaporation of water by hexadecanol monolayers depends only on the air velocity above the surface and is independent on the absolute rate of evaporation up to air velocities of 40 centimeters per second. This indicates that the monolayer does not affect the vaporization step but increases the size of the diffusion boundary layer. The mechanism (the creation of a surface pressure gradient in the monolayer which reduces the net stress on the surface by the air) is discussed.

Meher-Homji, V.M.
1965, "Aridity and semi-aridity: A phyto-climatic consideration with reference to India," Annals of Arid Zone, Vol. 4, No. 2, pp. 152-158.
Bases for classification of arid or semi-arid regions were reviewed. An index of aridity-humidity was proposed based on the ecological formulae of Gaussen. Three principal ecological factors, temperature, precipitation and dry periods were considered. Vegetation types were explained on the basis of this index and areas of India were classified according to the developed index.

Mukhenberg, V.V.
1967, "Albedo poverkhnosti sushi zemnogo shara (Albedo of the land surface of the globe)," Glavnaia Geofizicheskaia Observatoriia, Leningrad, Trudy 193:24-36.
Maps of the albedo of the surface of the continents for January, March, April, May, July, September, October and November. Distribution of the albedo on the surface of the land over the entire world, and the annual variations of the albedo on the various climatic regions are examined. A table of the albedo of natural surfaces of the Earth is given. Russian summary.

Murzaev, E.M.
1966, "Priroda sin'tsziana i formiorovaniie pustyn' Tsentral' noi Azii (Nature of Sinkiang and formation of the deserts of Central Asis)," Moscow. Translated, 1967, by Joint Publications Research Service, Washington, D.C., as JPRS 40299. 621 p.
Relief features of Sinkiang province and of the desert area of the Chinese People's Republic are described. Characteristics of each of the following are discussed: the climate in the area, the surface waters, the soil mantle and vegetation cover, and, the animal kingdom inhabiting the area. The history of the formation of this Central Asian landscape is given; recent glaciation in the region is discussed. An extensive bibliography of source material is included.

Nelson, H.L.
1968, "Climatic data for representative stations of the world," University of Nebraska Press, Lincoln. 81 p.
Presents climatic data, including elevation, temperature, and precipitation month-by-month and annual summary, that is representative of each state of the U.S. as well as eac' foreign country. The data included is sufficient to give a representative pattern of the major climatic types in each.

Peck, A.J. and Rabbidge, R.M.
1966, "Soil-water potential: direct measurement by a new technique," Science, Vol. 151, No. 3716, pp. 1385-1386.
A problem in studies of water relations in unsaturated soils is the accurate measurement in situ of the potential of soil water. This potential is negative with respect to that of the standard reference state: pure free water at atmospheric pressure. The difference between the equilibrium pressure and the osmotic pressure of a solution physically constrained in a container that is surrounded by unsaturated soil, is numerically equal to the specific free energy of the soil water. This difference is a measure of the potential of the soil water. To determine soil-water potential, pressure measurements were obtained. Instruments were designed and constructed to apply this principle.

Pearson, P.H.O.
1969, "Basic atmospheric parameters as measured by four falling sphere experiments at Woomera, July to November 1966," Weapons Research Establishment, Salisbury, Australia. 38 p.
Four falling sphere experiments were conducted at Woomera from July to November 1966. These results form the fourth group obtained during the second year of firings in a series to measure the seasonal variation of density temperature, pressure, and winds shortly after sunset.

Peterson, J.T. and R.A. Bryson
1968, "Influence of atmospheric particulates on the infrared radiation balance of northwest India," National Conference on Weather Modification, 1st, Albany, N.Y., April 28-May 1, 1968, Proceedings p. 153-162/
Field study of Indian climate was conducted in late April 1966. Observations of long wave radiative flux and atmospheric particulars support the general conclusion of Bryson and Baerreis (1967). The effects of quartz aerosols, water vapor, and carbon dioxide on infrared radiative transfer were considered. The data indicate that the difference between the infrared upward flux observed and that which is calculated is related to the amount of dust in the atmosphere. It was found in all cases that the upward flux was greater than the corresponding calculated flux, and the 2 values diverged throughout the lowest several thousand feet of the atmosphere. The analysis showed that incorporation of the influence of aerosols into the calculation of the upward flux lowered the values below those calculated for a dust-free atmosphere rather than raising the values to magnitudes similar to those observed. This negative result did not depend on the partitioning of the aerosol extinction into its components of scattering and absorption. The effect of either component was to reduce the calculated upward flux.

Polavarapu, R.J.
1968, "Some studies of sensible and latent heat fluxes at Waltair, Southeastern coast of India," Agric. Meteorol., Vol. 5, No. 4, pp. 255-268.
Sensible and latent heat fluxes were estimated over a 22-month period at Waltair, India using three methods: Halstead's model of non-equivalence of turbulent transfer coefficients, the classical concept of equivalence of turbulent transfer coefficients, and by use of the Bowen ratio. Halstead's method gave the best evaluation of sensible and latent heat fluxes. Agreement of fluxes obtained by the Bowen ratio method and Halstead's method was best during daytime and poor during night time. The diurnal, seasonal, and annual variation of the sensible and latent heat fluxes were discussed. A relation between the Bowen ratio and the mean moisture content of the top 30 cm soil-layer was established. The Bowen reached a limiting value as the moisture content in the soil increased to field capacity.

Priestley, C.H.B.
1966, "The limitation of temperature by evaporation in hot climates," Agr. Meteorol., Vol. 3, No. 3/4, pp. 241-246.
Many factors affecting plant growth and well-being are sensitive to the temperature of the plant and its environment, particularly at high temperatures. A review of data was done to see what are the general principles which govern the maximum temperatures which can be obtained in the environment of a growing plant, plentifully supplied with moisture. A resume of heat balance was given. A climatic evaluation was done for 1850 stations distributed over the land surfaces of the world. Data collected by Linacre have indicated a reversal of heat transfer between leaf and air in the vicinity of 33° C for thin-leaved plants exposed to bright sunshine. An alternative view advanced in the paper and supported by a climatic study was that the phenomenon was quite general and that 33° C represents the maximum temperature attained by the air over any extensive freely evaporating surface which is naturally exposed.

Rao, M. Rama
1965, "Water balance and evaporation studies," Nature, Vol.209, No. 5012, pp. 776.
During the winter months on clear-sky days, systematic measurements were made to find the surface soil moisture over Poona, India. It was found that there was a daily variation of soil moisture, reaching a minimum at the maximum epoch of temperature and a maximum at the minimum temperature epoch. It appeared from Penman's equation for evaporation that both during day and night there was a process of condensation taking place near the surface of the earth which in the day was completely outbalanced by the incoming short-wave radiation, resulting in a net evaporation. In arid and semi-arid zones this factor is important for the study of water balance in relation to crop development in winter and may explain the large vegetation growth during these months when there is no rainfall.

Rathjens, C.
1968, "Schichtflachen und Schnittflachen in Trockenklima (Bedding and erosional surfaces in arid regions)," Regio Basiliensis 9(1):162-169.
Cuestas developed under arid climatic conditions have been examined in the eastern Iranian upland, southern Afghanistan, the Thar desert of northwestern India, Turkey, and the southwestern United States. In this type of climatic conditions the prevalence and stability of steep slopes, the characteristics of pediments, and the close relationship between surface form and geologic structure are principal factors in the development of the cuesta landscape. Comparisons are made with the morphology of cuestas developed in areas of humid climate. French summary.

Sellers, W.D.
1964, "Potential evapotranspiration in arid regions," J. Applied Meteorology 3:98-104.
The concept of potential evapotranspiration, as applied to arid regions, is examined using an energy balance approach suggested by Budyko. Using data for Yuma, Arizona, it is shown that a 50% increase in the relative humidity of the air above an irrigated field is accompanied by a 10-15% decrease in potential evapotranspiration, a negligible decrease in net radiation, and a temperature increase of the surface relative to the air of 2-3°C.

Stark, N.
1967, "Transpirometer for measuring the transpiration of desert plants," Jour. of Hydrology 5(2):143-157.
This study compares transpiration results using the electronic hygrometer and quick weighing methods. The study determined that quick weighing results from several species compare closely to hygrometer data in direction. The study describes the water loss from greasewood (Sarcobatus vermiculatus) branches differing in condition and from saltgrass (Districhlis stricta) where separate clumps were studied. The dark green leaves of greasewood appear to be better able to control water loss than the yellow-green leaves. The study follows the curves for water loss during flowering and fruiting of sagebrush (Artemisia tridentata) and rabbitbrush (Chrysothamnus mauseosus albicaulis) using the same 10 branches for study over a 2-month period. Both of these latter species appear to be able to control water loss during the period of fruiting somewhat independent of air temperatures and relative humidity. Water loss is rapid in rabbitbrush as the fruit accessory tissues dry out.

Stanhill, G.
1965, "The concept of potential evapotranspiration in arid zone agriculture," UNESCO Arid Zone Research, Vol. 25, pp. 109-117.
An examination was made of the accuracy of eight widely used meteorological methods of estimation using data taken at Gilat in the arid region of southern Israel. The methods based on open water evaporation, either estimated from Penman's meteorological formula or measured in an evaporation tank, gave the most accurate estimate with the smallest error term. The use of Penman's formula was preferred since it offered the possibility of analyzing the relative importance of various climatic factors in determining rate of water loss under non-limiting soil moisture conditions. For agricultural purposes, use of measured or calculated open water evaporation with empirically derived reduction constants appeared to give the possibility of a practical and accurate method of irrigation control.

Stone, Richard O.
1967, "A desert glossary," Earth Science Rev., Vol. 3, No. 4, pp. 211-268.
A compilation of current terms describing desert features and desert phenomena is presented. An attempt was made to simplify and consolidate the terminology used in describing deserts. Entries in the glossary were largely physiographic and geographic, but botanical, pedological, meteorological, climatological and several archaeological terms are included. The glossary is presented in two parts. In the first section, which is the more complete, the deserts of Mexico and the U.S.A. are grouped together. The second section consists of terminology applied to deserts of Arabia, Australia, Central Asia, Chile and Peru, Egypt, Iraq, Jordan, Pakistan, Iran, southwest Africa, and Syria. It contains 985 definitions.

Tanner, C.B. and E.R. Lemon
1962, "Radiant energy utilized in evapotranspiration," Agronomy Journal 54:207-212.
An evaluation of the amount of radiant energy utilized in evapotranspiration under field conditions. Considers the radiation balance, the various components of the energy balance, the crop and soil factors influencing the amount of net radiation exchange utilized in evapotranspiration. Data presented show that when soil moisture is available and a substantial crop cover shades the ground, most of the net radiation is used in the evapotranspiration process.

U.S. Air Weather Service
1967-68, "U.S. Naval Weather Service world-wide airfield summaries. V: Australia, South Pacific, Antarctica; VI(1): South America (Argentina, Brazil, Uraguay); VII: Central American (Mexico, etc.)," U.S. Environmental Science Services Administration, Asheville, N.C.
Almost entirely data. "Data" sources listed in front of each volume. Part of a series of compilations, which when completed, will include data for approximately 3000 locations, and climatological summaries for selected airports and for the climatic areas in which they are

located. The summaries are presented by country (in alphabetical order); within each country, arranged according to numbered climatic areas; and by increasing WMO Station Index Numbers within the climatic areas. Criteria for data sources, list of 120 international data sources, and Station Index in each volume, are included. Copies of excerpts of these documents are available to the public from the National Weather Records Center, Federal Building, Asheville, N.C. 28801, for the cost of duplication.

Van Hylckama, T.E.A.
1966, "Evaporation from vegetated and fallow soils," Water Resources Res., Vol. 2, No. 1, pp. 99-103.
In 1962 five evapotranspirometers were located southeast of Buckeye, Arizona. Two were planted in salt cedar and the others were left bare. The goal was to determine the water losses from bare soil compared with losses from vegetated soil exposed to virtually identical natural surroundings. Harmonic analysis provided a method of describing periodic phenomena. The double peak of the second harmonics was present. The first peak (in the morning) was due to actual evaporation, the second (in the evening) was due to recharge. The near disappearance of the second harmonic in August and September was possibly due, not to evaporation, but to recharge of the soil above the water table.

Venkataraman, S. and V. Krishnamurthy
1967, "Radiation climate over India," Indian Journal of Meteorology and Geophysics 18(1):39-44.
As solar radiation data for India available at present are not extensive enough to meet the increasing demands for the climatological information of this parameter, use of data of bright hours of sunshine to estimate the radiation receipt is examined. Monthly normal radiation maps based on the estimated solar radiation values for 52 stations are presented and discussed.

Wallen, C.C.
1967, "Aridity definitions and their applicability," Geografiska Annaler, Vol. 49A, No. 2/4, pp. 367-384.
A review of the various approaches to the problem of defining aridity were given. The classical, index, and water-balance approaches were discussed with particular emphasis on a critical analysis of the different indices developed by Koppen, deMartonne, Emberger, and Gaussen. In the latter part of the article a summary was given of an investigation, which was an attempt to establish from the available climatological information, the agricultural potentialities of the semi-arid and arid regions in the Near East. The countries involved were Lebanon, Syria, Jordan, Iraq, and Iran. The results from a purely classical approach were compared with an approximate determination of the water-balance conditions based on Penman's formula.

that the optimum temperature was lowest in rape (just over 20 deg C) and highest in maize (just below 30 deg C). Relative growth-rate (RW) was almost identical with relative leaf-are growth-rate (RA) at each temperature for rape and sunflower and both RW and RA rose more steeply than EA with increasing temperature. In hot climates EA fell with an increae in temperature in those species which had low optima. In warm conditions the EA rate varied little with temperature by only plus or minus 10% between 12 and 30 deg C for rape and 23 and 36 deg C for maize.

Wilson, J. Warren
1966, "High net assimilation rates of sunflower plants in an arid climate," Ann. of Botany, NS Vol. 30, No. 120, pp. 745-751.
The rate of increase of dry matter per unit leaf area (net assimilation rate, E) varies with species and environment. Sunflower plants were grown in rooting mediums of soil and nutrient culture. The studies on the plant's growth at Deniliquin, New South Wales, indicated maximum values of E near 2.0 grams of dry matter to the minus two power, week to the minus one power. The values of E exceeded by a large margin all values of E previously recorded for the sunflower or any other species in any part of the world. The high E values were attributed to the climate. Both dry-matter harvesting and gas-analysis indicated that plants of certain species grown in fertile soils could achieve, in arid climates, rates of assimilation roughly double those hitherto regarded as maximal.

Wilson, J. Warren
1967, "Effects of seasonal variation in radiation and temperature on net assimilation and growth rates in an arid climate," Ann. of Botany, NS, Vol. 31, No. 121, pp. 41-57.
The study examined the effects of radiation and temperature on the growth of rape, sunflower and maize at various times of the year in the arid climate at Deniliquin, New South Wales. The net assimilation rate, relative growth-rate, and leaf-area ratio were measured. Temperature range did not appear as a significant variable except in interaction with radiation and with mean temperature. Multiple regression analysis showed the net assimilation rate to rise with radiation. For all three species, the relative growth rate showed a tendency to increase with both temperature and radiation. The leaf-weight ratio t tended to increase with radiation in both rape and sunflower, Sunflower showed the rise in specific leaf area with falling radiation, but the response to temperature was not significant. Most of the variation in net assimilation rate and relative growth rate was accounted for in terms of radiation and temperature.

Woodruff, N. P. and Armbrust, Dean V.
"A monthly climatic factor for the wind erosion equation," J. soil and Water Conserv., Vol. 23, No. 3, pp. 103-104.

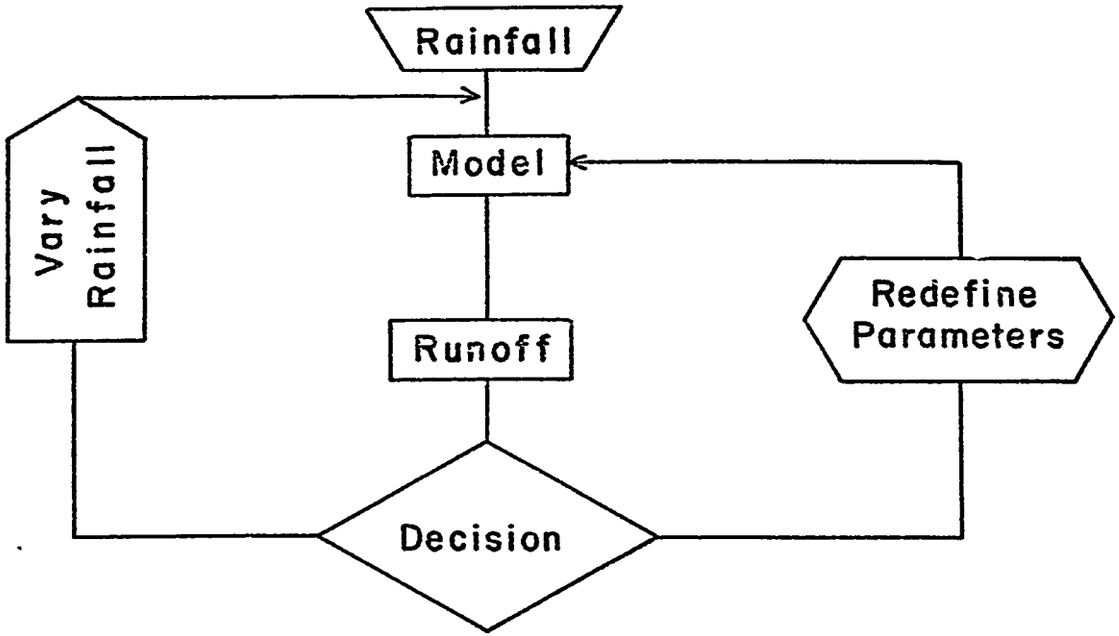
For areas of the United States where wind erosion is most severe, maps were prepared with indicated lines of equal wind erosion climatic factor by month. Areas were: Great Plains, Pacific Northwest, Great Lakes and Atlantic and Gulf Coast States. Equations used to calculate annual and monthly climatic factors showed that wind velocity differences strongly influenced the climatic factor which may vary from a small value, indicating low erosion potential, to a large value, indicating high erosion potential, during the year. Applying the equation to a wind erosion problem at Midland, Texas, it was found that month to month variation in the climatic factor caused month to month variation in erosion potential or residue requirements for wind erosion control even though soil, residue and roughness conditions remained constant throughout the year. Monthly climatic factors reflected short-term condition better than annual factors. Use of the monthly factors was recommended in all applications of the wind erosion equation.

Zubenok, L. I.
1965, "Worldwide evaporation maps," (Translated tile). Glavnaya Geofizicheskaya Observatoriya, Leningrad, Trudy 179:144-160.

World maps are given showing evaporation for the year and for each separate month. Method used for calculating evaporation was developed at the Main Geophysical Observatory. The calculations were made for 1460 points located on all continents except Antarctica and mountainous regions. These maps show that the evaporation is zonally distributed outside the tropical latitudes. Deviations from this zonal distribution are observed close to shore lines where cyclonic and monsoon circulation develops due to a reduction in radiation balance for these territories. The distribution of evaporation in the tropical latitudes depends mainly on the distribution of the radiation balance. A maximum evaporation of more than 250 centimeters per year is observed in the Sahara Desert. Curves are given showing the annual behavior of evaporation for various sections of the earth. The extratropical latitudes show a single maximum in evaporation during the summer. Two maxima are observed in the equatorial latitudes, one in the spring and one in the fall.

Rainfall

The variability in rainfall producing runoff from semiarid watersheds, rainfall distribution and artificial rainfall simulators are discussed in the following abstracts. Rainfall data from Pakistan, Australia, Israel, South Africa, Sudan, India, and Chile are included.



Rainfall Model

Drissel, J. C., and Osborn, H. B.
1968, "Variability in rainfall producing runoff from a semiarid rangeland watershed, Alamogordo Creek, New Mexico," Journal of Hydrology (Amsterdam) 6(2):194-201. Maps.
In eastern New Mexico, most of the winter precipitation occurs as low-intensity rain or snow along slow-moving cold fronts, whereas summer rains are produced by short-duration, high-intensity thunderstorms, from purely convective buildup, or from convective cells developing along weak, fast-moving cold fronts. These summer convective storms (May-October) Produce about 80 percent of the annual rainfall. Since runoff-producing precipitation on semiarid rangeland watersheds is of primary interest at the Southwest Watershed Research Center, the variability in rainfall affecting runoff was analyzed for the Alamogordo Creek watershed. The 10-year, mean, annual, seasonal, and monthly variations were analyzed and compared with the long-term averages of nearby weather stations. The distribution and orographic effects have been discussed in detail. Variations in runoff yields were discussed and analyzed for the period of record.

Domros, M.
1968, "Zur Frage der Niederschlagshaufigkeit auf dem Indisch-Pakistanischen Subkontinent nach Jahresabschnitten (Rain frequency on the Indo-Pakistan Subcontinent by periods of the year)," Meteorologische Rundschau 21(2):35-43.
Based on monthly means of rain frequency of 2912 rain gage stations on the Indo-Pakistan Subcontinent, the author has compiled maps of rain frequency (number of rainy days) for the periods: Jan.-March (winter monsoon), April-May (hot period of pre-monsoon period), June-September (summer monsoon), and October-December (post-monsoon period or retreat of the monsoon). This paper offers a condensed review of the rain frequency maps and tries to explain local differences in rain frequency. During what the author calls winter monsoon period the regime of the winter monsoon or Northeast-Passat results in a rather low rain frequency over the Indo-Pakistan Subcontinent; during that time rainfall in the North of the Subcontinent is caused by western disturbances. The map of rain frequency during pre-monsoon period clearly shows an increase of the rain frequency in the south, east, and especially northeast of the Subcontinent; this is the result of a change of low level wind flow conditions of the winter monsoon, based on the establishment of a heat low above the southern parts of the Subcontinent. During summer monsoon period the Southwest monsoon is responsible for the maximum of rain frequency as well as for remarkable local differences. Abundant precipitation is partly the result of the equatorial westerlies (Southwest monsoon), causing orographic rainfall in the west Ghats and west coast as well as in Assam/Bengal (in this area correlated with the quasi-stationary monsoon covergence above the Khasia Hills), but also of traveling disturbances: monsoon depressions along the monsoon trough are responsible for rainfall in the eastern parts of the Deccan Plateau. During postmonsoon period the Subcontinent is marked by rather low rain frequency; rainfall is important only in Southeast India, caused by cyclonic disturbances.

Feth, J.H.
1967, "Chemical characteristics of bulk precipitation in the Mojave Desert Region, California," U.S. Geol. Survey, Prof. Paper 575-C, pp. 222-227.

Determinations of chemical composition were made on 39 samples of bulk precipitation from 12 locations on the Mojave Desert Region, Calif. Bulk precipitation is defined as the solution that results when melting snow or rain falling on the land surface, whether in its natural state or modified by man, collects and incorporates the products of dry fallout. Collections were made in rain gages with a layer of transformer oil to prevent evaporation. The samples were analyzed by methods standard in the U.S.C.S. with the exception of chloride which was determined by a more sensitive method. Specific conductance ranged from 8.9 to 823 micromhos and varied inversely with quantities of rain. The chemical composition of the samples was strikingly similar to analyses made at Menlo Park, California, a totally different environment. Dust that contained saline materials appeared to have governed the composition and concentration of bulk precipitation. Although bulk precipitation varied from place to place and with time it was mainly a calcium bicarbonate type as is most precipitation.

Fitzpatrick, E.A., and A. Krishnan
1967, "A first-order Markov model for assessing rainfall discontinuity in Central Australia," Archiv fur Meteorologie, Geophysik und Bioklimatologie, Serie B, Vol. 15, No. 3, pp. 242-259.

The applicability of a simple first-order Markov model within the arid interior of Australia was examined using rainfalls combined over five-day periods. The periods were classed as either wet or dry according to whether a total of at least 0.1 inch of rain had occurred. A Markov model and a simple random model were constructed for distribution of runs of wet and dry periods. The random model gave a poor fit to the observed frequencies. The Markov model could be further improved to be a practical statistical tool for assessing the long-term incidence of runs of wet or dry weather in arid central Australia.

Gabriel, K.R.
1967, "Israeli artificial rainfall stimulation experiment: statistical evaluation for the period 1961-1965," Symposium on Mathematical Statistics and Probability, 5th, Berkeley, California, 1965-66, Proceedings 5:91-113.

A rainfall stimulation experiment is being carried out in Israel by seeding AgI from an aircraft in a randomized cross-over design. Results of 4 1/2 seasons show 15 percent more rainfall with seeding than without, a result which is 5 percent significant. It is suspected that the excess precipitation has occurred mainly on a small number of days on which seeding apparently was very effective. It has not been possible to identify meteorological conditions particularly favorable to seeding effectiveness. No evidence has been found that seeding effects persist beyond the day of seeding.

Gouws, V.C.
1967, "Analysis of rainfall over South Africa for the period July 1-December 31, 1967," South Africa, Weather Bureau, Nuusbrief 225:203-205.
Results of an analysis of data from 130 selected stations in South Africa and bordering territories are presented in a map showing 1) isolines of the rainfall for the period in percent of normal and 2) total rainfall amounts in whole millimeters for the 6 months. The rainfall situations for each of the 4 provinces of the Republic, South West Africa, and Botswana are discussed separately.

Hammer, R.M.
1968, "Note on rainfall in the Sudan," Weather 23(5):211.

Data for 1961 from 24 randomly chosen rainfall stations in the Sudan have been examined to determine the contribution of various daily rainfall amounts to the total annual rainfall. Results indicate that 14.8 percent of the raindays produced 46.3 percent of the total rainfall, and 32.2 percent produced 72.5 percent of the total rain. These figures agree with similar figures for tropical areas found by Riehl. A graph showing the average curve of cumulative percentage of raindays against percentage of annual rainfall is shown.

Mallik, A.K.
1966, "Arid-zone agrometeorology in India," Agr. Meteorol., Vol. 3, No. 1/2, pp. 3-34.
Areas with a normal annual rainfall of less than 500 mm have been considered as arid regions in India. A geographic-climatological outline which included geography, climatology, rainfall, temperature, sunshine, radiation, evaporation, wind, thunderstorms, dust storms and hail storms was given for the area under study. A description of agricultural patterns, forms, settlement, main crops, livestock and agro-technical methods was discussed. The available water and its utilization for agriculture, methods of conservation of rainfall, methods of irrigation and problems of soil salinity were considered together with the climatic interaction between the region and its surrounding area. Methods of protection against wind, raising sand, dust and frost were studied along with the pests and diseases that were favored by the climatic conditions of the area. A survey of the agro-meteorological tasks lying ahead included the augmentation of the water supply, afforestation and soil conservation, maximum use of available water, crop farming verses animal farming, and the role of the agrometeorologist in arid zones.

McGee, O.W.
1966, "Harmonic analysis of the rainfall over South Africa," South Africa, Weather Bureau, Notos 15(1/4):79-90.
The rainfall climatology of South Africa is characterized by abundant precipitation at the time of increased influences from the Indian Ocean during summer in the eastern part of the country and by winter rainfall in southwestern Cape Province brought by disturbances in

the westerlies. Regimes merge in the intermediate area. This spatial distribution of rainfall regimes across South Africa is described objectively by harmonic analysis. Maps present the total variance of the mean monthly rainfall, the percentage variance of the first 3 harmonics, the residual contributed by the higher harmonics, the amplitudes and phase angles of the first 3 harmonics, and the ratio of the amplitudes of the 1st to the 2nd harmonics. It is found that annual rainfall curves are reproduced adequately by the first 3 harmonics. The analysis clearly demonstrates the gradual overlapping of rainfall regimes in a broad belt extending from South West Africa to the southern Cape coast. The most impressive features borne out consistently by the various maps are the rapid transition from the southern Cape mountains to the coast, and the abrupt change of the rainfall regime at the western edge of the plateau.

Ramachandran, G.
1967, "Rainfall distribution in India in relation to latitude, longitude and elevation," Indian Jour. of Meteorol. and Geophysics 18(2):227-232.

An analysis of the normal rainfall of 167 observatory stations distributed over India and the neighborhood has been made using regression equations representing monthly and annual rainfall as a linear function of latitude, longitude, and elevation above sea level. The multiple CCs are high, being 0.8 to 0.9 except in some months. The anomalies after eliminating the systematic variations have also been studied. These bring to light other factors which influence rainfall, viz: the orographic effects and the effect of lee-side of mountains.

Snead, R.E.
1968, "Weather patterns of southern West Pakistan," Archiv fur Meteorologie, Geophysik und Bioklimatologie, Serie B, 16:316-346.

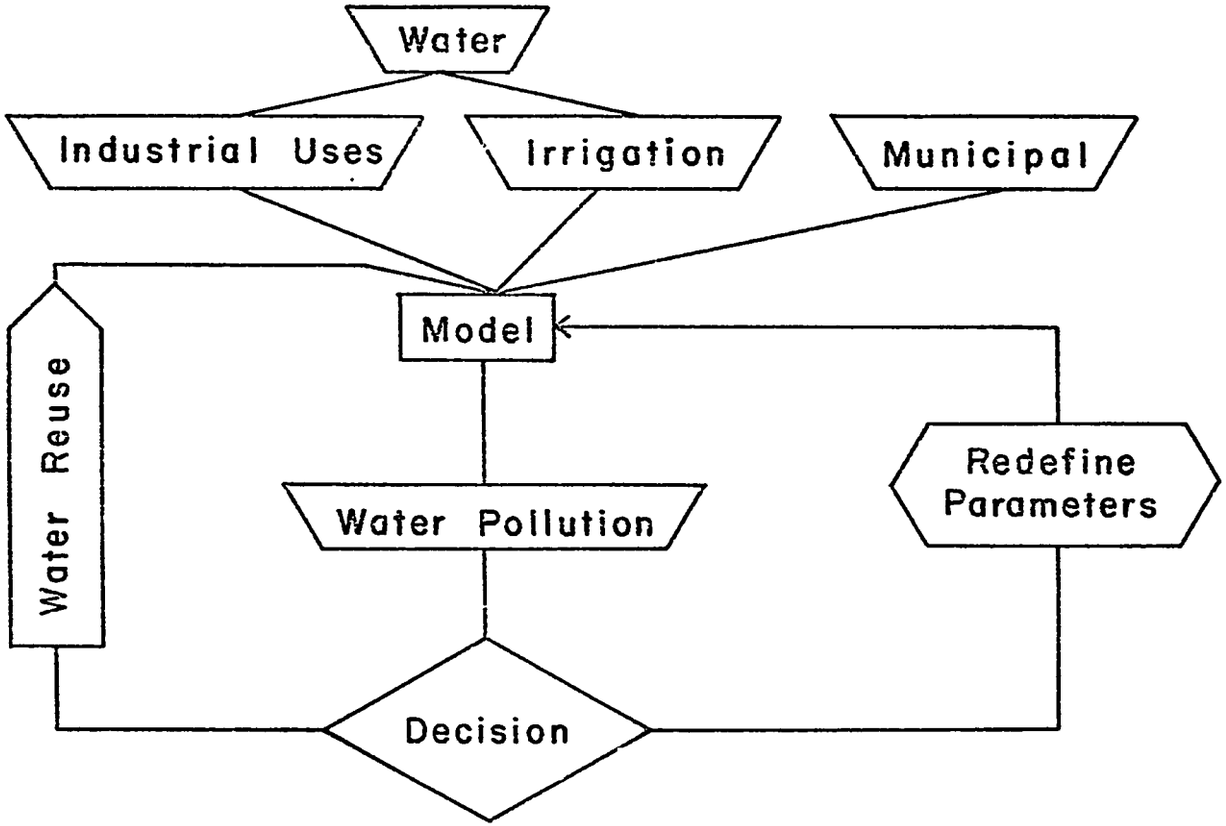
Southern West Pakistan is an area of transition between the Indian summer monsoon system to the east and the winter cyclonic system of southwest Asia to the west. As a transition area, it receives scanty, unreliable rainfall averaging less than 10 inches (254 millimeters) per year from several storm types. Six main weather patterns cross the region: the large subtropical anticyclonic high pressure cell which predominates most of the year; western depressions originating over the Mediterranean Sea; Arabian Sea cyclones; local thunderstorms and dust storms; a modified monsoon pattern; and eastern depressions originating over the Bay of Bengal or central India. A discussion of the physical and synoptic characteristics for each weather sattern and storm type is presented and summary charts of the weather patterns are included.

Van Husen, C.
1967, "Klimagliederung in Chile auf der Basis von Haufigkeitsverteilungen der Niederschlagssummen (Climate classification in Chile on the basis of frequency distribution of precipitation totals)," Freiburger Geographische Hefte 4. 113 p.
The precipitation conditions in Chile are investigated and a criterion for the climatic classification of the country on the basis of frequency analysis of the monthly precipitation is developed. The precipitation aggregates were formed out of the separate precipitation totals for the 3 summer and the 3 winter months. Of the zones distinguished from one another by definite hygric characteristics is the zone of total annual drought (30 degrees to the equator). German, English, and Spanish summaries.

Van Rooy, M.P.
1966, "Regional analysis of South African rainfall for the twelve-month calendar period ending June 30," South Africa, Weather Bureau, Notos 14(1/4):13-28.
An anomaly index which measures the relative local degree of rainfall over South Africa for a time unit of 12 months ending 30 June. Informative regional patterns are obtained of the probability (percentage) distribution for exceptionally dry, wet, and normal periods, and of the anomaly index distribution for outstanding dry and wet periods.

Water Quality

Water contamination hazards in arid basins, water reuse, and water pollution control are discussed in the following abstracts. Of special interest is an abstract presenting a computer model for predicting the quality of water percolating through stratified substrata. Natural contamination hazards in arid basins due to naturally occurring chemical substances is of great importance when studying the role of water in an arid region. Water reuse in some arid regions is feasible where industrial usage has a high priority for water. The water is used for cleaning of buildings and equipment, fire protection, cooling, and various industrial processes.



Water Quality Model

Dixey, F.
1966, "Water supply, use and management," In E.S. Hills, ed., Arid Lands: a geographical appraisal, pp. 77-102. Methuen, London.

This general discourse on streamflow and ground water in arid and semiarid lands contains some interesting information and illustrations (photos and map) on subterranean collecting galleries called qanats, foggaras, and socavones in different parts of the world. A general discussion of what is well known about salinity in arid regions and about tolerance of plants, animals, and man to salinity is given in the last section.

Feth, J.H.
1967, "Natural contamination hazards in arid basins," In Groundwater development in arid basins, Symposium, Utah State University, Logan, Proceedings, pp. 21-35.

Naturally occurring chemical substances that are possible contaminants of ground water are discussed and examples from the Great Basin are cited. Ground water quality is reviewed, including occurrence of brines. The questions of why there is so much ground water of tolerable to good chemical quality in arid basin aquifers, and to what extent these resources are renewable are largely unanswered. Sources of contamination in the atmosphere, lithosphere, hydrosphere, and biosphere are discussed. Remaining areas of ignorance, in which work should be done, are mentioned.

Gomez, H.J.
1968, "Water reuse in Monterrey, Mexico," Water Pollution Control Federation, Jour. 40(4):540-545.

Extensive reuse of treated domestic wastewater for industrial uses is practiced in Monterrey, Mexico. The aridness of the region, an extended drought, industrial development, and the population explosion necessitated this practice as early as 1955. Some industries treat and reuse water independently; others use central treatment facilities through a cooperative association. The water is used for watering gardens, cleaning of buildings and equipment, fire protection, cooling, boiler feed, and various industrial processes, with treatment for each use suited to the quality demanded. About 60 percent of the wastewater from a city of 1,000,000 is reused.

Shuval, Hillel I.
1967, "Water pollution control in semi-arid and arid zones," Water Research, Vol. 1, No. 4, pp. 297-308.

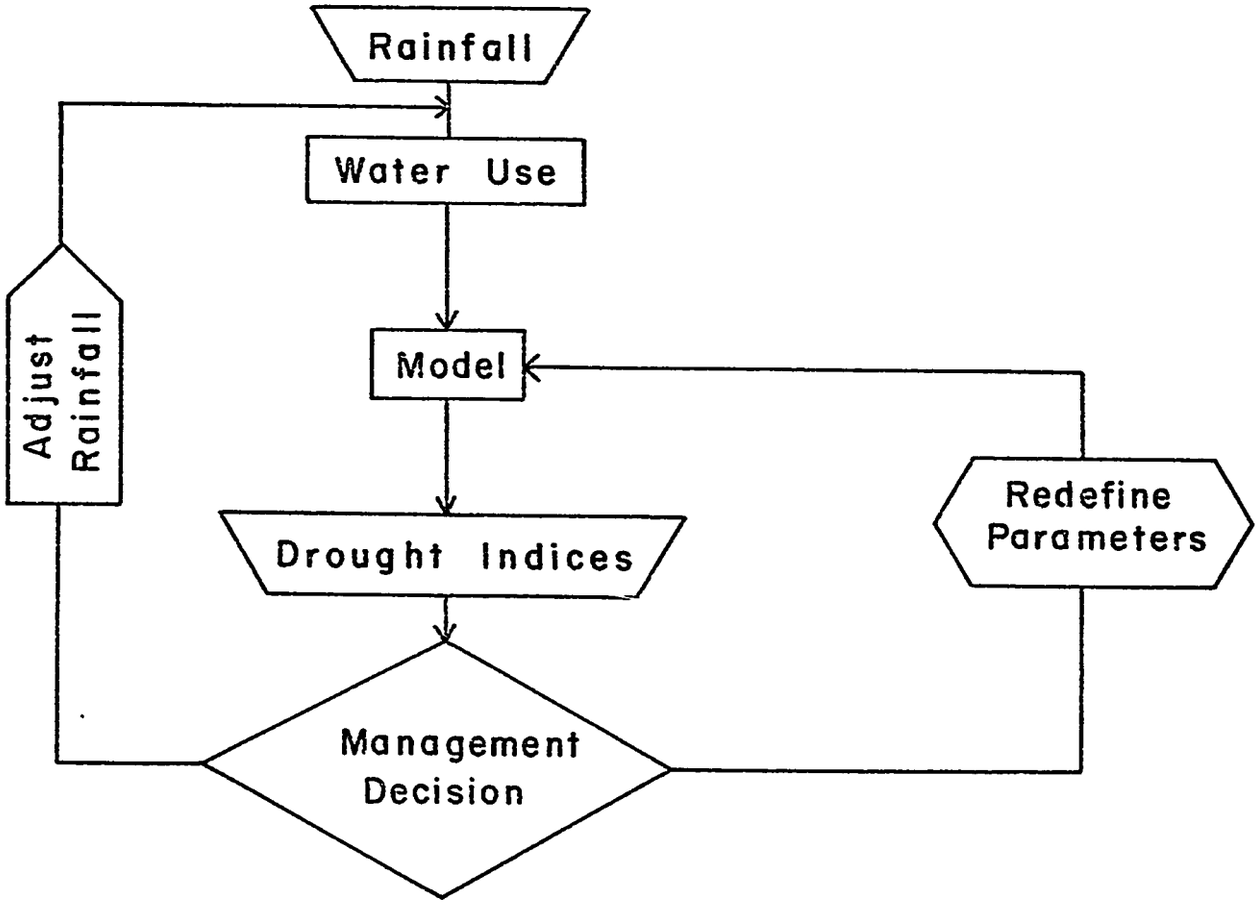
Limited water resources in semi-arid and arid zones caused special water pollution problems. Aspects of water utilization were discussed. It was suggested urban and industrial waste waters be utilized for direct irrigation, industrial purposes and recharging and replenishing the aquifer under arid zone conditions. Israel was presented as a case study in waste water utilization. Agricultural irrigation, both restricted and unlimited were discussed as was water recharge.

Tanji, K.K., Deneen, L.D. and Paul, J.L.
1967, "The quality of waters percolating through stratified substrata, as predicted by computer analyses," Hilgardia, Vol. 38, No. 9, pp. 319-347.

This paper presented theoretical consideration and procedures utilized in Fortran computer programs and resulting predictions on quality of waters percolating through three substrata profiles in the arid San Joaquin Valley of California. A study was done on prediction of chemical changes induced by saturating a stratified substrata profile, prediction of quality of the percolating water and changes in chemical properties of the profile. Comprehensive predictions on solute concentrations in the percolate and chemical changes in the substrata profile were presented. Formulations in the computer programs were based on theoretical considerations concerning solubility and dissociation of gypsum and cation exchange.

Drought

The economic aspect of drought and drought indicators are discussed in the following papers. Drought can only be defined in terms of the use to which water is put. Rainfall is the best indicator of drought. If the minimum water need for a period of time is met by rainfall of a given amount of "x", drought may be said to occur whenever the rainfall during that time interval is less than "x". Drought assessment of rainfall using computers for statistical analysis of rainfall data helps to determine drought indices.



Drought Model

Australian and New Zealand Association for the Advancement of Science
1967, "Symposium on drought. ANZAAS Congress, 39th, Melbourne, January 16-20, 1967, Report. Australia, Director of Meteorology, Melbourne. 71 p.

Of the 6 papers, 2 deal with economic aspects, 1 discusses the effects on sheep and cattle, and 1 deals with drought and plants. The 5th, Drought amelioration by W. J. Gibbs defines drought as follows: "if the minimum water need for a given period of time is met by rainfall of a given amount 'x,' drought may be said to occur whenever the rainfall during that time interval is less than 'x,' and the severity of drought linked to the amount by which rainfall falls short of requirement." It discusses rainfall occurrence and decile maps and concludes inter alia that: "Drought can only be defined in terms of the use to which water is put." Rainfall is the best single indicator of drought. It is most unlikely that the whole of the Australian continent will ever be drought-affected at any one time. In the last paper, drought assessment by statistical analysis of rainfall, J. V. Maher discusses briefly the definition of drought and its history in Australia, and the advantages of a statistical approach to drought study, using computers for analysis of rainfall data. Two sections are devoted to the use of the Foley (1957), Palmer (1965), and Body (1966) drought indices, and the work carried out by Gibbs and Maher (1966a,b), using deciles of annual rainfall to relate rainfall deficiencies to drought occurrence in Australia from 1885 tO 1965. Some of the conclusions are: There have been 8 major droughts, of which that from 1895-1903 was the most severe. Computers and long period rainfall records can be used advantageously in the study of drought behavior. Throughout Australia and in other parts of the world there is persistence between monthly rainfalls which accentuates runs of dry conditions once they are established.

Beard, J.S.
1968, "Drought effects in the Gibson Desert," Royal Society of Western Australia, Journal and Proceedings 51(2):39-50. Map.

On a recent expedition through part of the Gibson Desert and adjacent areas it was observed that most of the vegetation had been severly affected by drought during some recent period, with widespread death and dieback. Regeneration had since taken place. Brief details of the principal vegetation types and of the effects of drought are given. The latter are shown not to have been caused by fire and are traced to three years of drought in 1961-1964. It is suggested that infrequent severe droughts cause cyclic death and regeneration in these arid areas, producing more or less even-aged stands. The text includes desciptions of the following land forms: 1) sand dunes, 2) sand plains, 3) mulga, 4) mulga parkland.

Gibbs, W.J., Maher, J.V.
1967, "Rainfall deciles as drought indicators," Australia, Bureau of Meteorology, Bulletin 48. 33 p.

Abnormally low rainfalls in 1964-66 over central Australia and parts of New South Wales and Queensland produced a drought (the worst in 170 years) which quickened interest in research into its causes and

pattern of occurrence. Studies published by the Bureau at regular intervals include a comprehensive drought study by Foley (1957). This Bulletin summarizes Foley's study and presents maps of variability of annual rainfall for the years 1885-1965. The 80 maps of distribution of decile ranges of annual rainfall (1885-1965) are preceded by maps of amounts of annual rainfall exceeded 50 and 90 percent of years and one of annual rainfall which has not been reached in 90 percent of years. The introduction states inter alia that continuous rainfall record commenced in Adelaide in 1839 and that records are available for over 10,000 stations, of which about 7,000 are currently in operation. It is concluded from a brief discussion that drought may be said to occur whenever rainfall is less than the minimum water need for a given period. The severity of drought is linked to the rainfall deficiency. Sixteen pages of text on rainfall occurrence and variability and decile maps include tabulated data and a graph of Albury June rainfall showing the values of the deciles. A 14 page historical review of drought in various parts of Australia is included. Conclusions include the following: the occurrence of the first decile range on the 1885-1965 maps corresponds well with droughts recorded by Foley. It is most unlikely that the whole of the Australian continent will ever be drought affected at any one time.

Heathcote, R.L.

1969, "Drought in Australia: a problem of perception," Geographical Review 59(2): 175-194.

This article defines the drought phenomenon in general and investigates its occurrence in Australia in the periods 1888-1900 and 1958-1965. The investigation contains the following chapters: 1) the identification of drought (definition, measurements, registration); 2) the recognition of drought effects (negative effects, positive effects); 3) the appraisal of drought (attitudes and reactions); and 4) planning for the future.

Pejml, K.

1966, "Studies o kolisani klimatu v historicke dobe na zapadnim pobrezi Jizni Ameriky (Study on climate fluctuations in the historical time of the western coast of South America)," Hydrometeorologicky Ustav, Prague. 82 p.

Butchinski for middle and north Chile, and related to the 1969-1930 period prove that the severest droughts occurred within 1781-1810. Since the beginning of the 19th century, the climate generally became wetter. Fluctuations of climate in the median part of the western regions of South America are caused by extreme shifts of the ITCZ and by changes in magnitude of the Peruvian stream. This has been confirmed by an analysis of cliamte fluctuations occurring on the Galapagos Islands (1st havles of the 16th and 20th centuries). The period extending from 2nd half of 17th century to 1st half 19th century was wetter. This analysis was made from log-books and from meteorological observations. At the beginning of the 16th century the Old Empire (the Incas) lived under a drier climate (stronger

south Pacific anticyclone). It is supposed that, by the time of the Old Empire, shorter frost periods occurred on the Peruvian plains, especially in the Cuzco region. The migration of highly developed civilizations from the Guatemala plateaus to the Yucatan may be attributed to the penetration of cold waves from the North into the Central American plains. Regions ESE of Cochabamba underwent drier periods in the 16th, and perhaps also in the 17th century; more wet ones in the 18th century. A permanent decrease of the Titicaca water level may be supposed, which is clearly traceable as far back as the 2nd half of the 16th century. Conclusions may be drawn as to changes in the temperature regime of the region. Only fluctuations in, not changes of, climate were found. The shipping instructions by Cieze de Leon (1st half of 16th century) for the Panama-Peru route are valid even today.

Subrahmanyam, V.P.

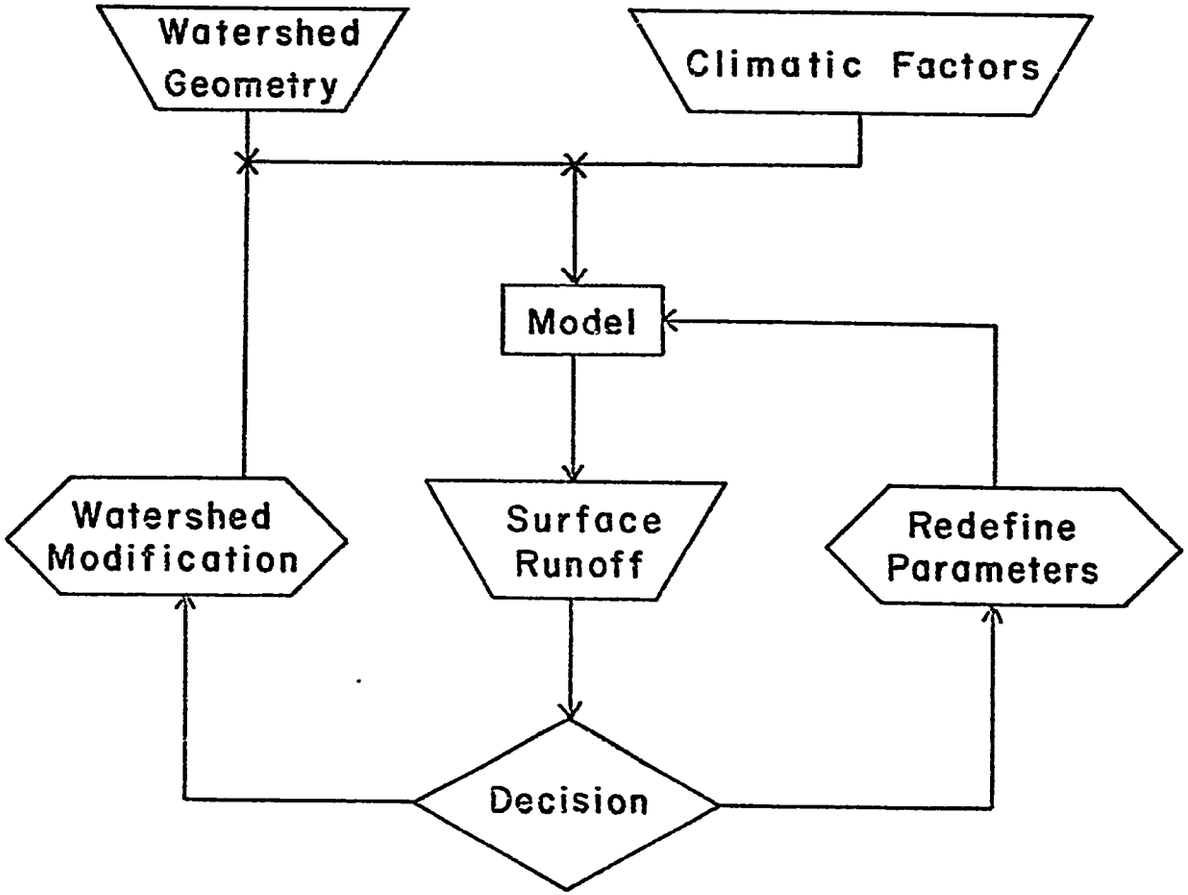
1967, "Incidence and spread of continental drought," International Hydrological Decade, Reports on WMO/IHD Projects 2. 52 p.

Presents the current status of research on the problems associated with droughts in general and of continental drought in particular. Section 1 presents some general ideas about the nature of drought phenomena and interpretation of aridity in the light of climatic classifications. Section 2 deals with definitions of drought adopted by different investigators and the various concepts underlying formulation of such definitions. Evolution and use of indices for the quantitative evaluation of drought magnitude are discussed in Section 3. Criteria employed for the purpose based on different approaches are also presented. Assessment of drought with special reference to their incidence, spread, frequencies of occurrence and persistence, as reported by workers in different parts of the world, is broadly covered in Section 4. Section 5 is devoted to major problems of drought requiring urgent attention. These range from such a common issue as the spelling and pronunciation of the word "drought" to the topic of prediction, the most intriguing aspect of the drought problem.

Surface Runoff

Many attempts have been made to successfully model overland flow. Man's daily routine in many arid regions of the world revolve around water. Hence, a model to successfully reproduce runoff phenomena and watershed is an asset. Several abstracts are devoted to runoff farmina and surface treatment to induce more runoff from a region.

The modeling of surface runoff ideally requires knowing all parameters influencing the phenomena. If rainfall infiltration, depression storage, evapotranspiration are known then surface runoff becomes the residual. Models developed thus far have only been applicable to small one to three acre watersheds. More generalized models such as the one discussed in Appendix A are being used in areas where the extensive data needed for modeling is lacking.



Surface Runoff Model

Bayusheva, M.I.
1966, "Spring slope runoff from the principal agricultural lands of the Kulunda Steppe," Soviet Soil Sci., Vol. 4, pp. 399-405.
An experiment to study the influences of the most commonly used surface cultivation methods on the amount of slope melt runoff was conducted in Northern Kulunda in a zone of inadequate moisture. Data was taken on air temperature, precipitation, determination of soil moisture content in individual plots, the amount of water in the snow and a measurement of melt water runoff from the plots. Variations in the water content in the snow per layer occurred on land plowed without a moldboard and clean fallow plot. The flow of water from the snow and the runoff from the plots took place in expressed daily waves due to the solar type of weather. The amount of surface runoff of melt waters depended greatly on the type of agricultural cultivation of the soil. The melt waters were most intensively intercepted on plots which had been plowed with and without a moldboard across a slope of a fall-plowed field. The highest runoff coefficients were observed with non-shallow-plowed wheat stubble. The results of a field experiment on a study of the slope runoff of melt waters from salinized soils were given.

Carlston, Charles W.
1966, "The effect of climate on drainage density and streamflow," Bull. of the Int. Ass. of Sci. Hydrol., Vol. 11, No. 3, pp. 62-69.
Recharge is dependent upon the amount and distribution of precipitation, less the amount of loss in direct overland runoff and evapotranspiration. Examination of the relation of drainage density to base flow in the 15 basins studied gave evidence that base flow was affected by precipitation or recharge (a climatic variable), while varying inversely with drainage density. As annual precipitation decreased to negligible amounts in passing through the sequence of increasing aridity in Steppe and desert climates. Drainage density was a function of flood runoff intensity whether the magnitude of runoff intensity was due to precipitation intensity or terrene transmissibility. In semi-arid and desert climates of the western and southwestern United States, recharge to the water table occurred only during exceptionally wet and cool winters or along flooded alluvial ephemeral watercourses at times of exceptional storms. These regions were characterized by extremely great variations in flood runoff and drainage density. There were great differences between the barren, angular, fine textured mountain ranges and the broad, smooth and aggrading depositional bolson floors of the intermountain basins.

Cohen, O.P., Evenari, M., and Shanan, L.
1968, "Runoff farming" In the Desert: II. Moisture Use by Young Apricot and Peach Trees - Agron. J., Vol. 60, No. 1, pp. 33-38.
Soil moisture and trunk growth of young apricot and peach trees were measured under flood water spreading conditions in the Negev highlands of Israel. Twenty access tubes for a neutron moisture probe were placed

in four concentric circles around each tree. The moisture measurements were taken to represent the soil moisture in a central cylinder and 3 concentric annuli having soil surface areas of 3.14m^2, 9.42m^2, 15.70m^2, and 10.1m^2, respectively. Rates of moisture depletion and trunk growth were different for each species and did not appear to be related to soil moisture availability. Young apricot trees produced nearly three times the trunk cross sectional area as peach trees per unit of water depletion. Root distribution of the trees was estimated by interpreting the changes in soil moisture.

Drissel, J.C. and Osborn, H.B.
1968, "Variability in rainfall producing runoff from a semiarid rangeland watershed, Alamogordo Creek, New Mexico," J. Hydrol. (Amsterdam), Vol. 6, pp. 194-201.

The study was conducted on the 67 square mile Alamogordo Creek watershed in New Mexico. Rain gage density was approximately one gage for every two square miles. Most winter precipitation occurred as low-intensity rain or snow along slow-moving cold fronts. Summer rains yielded 80% of the annual rainfall and were produced generally by short-duration, high-intensity thunderstorms. Mean annual precipitation for the period (1956-1965) was 11.18 inches, with a standard deviation of 4.92 and median of 10.96 inches. All runoff was produced by summer storms (May through October). Mean annual runoff was 0.37 inches (approximately 20 acre-feet per square mile or 1330 acre-feet), which was 3.3% of the mean annual precipitation. Runoff varied more than rainfall. In 1964 total runoff was only 0.03 inches (107 acre-feet) while in 1960, 2.34 inches (8360 acre-feet) were recorded. About 60% of the total runoff from 1956-1965 was produced in 1960. 93% of the total runoff for the 10 year period occurred during June, July, and August.

Evenari, M., Shanan, L, Tadmor, N.H.
1968, "Runoff farming in the desert. I. Experimental layout," Agron J., Vol. 60, No. 1, pp. 29-32.

An experiment was established to grow fruit trees, field crops, and pasture plants in a 100 mm winter rainfall desert region of Israel by harvesting surface runoff from small desert watersheds. Two ancient farm systems were restored to study the hydrology of the desert catchments and the water harvesting techniques of the ancient farmers. Restoration included rebuilding runoff-collecting hillside conduits, farm terraces, fences, and the distribution systems. Ratios of catchment to cultivated area were 16 to 1 and 25 to 1, respectively. Water stage recorders and weirs were installed to measure the runoff passing onto the farms and rain gauges were placed in the farm catchment area. A meteorological station was set up on one of the farms. The loessial farm soils were sandy and silty loams of aeolian or partly redistributed fluviatile origin, 2.5 to 3 meters deep. During 5 years of research agricultural crops have been subjected to extreme drought conditions and heavy floods.

Hadley, Richard F. and Lusby, Gregg C.
1967, "Runoff and hillslope erosion resulting from a high-intensity thunderstorm near Mack, Western Colorado," Water Resources Research, Vol. 3, No. 1, pp. 139-143.
Measurements of hydrologic and geomorphic processes were possible on a single high intensity convective thunderstorm in Badger Wash Basin, western Colorado on Aug. 12, 1964. The 12-acre basin, fenced to exclude livestock, has a reservoir at the lower end that retains all runoff and sediment. The maximum intensity of rainfall for a 10-minute period was 1.98 inches per hour. The total runoff measured in a reservoir was 0.508 inches over the basin and the total precipitation was 0.90 inches when runoff stopped. Erosion pins along 6 hillslope profiles indicated that approximately 0.11 acre-foot was eroded and 0.090 acre-foot was delivered to the lower end of the basin. Where diverse topography was not a complication, erosion pins were considered to be an accurate measure of soil loss.

Hickok, R.B.
1967, "Water management on semiarid watersheds," 17th Annual Ariz. Watershed Symp. Proc., pp. 9-14.
Research conducted on the 58-square-mile Walnut Gulch Experimental Watershed at Tombstone, Arizona, was used to determine optimum utilization of available water, whether on or off the watershed, and control of flash flood and sediment damage. Basic hydrologic processes involved were studied, including their interrelationships and their reaction to various watershed conditions. This basic information was used for predicting and improving behavior of other semiarid rangeland watersheds throughout the Southwest.

Hillel, D. and Rawitz, E.
1968, "A preliminary field study of surface treatments for runoff inducement in the Negev of Israel," International Congress of Soil Science, 9th, Adelaide, Australia, Transactions 1:303-311.
The possibility of obtaining additional supplies of water by the artificial inducement of runoff can be important in arid regions. Various surface treatments can affect the infiltration rate and stability of the soil and thus determine the quantity and frequency of runoff. Several such treatments were compared in field runoff plots in which the rainfall pattern and runoff rates were monitored during two seasons. These treatments included: mechanical compaction, sodic dispersion, fuel oil, cultivation, aggregation, contorl. An analysis is presented of seasonal runoff potential and of the performance of the various treatments (including total runoff yield, runoff ratio, average infiltration capacity, relation of runoff yield to storm size and total seasonal erosion). The formation of a layer of stable aggregates was found to reduce runoff to practically zero (especially during a drought season), whereas the formation of an artificial crust (e.g. with fuel oil, which had the triple effect of sealing, waterproofing and binding the soil surface) induced runoff in amounts exceeding 80 percent of seasonal rainfall.

Kirkby, M.J. and Chorley, R.J.
1967, "Throughflow, overland flow and erosion," Bulletin Inter. Assoc. Sci. Hydrol. Vol, 12, No. 3, pp. 5-21.
Different mathematical models have been used to the study of water and its behavior in arid regions. With the Horton infiltration approach to surface runoff and erosion, it has become apparent that this overland flow model represents only a specialized end-member of a series of models. The Horton model is most appropriate in aird and semi-arid clay or shale badlands. This model of overland flow is most dominant on unvegetated slopes in arid regions where the thin soil cover is hydrologically similar to the unweathered bedrock. The throughflow model is more appropriate to humid vegetated regions where a generally thick soil cover temporarily stores an appreciable amount of rainfall as soil moisture which plays a significant role in the basin hydrological cycle. Channel initiation or extension was found to take place where overland flow occurs and would take place preferentially in the above locations adjacent to existing channels.

Linsley, Ray K.
1967, "The relation between rainfall and runoff," Jour. of Hydrol. Amsterdam, Vol. 5, No. 4, pp. 297-311.
Three hundred years of research in rainfall and runoff were reviewed. In the late 1660's Perrault's crude experimentation confirmed the causal relationship between rainfall and runoff. Following that time a lengthy period of empiricism caused by inadequate data existed until the correlation era when a discriptive picture of the runoff process and correlations between precipitation and runoff were deveoped. The computer era has demonstrated the possibility of simulating the runoff process on a computer. If proper kinds of hydrologic data are obtained a general simulation model which can reproduce the streamflow hydrograph on any stream gauged or ungauged with accuracy equaling the computer is a possibility. Contains 49 references.

Longenbaugh, Robert A.
1967, "Mathematical simulation of a stream-aquifer system," Proc. Third Annual Amer. Water Resources Confer., Amer. Water Res. Assoc., Martha N. Francisco, Editor, pp. 74-83.
A generalized digital computer program was developed to simulate the conjuctive use of surface and groundwater of a 25 mile reach of the Arkansas River Valley between La Junta and Las Animas, Colorado. Water table fluctuations in the aquifer and water exchange between the aquifer and river were studied with time. Water applied within the area as irrigation; recharge due to precipitation; withdrawals from the aquifer by pumps and phreatophytes; and the geologic parameters of permeability, storage coefficient, bedrock elevation, and initial amount of water in storage were the variables considered in the model. The modeling of groundwater systems with digital computers provides flexibility, rapid analyses, and an economical approach. Use of digital computer models in making administrative decisions and for optimization of the water resources is expected.

Myers, Lloyd E.
1967, "Recent advances in water harvesting," J. Soil Water Conserv., Vol. 22, No. 3, pp. 95-97.
Water harvesting, the practice of collecting water from an area treated to increase runoff from rainfall and snowmelt, has been utilized in many countries and for a length of time. In the US, however, the expense of building such facilities has prevented use. Increased water needs will undoubtedly lead to increased water harvesting. Four low-cost methods are described. The first, sprayed asphalt catchments, showed considerable promise. They collected nearly 100% runoff precipitation, were strong and durable, and were low cost; however, they gave off oxidation products in regions of high solar radiation and low precipitation. The second, plastic sheeting catchments, were low cost but were not durable unless a protective layer of gravel was used. This decreased the percentage of collection. The third, sodium-treated catchments, was very low cost and may yield more than 70% runoff but created an erosion problem. The last is soil treated with water repellants, the most promising of which is sodium methyl silanolate. Although much research remains, current work has shown costs can be reduced initially to 10¢ per sq. yd. with an annual maintenance of 2¢ per sq. yd.

Rose, D.A.
1968, "Water movement in dry soils. I. Physical factors affecting sorption of water by dry soil," J. of Soil Sci., Vol. 19, No. 1, pp. 81-93.
The paper considered effects of various soil physical conditions on uptake of water from a moist atmosphere by a soil sufficiently dry that both liquid and vapor components of flow may be important. Water extraction by growing plants will dry soil in the root zone to c pF 4.2 and natural evaporation can dry surface layers to c pF 6 or even drier in arid regions. Theoretical aspects of water movement in dry soils were explained using 5 equations. Sorption took place in soil columns that were in a turbulent atmosphere at constant temperature and relative humidity. Diffusivity rose to a maximum and then fell as water content increased. Effects of environment and management were studied in the areas of temperature, pressure, porosity, organic manure, aggregate size, still atmosphere, mulching, salinity, evaporation suppressents, ignition and degradation of structure. In the dry soils tested, water movement was a mixture of liquid and vapor transfer andthe relative importance of the two modes of flow varied from soil to soil. The data showed the effect of pre-treatment on diffusity and sopptivity but there was no experience yet to indicate what changes might have agricultural significance.

Schreiber, H.A. and Kincaid, D.R.
1967, "Regression models for predicting on-site runoff from short-duration convective storms," Water Resources Res., Vol. 3, No. 2, pp. 389-395.
On-site runoff resulting from summer convective thunderstorms was studied in the Walnut Gulch Experimental Watershed, Tombstone, Ariz., using twelve 6 by 12 foot plots at two locations, based on five location-years of data from 34 storms, Average runoff increased as

precipitation quantity increased, decreased as crown spread of vegetation increased, and decreased as antecedent soil moisture increased. In a stepwise multiple linear regression equation, these independent variables accounted for 72, 3, and 0.5 percent of the prediction variance respectively. For any one location-year storm amount or intensity was always significant, crown spread was usually significant, and soil moisture was rarely significant. Soil moisture was never related significantly to runoff in simple correlations. Prediction equations of runoff were developed using total precipitation and storm intensity as independent variables. Crown spread of vegetation improved runoff prediction only 3 percent over the 72 percent that was obtained for total precipitation alone.

Thompson, J.R.

1968, "Effect of grazing on infiltration in a western watershed," J. of Soil and Water Conserv., Vol. 23, No. 2, pp. 63-65.

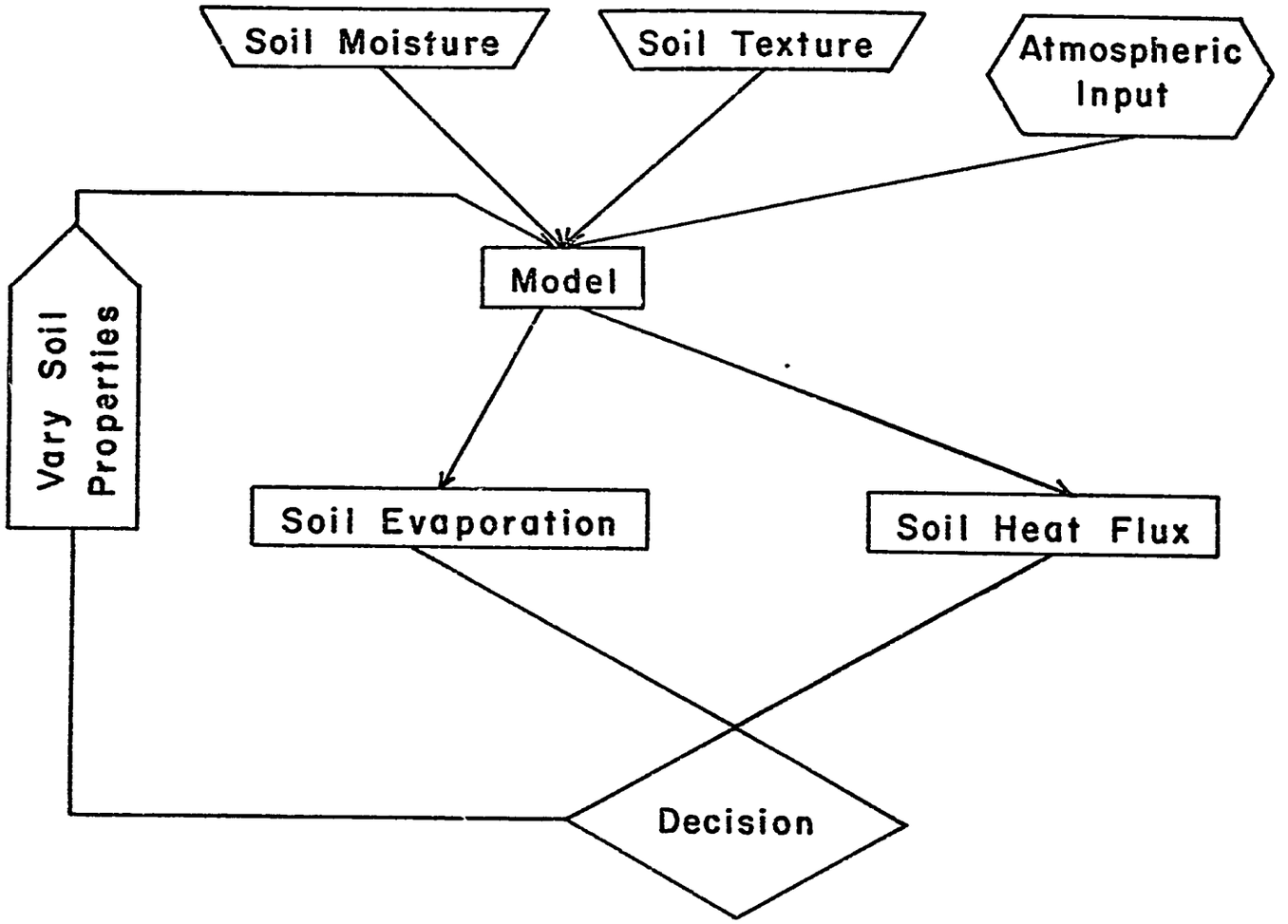
Twelve infiltrometer plots, stratified by major soil types, were located in each of 8 watersheds to test the effects of livestock exclusion and erosion of Badger Wash in western Colorado. The 4 soil types were derived from shale, sandstone, a mixture of shale and sandstone, and alluvium. Artificial rainfall was applied to 2.5-square-foot plots at the rates of 5 inches per hour. Runoff from the plots and amount and intensity of applied rainfall were measured with the Rocky Mountain infiltrometer. Average infiltration rates for dry soils were lower in 1963 than in 1953-1954 or 1958 on both grazed and ungrazed plots. In 1963 infiltration declined to a point lower than the pretreatment level for both grazed and ungrazed plots. In 1963 an apparently consistent increase in erosion accompanied the decrease infiltration. Penetrometer measurements and bulk density values indicated a slight improvement in surface soil conditions between 1958 and 1963 without respect to grazing treatment. Ground cover on grazed watersheds decreased significantly from 29% in 1953 to 20% in 1963. A possible explanation of decreases is discussed.

Soils

Desert soil covers an extensive portion of the globe, thus the characteristics of soils from a soil moisture point of view have been given close scrutiny in most arid or semi-arid regions.

Numerous studies have been made on the seasonal moisture patterns as related to a plants transpiration characteristics. The effects that thermal gradients have upon moisture movement is significant. Water loss from soils is dependent on thermal gradients and soil temperatures. Many attempts have been made to alter evaporation by reducing the water vapor transfer coefficient between the moist soil and the atmosphere or insulating the soil from the energy supply.

A geographical appraisal of arid lands is also needed. Soil properties, salinity, permability, depth and texture must be integrated with engineering and agricultural factors to yield an estimate of the real value of arid land.


Soil Moisture
Soil Texture
Atmospheric Input
Model
Vary Soil Properties
Soil Evaporation
Soil Heat Flux
Decision

Soil Model

Berend, J.E. and Kary, S.
1968, "Factors determining the hydrologic conductivity of red mediterranean soils and derived types," Inter. Congress of Soil Sci., Vol. 1, pp. 273-282.
This article reports a study of hydraulic characteristics on Israel's northern coastal plain. Although annual rainfall is 450-500 mm, the evaporation potential is approximately 1.1 m per year. Aims of the study were to locate perruous soils suitable for water spreading and imperruous soils suitable for water storage.

Bouyoucos, G.J. and Cook, R.L.
1967, "Measuring the relative humidity of soils at different moisture contents by the gray hydrocal hygrometer," Soil Sci. 104(4):297-305.
Experimental results show that the relationship between relative humidity and the amount of water the sensor adsorbs, as measured by its electrical resistance, is remarkably accurate, sensitive, and consistent. This is true even at the highest relative humidity. The sensor is highly sensitive to humidity changes.

Cary, J.W.
1967, "The drying of soil: thermal regimes and ambient pressures," Agr. Meteorol., 4(5):353-365.
Importance of evaporation from soil can hardly be over-emphasized when one considers the vast arid regions on earth. An insulated lucite cylinder 18 cm in diameter and 75 cm deep was used to hold a Columbia loam soil sample. 9 experimental treatments using continuous heating, continuous cooling, alternating temperature patterns, and various ambient pressures in all combinations were tested. The theory of water vapor contributing to evaporation is examined using equations. Thermal gradients will produce significant fluxes of water vapor in a moist soil profile which is subjected to natural diurnal temperature changes. Water loss from soils is dependent on these thermal gradients and soil temperatures. Transfer of water vapor upward through the dry layer to the soil surface is not strictly a molecular diffusion process. Loss of soil moisture may be reduced by reducing the transfer coefficient of water vapor between the moist soil and the atmosphere. Another way is to insulate soil from the energy supply of the atmosphere. The drying of soil is basically a heat-flow problem with some parameters affecting heat-flow controlled by the simultaneous transport of soil moisture.

Chatterji, U.N. and Mukherjee, Achala (nee' Chatterjee)
1968, "Effect of high temperatures on moisture depletion, imbibition and germination of seeds of Mimosa Hamata Willd," Ann. of Arid Zone, Vol. 7, No. 1, pp. 93-99.
Seeds of Mimosa hamata were subjected to temperatures of 70, 90, and 100 deg C for 24, 48, 96, and 144 hours to study what effect exposing seeds to high temperature would have on germination. The seeds which had a higher depletion of moisture germinated poorly in comparison to those seeds which lost a lesser amount of moisture. The treatment

of 70 deg C for 144 hours gave the highest percentage of germination. There was a direct correlation between the rate of imbibition and the degree and duration of the temperature of the viability of the embryo, and might be a physical process related to the colloidal particles found in the cells composing the seed. Radicle growth was found to be stunted by exposure to high temperatures. There was no significant difference in the behavior of large and small seeds with regard to their capacities for imbibition and germination as a result of their exposure to dry heat treatment.

De Felice, P.
1968, "Etude des echanges de chaleur entre l'air et le sol sur deux sols se nature differente (Study of heat exchange between atmosphere and soil over two different soils)," Archiv fur Meteorologie, Geophysik und Bioklimatologie, ser. B 16(1):70-80.
Soil temperature at 2 depths, surface, and air temperature near the ground in sand dunes of the Great Western Erg and in the hamadas, near the oasis of Beni-Abbes (Algeria) was measured. From these results thermal diffusivity coefficients for these 2 soils was deduced. Knowing incident, reflected, diffuse, and emitted radiation of the ground, the energy exchange between air and ground surface through convection and conduction could be computed. It was found that these energies vary with the nature of the soil and with time, and it is concluded that a breeze appears between dunes and hamada, quite similar to the sea breeze.

England, C.B. and Onstad, C.A.
1968, "Isolation and characterization of hydrologic response units within agricultural watersheds," Water Resources Research, Vol. 4, No. 1, pp. 73-77.
To extrapolate hydrologic relations from small to large areas, a watershed can be partitioned by isolation of units of relative homogeneity with respect to soil type, land form and land use that fall into a sequence compatible with the hydraulics of overland and subsurface flows. Size and distribution of hydrologic response units of different characteristics within a watershed may profoundly affect the areal- and time-distribution of potential over the area. Partitioning the hypsometric curve on the basis of soil group distribution may offer some clues as to the differences in hydrologic behavior of different sized watersheds within a given area. The methods discussed in the paper can be applied to arid watersheds to determine their hydrologic response performance.

Eyre, S.R.
1968, "Vegetation and soils, a world picture," 2nd ed. Aldine Publishing Co., Chicago. 328 p.
Originally published in 1963, this book is an introduction to the study of worldwide vegetation patterns, their development, and relationships to soil types. It is divided into four parts: Part I is devoted to the evolution of plant communities and soil profiles; part 2 covers areas

outside the tropics which include coniferous forest regions, mixed and broad-leaved forests of the middle latitudes, alpine and arctic tundras, grasslands, and woodlands and scrublands; part 3 discusses the British Isles; part 4 considers tropical regions with chapters on rain forests, seasonal tropical forests, semi-desert and desert areas, the savanna, and mountain areas. An extensive bibliography and continental vegetation maps are included.

Fisser, Herbert G.
1968, "Soil moisture and temperature changes following sagebrush control," J. Range Manage., 21(5):283-287.
A study was conducted in western Wyoming to evaluate soil moisture, soil temperature and herbage production changes following chemical control and non-grazing treatments of big sagebrush. Two sites, one a mesic grassland and the other an arid shrub type were studied. Soil moisture recharge during the spring period at the mesic site was much greater under the non-use treatment than in the grazed area. Soil moisture withdrawal was similar at both the arid and mesic sites. Variation of seasonal moisture levels combined for all depths and years showed a much greater variation at the mesic site than at the arid site. At the mesic site, grasses utilized almost all available moisture in the upper two feet of the soil. That which was not utilized moved downward to accumulate in the 36-60 inch zone from which sagebrush draws its major water supply.

Hanks, R.J., Gardner, H.R. and Fairbourn, M.L.
1967, "Evaporation of water from soils as influenced by drying with wind or radiation," Soil Science Soc. of Amer., Proc. 30(4):593-598.
The evaporation rate from 3 soils initially wet was made the same by adjusting the wind and radiation intensity. The wind treatment caused a temperature depression at the soil surface initially which nearly disappeared after about 5 days. The radiation treatment caused a temperature increase at the soil surface which increased with time. Soil water content profiles measured as a function of time showed the water content near the soil surface to be higher for the wind treatment than for the radiation treatment. The components of flow due to temperature and suction gradients for both liquid and vapor flow were estimated using the analysis of Philip and De Vries. This analysis indicated the cumulative downward vapor flow due to temperature gradients amounted to about 10 percent of the net upward flow in 40 days at the 5-centimeter depth for one soil for the radiation treatment. Computations of evaporation assuming isothermal conditions for soils initially wet to near saturation would probably estimate total evaporation within 10 percent, and probably be sufficiently accurate for many purposes.

Hearn, A.B., Rijks, D.A. and Wilcox, D.E.
1966, "Reclamation of ancient agricultural soils in Wahidi, South Arabia," Exp. Agr., 2(4):270-286.
The rehabilitation and utilization of ancient silty soils has been attempted by growing cotton as the rain-cash crop under irrigation from wells. Growth in the early years was poor and crop failures were frequent. A heavier pre-planting irrigation was proposed to overcome the physical impedance to drainage. Data indicated that heavy pre-planting irrigation was necessary to avoid poor growth. The extra water applied was available for growth later in the season, permitting subsequent irrigation to be reduced without loss of yield. The timing and quantity of the first irrigation after planting was important.

Hyam, G.F.S.
1968, "Soil moisture and food production," South African J. Sci., Vol. 64, No. 1, pp. 13-19.
Some of the benefits which accrue if fuller use is made of available soil moisture have been shown in South Africa. Land benefiting from irrigation comprises only 1 million morgen (a unit of land measurement equal to 2.116 acres) of a 143 million morgen total land area. Therefore emphasis is placed on utilizing drier lands which comprise 11 million moregen to their full potential. Factors considered are water requirements of plants, control of water used by weeds, moisture distribution in soil and methods to increase moisture content, seedbed preparation methods avoiding unnecessary evaporation and erosion, time of planting and root development. Increased management of the veld is recommended to slow down runoff rate and increase degree of water penetration through fertilization and increased vegetation.

Jewitt, T.N.
1966, "Soils of arid lands," In E.S. Hills, ed., Arid lands: a geographical appraisal. p. 103-125. Methuen, London.
Those arid soils are discussed in which soluble products of weathering are accumulated within the upper part of the profile as CaCO sub 3 and soluble salts. Much of the interest in desert soils is directed to: 1) the assessment of their value under irrigation, and 2) the best methods of irrigation and cultivation. Accordingly, an outline of processes of general soil genesis and a discussion of soil genesis in arid regions are followed by a narrative treatment of salinity and alkalinity, reclamation of saline soils, fertility of desert soils, and drainage of irrigated soils. It is concluded that soil properties, salinity, permeability, depth, and texture must be integrated with engineering and agricultural factors to yield an estimate of the real value of the land for irrigation.

Kovda, V.A., Lobova, E.V.
1965, "Geografiya i Klassifikatsiya Pochv Azii (Geography and classification of soils of Asia)," Moscow. 260 p. Translated 1968, by A. Gourevitch.
The collection aims to present a general idea of soils of those countries of Asia which have not been much studied in the past, and also to bring before a large scientific audience certain very recent and practical data pertaining to the theory of soil formation. The first part of the collection includes papers on soils of the arid zone. Desert soils cover an extensive territory, stretching east and west, between the Caspian Sea and the mouth of the Yellow River. It has been possible to suggest a classification of desert soils, subdivided into types, genera, species; this classification is closely related to the character of vegetation and agricultural utilization of the soils. Mountain massifs cover tremendous areas in Asia, and certain mountain soils are already being utilized selectively; the problem of classifying the mountain soils has thus become particularly urgent. Soils of Asian countries outside the USSR are described in the papers on Iran, Afghanistan, and Syria.

Rose, G. W., Stern, W.R., Drummond, J.E.
1965, "Determination of Hydraulic Conductivity as a Function of Depth and Water Content for Soil in Situ," Australian J. Soil Res., Vol. 3, No. 1, pp. 1-9.
The paper shows how hydraulic conductivity may be determined in the field over the entire range of water contents on a soil of non-uniform profile. A theory is presented to calculate hydraulic conductivity as a function of depth and successive measurements of water content profiles for soils in situ. With unsaturated soil, potential gradients are inferred using moisture characteristics. With saturated soil potential gradients must be measured directly. Correction due to the overburden effect should be checked whenever in situ soil water suction is inferred from water content via soil moisture characteristics. A possible limitation to the method, particularly if radiation is intense such as in arid climate, might be the effect of daily temperature waves on water redistribution in either liquid or vapor phase. This effect will usually be restricted to the top 20 cm. of the soil profile.

Radwanski, S.A.
1968, "Field observations of some physical properties in alluvial soils of arid and semi-arid regions," Soil Science 106 (4): 314-316.
Alluvial soils may become sealed or water tight from alignment of mica flakes, from the growth of certain salts, from compaction by wind of silt and fine sand, and from water deposited or aquamorphic layers laid down during monsoon seasons.

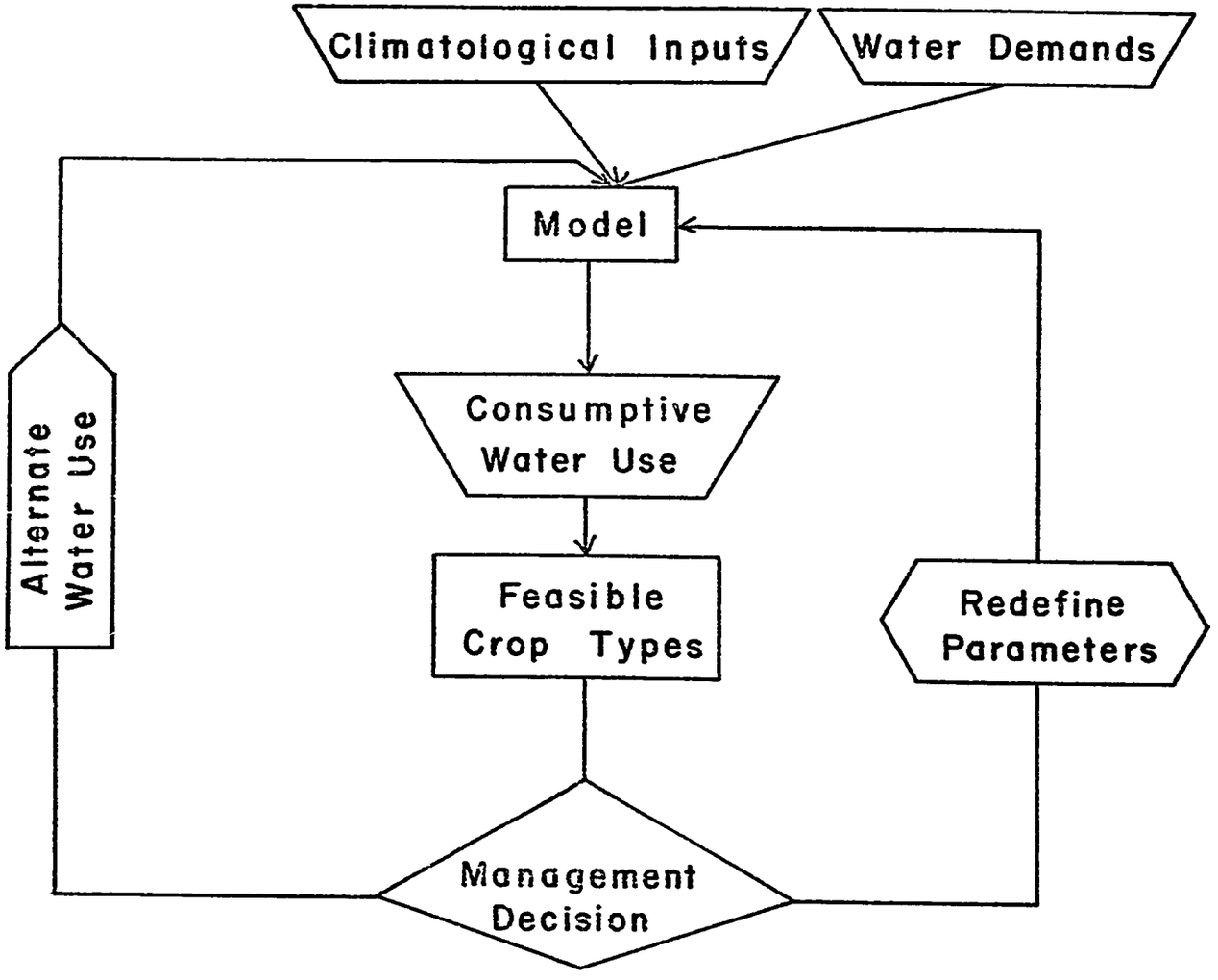
Rickard, W.H.
1967, "Seasonal soil moisture patterns in adjacent greasewood and sagebrush stands," Ecology 48(6): 1034-1038.
Soil moisture measurements were made over a 2-year period in adjacent greasewood (Sarcobatus vermiculatus) and sagebrush (Artemisia tridentata) stands in the desert steppe region of southeastern Washington. Soil moisture accumulated during fall and winter. The greater accumulation of moisture in the upper 4 decimeters of the greasewood stand appeared to be the result of decreased evaporation losses and the lack of transpiration from shrub species which are leafless during winter and early spring. The more luxuriant growth of cheatgrass in the greasewood stand was related to winter and spring retention of soil moisture.

Rylov, S.P.
1967, "Ob uvlazhnenii malykh vodosborov v stepnoi i polupustynnoi zonakh Severhoge i Zapadnogo Kazakhstana (Soil moisture of small catchments in the steppe and semi-desert zones of northern and western Kazakhstan)," Nauchno-Issledovatel Alma-Ata, Kazakhstan, Trudy 26-30-232.
Discusses the distribution of soil moisture (SM) on the areas of small catchments of the west Kazakhstandand Novorybinsk runoff stations, seasonal and long term change. water balance of SM in the fall, and characteristics of fall wetting in north and west Kazakhstan. Following are some of the conclusions drawn from the data and results of analysis presented in tables, graphs, and in a soil moisture chart. A high accuracy (2-5 percent) in determining average SM on catchments up to 6 square kilometers can be obtained with 20-30 sampling points. Soil moisture sampling traverses across the middle of the catchment are most representative. The close relationship between moisture content of various layers makes it possible to obtain total SM of deeper layers from that of the upper layers. SM in the 1 meter layer at the end of summer is 30 to 50 percent of field capacity (FC) which is 1/2 to 1/3 of that in the spring (80-120 percent of FC); at the end of the fall it is 25-50 percent higher than in the summer and remains practically constant (at 50-70 percent of FC) until the beginning of snow melting. September-October precipitation can be used as an indirect index of fall soil moisture.

Stace, H.C.T.
1968, "A handbook of Australian Soils." Rellim Technical P-blications, Glenside, South Australia. 434 p.
Contents: Soils showing no profile development, showing minimal profile development, mildly leached dark soils, mildly leached brown soils, soils with profile dominatedby sesquioxides, mildly to strongly leached, highly differentiated soils, organic soils, gilgar phenomenon.

Irrigation Development

Development of an irrigation system in an underdeveloped arid region often must depend on limited data. The Blaney-Criddle method estimates consumptive use and irrigation requirements for areas where few or no data exist, except for limited climatological data. The method can be used to determine the consumptive use for planning water developments in arid climates. Irrigation of the dry areas of the earth may not solve all food production problems, but because of more pleasant living conditions, these dry areas will be more heavily populated.



Irrigation Development Model

Blaney, Harry F., Sr., Griddle, Wayne D.
1966, "Determining Consumptive Use for Planning Water Developments," Irrig. Drainage Speciality Conference, American Society of Civil Engs., Las Vegas, Nevada, up 1-34, November 2-4,
The purpose of this paper was to describe the Blaney-Griddle (B-C) method for estimating consumptive use and irrigation requirements for areas where few or no data, except limited climatological data, are available. Many terms used in the report are defined. The procedure was to correlate existing consumptive use data for difference crops with monthly temperature, percent of daytime hours, precipitation, frost-free (growing) period, or irrigation season. The coefficients developed were used to transpose the consumptive-use data for a given area to other areas for which only climatological data were available. The method was found to be satisfactory for computing use where measured water use data were not available. The described method can be used to determine the consumptive use for planning water developments in arid climates.

Hoare, E.R.
1967, "Irrigation in Semi-Arid Regions," Outlook on Agr., 5(4):139-143.
Semi-arid lands having less than 15 inches rainfall and evaporation from a surface of more than 45 inches are considered. Comparisons are made between arid and humid areas, water as a food producer, sources of water from the land and seas, amounts of water needed for various agricultural commodities and human needs. The ability of different countries to supply its peoples with food in respect to the supply of water are discussed. Irrigation of the dry areas of the earth will not necessarily solve the gigantic food production problems which face the world, but because of pleasant living conditions, these dry areas will be more heavily populated in the future. Includes map of arid and semi-arid areas and tables showing water requirement for agricultural products and human needs.

Israel Ministry of Agriculture, Water Commission, Hydrological Service.
1968, "Hydrological year-book of Israel, 1965-1966," Israel Ministry of Agriculture, Water Commission, Hydrological Service, Jerusalem. 121 p.
This volume, 20th in the series, contains the hydrological and chemical data for gaging stations of rivers, wadis, main springs, and lakes for October 1, 1965-September 30, 1966. Ground water data are summarized on a map providing water levels and salinity contours in the aquifers of the coastal plain and foothills. Rainfall was below the 1931-60 average in all parts of the country varying on the average from 45 to 80--80 percent to 100 percent in eastern and western drainage areas. During the period, the intensity and number of floods was on the low side; the total storm water runoff was only slightly above the volume of flow recorded in 1950/51. Data, symbols, and methods used are explained.

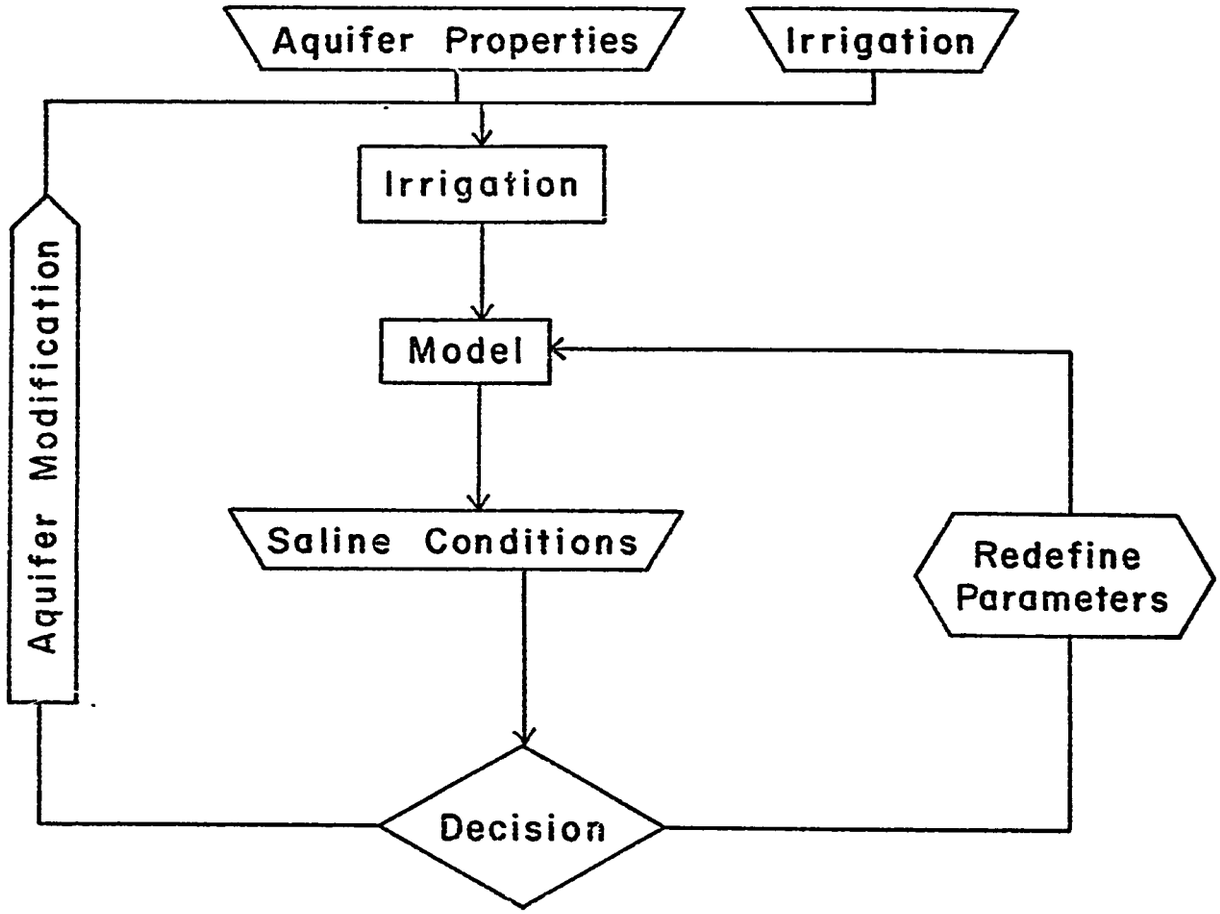
Maxey, G.B.
1968, "Hydrogeology of desert basins," Ground water 6(5): 10-22. In the Great Basin two general categories of ground-water flow systems are recognized: (1) local flow systems where drainage areas are small, flow paths are relatively short, interbasin flow is uncommon, springs have large variations in discharge, and water temperature and Na, K, Cl, and SO sub 4, concentrations are low, and (2) regional flow systems, wehre drainage areas are large, flow paths long, interbasin flow common, springs have large discharge, and water is usually higher in temperature and K, Na, Cl, and SO sub 4 concentrations. Hydrologic approaches used, inaaddition to conventional methods, include hydrologic budget, water potential, and water-chemistry studies. Although detailed delineation of most flow systems in Nevada has not been accomplished, integration of hydrologic, geologic, and chemical methods allow approximate portrayal of many systems, both local and regional.

Mishari, H.E.H.
1968, "Towards full water utilization in Saudi Arabia," In Water for Peace. 2:832-841. International Conference on Water for Peace, Washington, D.C.
Ground water, aquifer distribution-characteristics.

Morris, A.S.
1969, "The development of the irrigation economy of Mendoza, Argentina," American Association of Geographers, Annals 59(1):97-115.
The agricultural pattern of Mendoza, Argentina, has two main elements, an early-developed region of vineyards around Mendoza city, and a region to the west, south, and east with more crop diversity and modern technology. Four principal factors contribute to the difference between these two, 1) climate; 2) the chronology of agricultural settlement; 3) land tenure; and 4) the manner of water provision. The Mendoza city region is associated with higher temperatures and longer growing season than the peripheral region, with earlier development of irrigated land, with backward forms of land tenure, and with only limited use of well water to aid river supplies. Both land tenure and water provision are changing factors with considerable impact on the rate of agricultural development. The probable qualitative effect of two further changes in water supply, high dams, and new water control legislation, is comparable to that of well use. By contrast, canal lining and river diversion are primarily quantitative additions with little developmental effect.

Salt Accumulation

Salinity is a problem in many arid regions of the world. It is caused by irrigating with saline water or a saline water table near the surface. A model for tracing salt distribution in the soil profile in response to varying irrigation conditions would be an invaluable tool. Large-scale reclamation of arid regions could cause drastic changes in the chemical and physical properties of some soils. Detection of the saline areas and of the degree of salinity in the rooting profile is of considerable interest. Indicator plants show a response to saline conditions that can be detected using infrared techniques. This method would provide a rapid survey technique of saline land, and when coupled with computer mapping programming, would give three dimensional maps of the saline levels in the soil.



Salt Movement Model

Birkhead, Guthrie S.
1967, "Water in West Pakistan," Water Resources Res., 3(2): 307-318.
The article describes several of the salient problems of water and the administration of water programs in West Pakistan with emphasis on the West Pakistan Water and Power Development Authority and the Indus Basin Plan. In the early 1960's, it was estimated that about 100,000 acres of land per year in the Basin were being removed from cultivation due to poor cultural practices and drainage facilities. In 1960, the Indue Water Treaty was signed which provided for dams and canals to distribute water in the Indus Basin. Pakistan's agent to oversee the construction of these projects was the West Pakistan Water and Power Development Authority.

Boyko, Hugo.
"Salt-Water Agriculture," Sci. Amer., 216(3): 89-96.
Irrigation with salt water holds some promise of turning sandy soils of many arid lands into productive areas. Principles of salt water irrigation figured in the success of the Desert Garden of Eilat in the Negev Desert in 1949 where some 180 species of non-halophytic plants were grown. Tolerance experiments followed with four types of seawater: Caspian, North Sea, Red Sea or Mediterranean, and an oceanic concentration containing between a 3 and 4% total of dissolved solids. Ten species of plants were used. Four survived oceanic type irrigation and six survived the Caspian Sea type. The principles working in such experiments with salt water and sandy soils included the following: Salt did not accumulate in a well percolated soil thus rinsing through sodium chloride and leaving well aerated roots. Newer principles included partial root contact, subterranean dew, viscosity principle, and ionic balance between the living system and salt water.

Branson, F.A., Miller, R.F., McQueen, I.S.,
1967. "Geographic Distribution and Factors Affecting the Distribution of Salt Desert Shrubs in the United States." J. of Range Management, 20:287-296.
The origin of salt desert shrub vegetation was given. Four published classifications of intermountain shrub vegetation and a new classification based on maximum salt tolerances and water relationships were presented. The distribution of salt desert shrub communities together with the geographic distributuion of salt desert shrub species and some causative factors for the presence of salt desert shrub communities were given. Soil-moisture relationships were the primary cause of the different plant communities. Quantities of soil salts appeared to be important as a cause of community differences.

Bresler, Eshel.
1967, "A Model for Tracing Salt Distribution in the Soil Profile and Estimating the Efficient Combination of Water Quality and Quantity Under Various Field Conditions," Soil Sci., 104(4): 227-230.
Methods used for equating salt concentration in soils were limited by assumptions of steady-state conditions. In the present study a model is presented, based on the law of mass conservation, for tracing the

distribution of a nonabsorbed ion in the soil profile in response to varying irrigation conditions in Israel. Parameters included soil-water characteristics, initial salinity, moisture use in each soil layer and quantity and quality of water applied at each irrigation. Data from three irrigation experiments were compared to values calculated according to the model. The model was applied using linear programming techniques for evaluation of efficient combinations of quality and quantity of irrigation water according to the desired salinity distribution.

Dixey, F.
1967. "Water supply use to management". Arid Lands. p. 77-102. Methuen, London.
This general discourse on streamflow and ground water in arid and semiarid lands contained some interesting information. A general discussion of what is well known about salinity in arid regions and about tolerance of plants, animals, and man to salinity is given in the last section.

el Abedine, A. Zein, Fathi, A., Abbas, R.
1967. "A preliminary investigation on the main factors affecting soil salinity and aklalinity in Kafr El Shaikh governorate, U.A.R," J. Soil Sci. United Arab Republic, 7(1): 33-43.
The soil salinity of the perennially irrigated soils of the arid regions of the upper Nile Delta and the Valley was mainly due to high and salty groundwater. The main source of this high groundwater level was the Nile River and its distribution canals. Surface soil samples and underground water samples were analyzed for electrical conductivity, exchangeable sodium percentage, organic matter, calcium carbonate, pH and clay content. The factors of high groundwater level, high groundwater salinity, soil relief, the heavy texture of the soil and restricted drainage all contributed to the problem of soil salinity and alkalinity in the area under study.

Gupta, I. C., Abichandani, C.T.
1967. "Seas nal variations in the composition of some saline irrigation waters of western Rajasthan," Annals of Arid Zone 6(2): 108-116.
Saline ground waters from 7 sites in Jodhpur and Pali districts of western Rajasthan were examined for seasonal variations in salt composition. Salinity varied from 2316 to 10,160 micromhos EC/centimeters during rabi season of wheat cultivation. Recharge of waters in the wells was prominent after the start of monsoon and sites with recharge source nearby showed more seasonal fluctuations in salinity levels than sites with recharge source further away. The waters were predominantly Cl-SO sub 4-Na-Mg type, except at Surayata, where the water was Cl-SO sub 4-Mg-Na type. After the monsoon, sites with recharge sources nearby tended to be Cl-HCO sub 3-Na-Mg type and this change was accompanied by sharp drop in the SAR (sodium absorption ratio) value.

Hills, E.S.
1966. "Research and the future of arid lands," In E.S. Hills, ed., Arid lands: a geographical appraisal. p. 439-461. Methuen, London.
Describes the work being done and the schemes being proposed which relate directly or indirectly to the "arid zone" problems. Rain making and proposals for melting the Arctic Sea ice are mentioned in this recapitulation of work on water desalination, solar and wind power, etc.

Hodges, C.N., Hodge, C.O.
1969. "Power, water and food for desert coasts: an integrated system for providing them," American Society for Horticultural Science, 66th annual meeting, Pullman, Washington, August 20-22, 1969, paper presented.16 p.
Of the world's 20,000 miles of arid coastline, a large percentage remains bereft of cultivation. Considerable portions of these sparse areas could be made productive if the basic amenities of life were present. On this premise, investigations were started in November 1966 on possible designs for an economical package for power-water-food production in such locations. An integrated, closed-environment system has been devised. Waste heat from engine-driven electric generator sets is used to desalt seawater. This fresh water, in turn, is utilized for the irrigation of vegetables planted within greenhouses of air-inflated plastic. High-quality vegetables have been growth in a pilot facility on the Gulf of California while planning has begun for the first large-scale installation, in the Arabian Peninsula Shaikdom of Abu Dhabi. The concept is believed to be wi ely applicable.

Hughes, Eugene E.
1967. "Influence of environment on shoot growth and total carbohydate reserves of saltcedar," Weeds, 15(1): 46-49.
A three year study (1962-1964) on saltcedar (Tamarix pertandra Pall.) was conducted on the Rio Grande floodplain near Bernardo, New Mexico, to relate carbohydrate levels to plant shoot growth and environmental conditions, thereby estimating the most susceptible stage of growth for applicaton of herbicides. Environmental variables included air and soil temperatures, humidity, wind, barometric pressure, solar radiation, depth to water table, water quality and evaporation from a free water surface. Total shoot length was the best estimate of carbohydrate level in storage organs of saltcedar. With the variables used, none were reliable in indicating the level of minimum carbohydrate variation in growth rate and total carbohydrate storage in roots and stems. These were probably a reflection of a variation in growth.

Meyers, Victor I., Carter, David L., Rippert, William J.
1966. "Remote sensing for estimating soil salinity," J. Irrig and Drain Div. ASCE. 92(IR4): 59-68.
Many soils in arid areas of the world are affected by high water tables and resultant soil salinity. Detection of the saline areas and of the degree of salinity in the rooting profile is of considerable interest to agricultural workers involved in reclamation of these soils. Cotton was used as an indicator plant to relate the

the salinity in the 0 to 5 ft. profile at some reference locations to that at a number of predicition sites where the salinity was unknown. Aerial photographs were taken using ektachrome infra red aero film for observing the salinity-affected cotton. On the basis of color tones it was possible to distinguish five levels of salinity. Infra red radiometer measurements of cotton leaf temperatures were make on the ground and from an airplan . Statistical studies of the temperature data taken on the ground indicated that soil salinity could be predicted from cotton leaf temperatures with reasonable accuracy.

Prokopovich, N.P.
1969. "Some geologic problems in reclamation of arid lands. U.S. Bureau of Reclamation, Sacramento. 52 p.
The large-scale reclamation of arid regions may involve importation of waters which are geochemically strange. This could cause drastic changes in the chemical and physical properties of some fine-grained unconsolidated deposits. Leaching of saline clays, or an increase of their salt content due to migration of salts and associated ion exchange reactions, flocculation and deflocculation could modify the engineering properties, particularly plasticity and permeability of clayey soils. Surface application of water and/or overdraft of ground water may cause land subsidence. This paper discusses the general character of some of these processes and the need for their recognition and analysis by geologists prior to reclamation. Some modifications of standard laboratory tests, for example treatment of arid materials with 'project waters' prior to the testing,could be particularly useful in planning developments in desert environments.

Parsons, Co., Ralph M., Los Angeles.
1968. "Water import systems for arid land development," International Symposium About Increasing of Food Production in Arid Lands, Instituto Technologico de Estudios Superiores Monterrey, Monterrey, Nuevo Leon, Mexico.
The North American Water and Power Alliance is thoroughly discussed in this article. The NAWAPA concept geographical and climatological features of the North American Continent to collect and store excess water of northwestern areas of the continent and distribute it to arid areas of Canada, the United States and northern Mexico. The concept envisions water deliveries from these surplus areas in times of drought into the American Desert about 9 years after initiation. The NAWAPA is economically feasible and financially within the existing money markets.

Schroo, H.
1967. "Notes on the reclammation of salt-affected soils in the Indus plain of West Pakistan," Neth J. Agr. Sci. 15(3): 207-220.
In the alluvial land along the Indus River and its tributaries, increasing salinization of the land has presented a major restraint to agricultural cropping and to the national production for the people and livestock of West Pakistan. The tremendous expansion of canal irrigation, with a grass area of 38 million acres, has induced a hazardous rise in the ground water tables caused by increased recharge due to canal leakage and shortage of irrigation water

resulting in inadequate leaching. The data indicated that near the soil surface, a distinct shift towards saline-alkali condition was most common. It was due to a relative shortage of divalent cations. The salt accumulation near the soil surface does not cause an increasing incidence of merely saline conditions. When saline-alkali and alkali soil layers are devoid of gypsum or other soluble calcium-magnesium salts, soil amendments to activiate the solubility of these carbonates to supply the divalent cations were used. Proposals were given to solve this national twin-problem of salinity and water-logging effectually with the aid of manure amendments and additional water allotments to make leaching possible. In the south where the divalent cation content content is high, areas are most easily reclaimed.

Sokolovskly, S.P.

1967. "Water salt regime of floodplain soils of Ciscaucasia based on the Kuma River Valley," Soviet Soil Sci. (7): 962-972.

The factors determining the water-salt regime of floodplain soils in the steppe part of Ciscaucasia are aridity, extensive development of salt-bearing materials in river basins, low water and brief periods of flooding, increased mineralization of river and groundwaters, predominance of fine-textured clay soils, poor natural drainage and a very low water permeability of soils and underlying materials. The water regime was divided into the seepage, with meadow and solonchak subtypes, leaching and nonleaching. A seasonable-reversible type of salt regime was established in the meadow water regime and no upward rise of salts was observed in wet years even during the summer. The absolute amounts of water soluble salts in the upper 0.5 m layer usually did not exceed the concentrations permissible for plants (0.25-0.3%). The chloride content varied between 0.06 and 0.020%. In the dry climate regions of Ciscaucasia, a downward capillary flow had brought about an accumulation of large amounts of water soluble salts (3 + %). Leaching water regime was formed in areas which had a sufficiently natural or artificial drainage. A nonleaching water regime was observed in the non-irrigated regions of floodplains which had deep groundwaters. The salt regime was of the seasonal-reversible type.

Tanji, K.K., Dutt, G.R., Paul, J.L.

1967. "A computer method for predicting salt concentrations in soils at variable moisture contents," Hilgardia, 38(9): 307-318.

A computer method is presented for predicting the equilibrium salt concentration in a soil-soil solution-gypsum system and exchangeable cations at any given soil-moisture content from extract data obtained initially at a different moisture content. The calculations were based on ionic activities, solubility product constant of CaSO sub 4. 2H sub 2 0, dissociation constant of gypsum, and cation exchange equations. The computer program was developed for the IBM 7040 and a source statement along with a diagram to illustrate the flow of computation is included. Tests on five agricultural soils showed good agreement between computed and observed values.

Whyte, R.O.

1966. "Use of arid and semi-arid land," In E.S. Hills, ed., Arid Lands: a geographical appraisal. p. 301-361. Methuen, London.

In this comprehensive review of past and present land use, a connotation is proposed for the terms arid and semiarid based upon expected or effective rainfall. The area dealt with lies between the Atlantic and the Gangetic Plain in northern India. Digressions are made to east and central Africa when data appear to be relevant. The factors which must be considered in the land classification are grouped by independent variables such as geomorphology, geology, and climate, and dependent variables such as soil, water, and vegetation. The latter change in relation to each other and to the 3 independent variables. In this paper, data collected by specialists in the disciplines concerned with the 6 variables are synthesized, and land units and systems are

Appendix A

Budyko (1963a) offered a method for estimating actual evapotranspiration from climatological data. In the model, moisture for evaporation is drawn entirely from the root zone of the vegetation. The water balance equation for this active soil layer is

$$r = E + S + W_2 - W_1 \tag{1}$$

where

r = rainfall (mm)

E = evaporation (mm)

S = moisture surplus or sum of runoff Δf and the downward percolation p of water

W_2-W_1 = change in moisture content of the soil layer during a selected time interval.

The following assumptions must be made to produce reasonable results using the model:

a) Moisture for evapotranspiration is drawn entirely from the root zone of the vegetation

b) If soil is bare, moisture for evaporation is drawn from upper 10 to 20 cm.

c) $E = E_o$ when $\overline{W} \geq W_k$ (2)

and $E = (\overline{W}/W_k)E_o$ when $\overline{W} \leq W_k$ (3)

where $\overline{W} = 0.5\ (W_1+W_2)$ (4)

and E_o = potential evapotranspiration rate (mm)

d) Assume S is directly proportional to the precipitation and the soil moisture content. That is

$$S = br\frac{\overline{W}}{W_{max}} \tag{5}$$

where b is an empirically determined constant of proportionality which according to Budyko (1963a), ranges from 0.0 to 0.8 and depends on both the precipitation intensity and the potential evapotranspiration rate. The equation used to determine b is given by

$$b = \frac{0.8r}{E_o+r} \tag{6}$$

Monthly potential evaporation rates may be determined using Thornwaite's method (1948). He obtained the following empirical relationships between potential evaporation (E_o) and the mean monthly temperature in degrees Centigrade,

$$E_o = 16\ (10\ T1)^a\ \bar{m}\bar{m}o^{-1} \tag{7}$$

where

$$a = (0.6751^3 - 77.11^2 + 179{,}201 + 492{,}390) \times 10^{-6} \tag{8}$$

and

$$I = \sum_1^{12} (T/5)^{1.514} \tag{9}$$

The summation is over the 12 months. The values of E_o obtained with the Thornwaite equations must be adjusted to take into account the variation of day length with latitude.

Combining of equation (1) to (5) gives

$$\overline{W}(1) = \frac{r+2W_1-E_o}{2+b\ \frac{r}{\overline{W}_{max}}} \tag{10}$$

when $\overline{W} \geq W_k$, and

$$\overline{W}(2) = \frac{r + 2W_1}{2+b\frac{r}{W_{max}} + \frac{E_o}{W_k}} \qquad (11)$$

when $\overline{W} \leq W_k$.

For the model, W_1 at the start of the first period must either be known or assumed. W_1 is obtained by estimating the rooting depth of the vegetation on the watershed and multiplying this value by the volume of water in percent the soil will hold. Entering this value into equation (10) along with r, E_o, W_{max}, and W_k, $\overline{W}(1)$ for the first period is calculated.

If $\overline{W}(1)$ is greater than W_k, $\overline{W} = \overline{W}(1)$; if $\overline{W}(1)$ is less than W_k, $\overline{W} = \overline{W}(2)$. The value of W_2 for the period is then obtained from equation (4) and set equal to W_1 for the following period. The process is repeated to give W_2 at the end of the second period or W_1 at the start of the third period, and so on.

W_{max} is calculated by knowing the field capacity, fc, of watershed's soil and the rooting depths, rd, of the plant cover, hence W_{max} = f.c. x r.d.

In accord with the results of Budyko (1956), and Denmead and Shaw (1962), W_k is taken as 0.75 W_{max}. The period previously mentioned is one month.

The model was programmed in Fortran IV for a CDC 6400 computer. Following is a listing of the program with the appropriate variables needed to obtain results.

```
      PROGRAM APID (INPUT, OUTPUT, TAPE 1 = INPUT)
C     RUNOFF SIMULATION MODEL
C     T(I) = AVG. MONTHLY TEMP (C)
C     R(I) = AVG. MONTHLY RAINFALL (MM)
C     CF(I) = CORRECTION FACTOR FOR THORNTHWAITES EQUATION
C     TO INCLUDE DAYLENGTH AND LATITUDE
C     W1(I) = INITIAL SOIL MOISTURE CONTENT (MM)
C     WK = MOISTURE CONTENT ABOVE WHICH PLANTS TRANSPIRE AT THE
C     POTENTIAL RATE
C     WMAX = PRODUCT OF ROOTING DEPTH AND SOIL FIELD CAPACITY
      DIMENSION T(12), R(12), W(13), EO(12), B(12), W1(12), W2(12),
     1W2(12), WA(12), EVAP(12), S(12)
      DIMENSION CF(12), HO(12)
      DIMENSION CK(12)
      DIMENSION SI(12)
      DIMENSION PS(12)
      DIMENSION Y1(12), X1(12)
      READ 40,N
   40 FORMAT (I3)
      READ331, IERR,TEMP,WN,H,NK1
  331 FORMAT ([3,F3.0,3I3)
      READ 1, (T(I), I = 1,N)
      READ 1, (R(I), I= 1,N)
      READ 1,(CF(I),I=1,N)
      READ 1,(CK(I), I = 1,N)
    1 FORMAT (12F6.1)
      SUM1=0.$ SUM2=0.
      IPZ = 0
C     ----------------------
C     INITIAL SOIL MOISTURE CONTENT FOR JANUARY
C     ----------------------
      W1(1) = 30.
      WMAX = 175.
 2501 WMAX = WMAX + 25.
      I = 1
      HI = 0.
      WK = 0.75*WMAX
      IPI = 0
      IX = 0
      SUM3=0.$ SUM4=0.$ SUM5=0.
      X = 0. $ XX = 0.
      HI = 0.
      JDATE = IDATE(1)
      KTIME = ICLOCK(1)
      PRINT 70,JDATE,KTIME
   70 FORMAT (1H1,11HTODAYS DATE,A10/1X,11HTIME OF RUN,A10////)
      PRINT 50
   50 FORMAT (1H0,*RUNOFF FROM A SEMI-ARID WATERSHED*)
      PRINT 15
      IPZ = IPZ + 1
      IF (IPZ.NE.1) GO TO 2401
      DO 84 I = 1,N
      T(I) = 5.*(T(I) - 32.)/ 9.
   84 R(I) = R(I) * 25.4
      I = 1
C     ----------------------
C     CALCULATE HEAT INDEX
C     ----------------------
    3 HI = HI + (T(I)/5.)**1.514
C     ----------------------
      I = I+1
      IF (I.LE.12) GO TO  3
C     ----------------------
C     CALCULATE EXPONENT VALUE
      A = (6.675*(HI**3)- 77.1*(HI**2)+ 1792*HI+ 49239)*.00 001
      DO 44 I = 1,N
C     ----------------------
C     CALCULATE MONTHLY POTENTIAL EVAPOTRANSPIRATION RATE USING
C     THORNTHWAITES EQUATION
C     ----------------------
C     CORRECT FOR LATITUDE AND DAY LENGTH
C     ----------------------
      EO(I) = 1.6*((10.*T(I)/HI)**A)
      EO(I) = EO(I)*CF(I)*CK(I)
      SUM2 = SUM2 + R(I)
   44 SUM1 = SUM1 + EO(I)
 2401 CONTINUE
      SUM3 =  0.$ SUM4 = 0. $ SUM5 = 0.
      ZO = 0.
      DO 4 I = 1,N
      X1(I) = I
      ZO = ZO + 1.
C     ----------------------
C     CALCULATE CONSTANT OF PROPORTIONALITY
      B(I) = 0.8*R(I)/(EO(I) +R(I))
C     ----------------------
C     CALCULATE MONTHLY SOIL MOISTURE CONTENT (MM)
      WA(I) =W(I)+2.*B(I)*(R(I)-EO(I))/(2. + B(I)*W(I)/WMAX)
C     ----------------------
      IF (WA(I).GT.WK) GO TO 5
      W2(I) =(W(I)+2.*B(I)*R(I))/(2.+(B(I)*W(I)/WMAX) + (EO(I)/WK))
      WA(I) = W2(I)
      X = 0.5*(W(I) + WMAX)
      IF (WA(I).GT.X) GO TO 6
      XX = 0.5*W(I)
      IF (WB(I).LT.XX) GO TO 7
      GO TO 13
    6 W2(I) = WMAX
      WA(I) = X
      GO TO 10
    7 W2(I) = 0.
      WA(I) = XX
      GO TO 10
    5 WA(I) = WA(I)
      X = 0.5*(W(I) + WMAX)
      IF (WA(I).GT.X) GO TO 8
      XX = 0.5*W(I)
      IF (WB(I).LT.XX) GO TO 9
      GO TO 13
    8 W2(I) = WMAX
      WA(I) = X
      GO TO 10
    9 W2(I) = 0.
      WA(I) = XX
      GO TO 10
   13 W2(I) = 2.*WA(I) - W(I)
```

```
   10 IF (WB(I).GE.WK)GO TO 11
C     -----------------------
C     CALCULATE EVAPORATION RATE
      EVAP(I) = (WB(I)/WK)*EO(I)
      GO TO 12
   11 EVAP(I) = EO(I)
C     -----------------------
   12 S(I) = R(I) - EVAP(I) + W1(I) - W2(I)
      IF (S(I).LT.0) S(I)=0.
      W1(I+1) = W2(I)
      SUM3 = SUM3 + EVAP(I)
      SUM4 = SUM4 + S(I)
      IF (I.EQ.1) 1006,1007
 1006 RO(I) = 0.3*S(I)
      SUM5 = SUM5 + RO(I)
      GO TO 3000
 1007 RO(I) = (S(I) + (S(I-1) - RO(I-1)))*0.3
      IF (RO(I).LT.0) RO(I) = 0.
      SUM5 = SUM5 + RO(I)
 3000 Y1(I)=RO(I)
    4 CONTINUE
C     -----------------------
C     CALCULATE MONTHLY RUNOFF
C     -----------------------
      DO 1002 I = 1,N
      IF (RO(12).GT.1) 1000,1001
 1000 IF (I.EQ.1)1004,1005
 1004 RO(I) = RO(I) + 0.3*(S(12) - RO(12))
      S1(I) =0.3*(S(12) - RO(12))
      GO TO 2000
 1005 RO(I) = RO(I) + 0.3*S1(I-1)
      S1(I) = 0.3*S1(I-1)
      IF (S1(I).LT.1) 1001,2000
 2000 SUM5 = SUM5 + RO(I)
 1002 CONTINUE
 1001 PRINT 20, (T(I), I = 1,12)
   20 FORMAT (1X,4HT(C),10X,12F7.2)
      PRINT 21, (EO(I), I = 1,12),SUM1
   21 FORMAT (1X,6HEO(MM),8X,12F7.2,3X,F7.2)
      PRINT 22,(R(I),I = 1,12),SUM2
   22 FORMAT (1X,5HR(MM),9X,12F7.2,3X,F7.2)
      PRINT 23,(R(I), I=1,12)
   23 FORMAT (1X,1HR,13X,12F7.2)
      PRINT 24,(W1(I),I=1,12)
   24 FORMAT (1X,5HW1(MM),8X,12F7.2)
      PRINT 25, (EVAP(I), I = 1,12),SUM3
   25 FORMAT (1X,9HEVAP,(MM),5X,12F7.2,3X,F7.2)
      PRINT 26,(S(I), I = 1,12),SUM4
   26 FORMAT (1X,1HS,13X,12F7.2,3X,F7.2)
      Z1 = ABS (W1(13) - W1(1))
      IF (Z1.GT.0.5) GO TO 3005
      GO TO 3001
 3005 W1(1) = W1(13)
      GO TO 2401
 3001 PRINT 27,(RO(I),I=1,12),SUM5
   27 FORMAT (1X,11HEST. RUNOFF,3X,12F7.2,3X,F7.2//////////)
   15 FORMAT (40X,5HMO.TH/18X,1HJ,6X,1HF,5X,1HM,6X,1HA,[illegible]
     15X,1HJ,5X,1HJ,5X,1HA,5X,1HS,5X,1HO,5X,1HN,5X,1HD,5X,3HEST[illegible]/)
      PRINT 34
   34 FORMAT (20X,*EST. RUNOFF VS. MONTHS OF YEAR*////)
      PRINT 60
   60 FORMAT (1X,*DATA FROM WALNUT GULCH WATERSHED, TOMBSTONE ARIZ.*)
      DO 31 I = 1,11
      IP1 = I+1
      DO 31 J = IP1,12
      IF (Y1(I)-Y1(J))31,31,32
   32 TX = Y1(I)
      Y1(I)=Y1(J)
      Y1(J) = TX
   31 CONTINUE
      XL = X1(1)
      XU = X1(12)
      YL = Y1(1)
      YU = Y1(12)
C     -----------------------
C     CALL PLT1 IS A PLOTTING ROUTINE COMPATABLE ONLY WITH
C     THE CDC 6400.
C     -----------------------
      CALL PLT1(IEPH,TEMP,NSYM,XL,XU,YL,YU,X1,Y1,60)
      IF (WMAX.LE.350) GO TO 2501
      STOP
      END
```

To test the model's capability in an arid region, computed runoff was compared to actual runoff from Walnut Gulch watershed located near Tombstone, Arizona (1962). Average monthly rainfall and temperature are needed for the model. Table I-A lists these variables by month. Precipitation data is from the watershed, but monthly average temperatures are for Tombstone.

Table I-A.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Precipitation (in.)	1.17	.01	.58	0	0	0	4.47	.29	1.11	.03	.56	.92
Temperature (°F)	45.2	52.8	50.6	66.7	68.2	76.4	77.0	80.9	75.2	67.6	59.6	50.8

Table II-A gives the output from the Fortran IV program. The table is essentially self-explanatory giving the variables on the left and their appropriate monthly values. Air temperature, T, has been changed from °F to °C, and rainfall, R, from inches to millimeters. B is the empirically determined constant of proportionality depending on rainfall and potential evapotranspiration. W_1 is the soil moisture content at the beginning of each monthly period. A value of 30 mm was assumed in January, and the corresponding initial monthly moisture content was then derived from equation (4) with W_2 becoming W_1 for the next month. The evaporation rate tended to be lower than the potential evaporation rate throughout the year because of relatively dry conditions. Storage, S, was calculated from equation (1). With r, E, W_1 and W_2 being known for each monthly period, S became the residual of the equation.

With S being known, then a part of the storage became available for runoff. Thornwaite (1948) suggests that for any one month approximately one-half of the water runs off and the other half remains on the watershed to run off

Table II-A. Model Output.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Sum
E_o (mm)	36.40	92.21	64.38	150.19	138.62	191.12	177.74	199.61	126.17	95.20	66.22	62.31	1400.16
R (mm)	29.72	.25	14.73	0.00	0.00	1.78	113.54	7.37	28.19	.76	14.22	23.37	233.93
B	.36	.00	.15	0.00	0.00	.01	.31	.03	.15	.01	.14	.22	
W_1 (mm)	54.52	74.08	53.43	55.39	32.04	19.37	10.87	88.37	47.49	52.67	38.07	42.58	
Evap. (mm)	8.32	20.90	12.46	23.35	12.67	10.28	31.36	48.21	22.47	15.36	9.49	10.76	225.62
S	1.83	.00	.32	0.00	0.00	.00	4.68	.04	.55	.00	.22	.66	8.30
Est. Runoff	.55	.38	0.00	.10	0.00	.00	1.41	1.00	0.00	.17	.02	.26	3.87

the next month. This approach is feasible for watershed monitoring over a period of several years where S should equal the runoff rate. On a yearly basis though, some water is left on the watershed in the form of storage. As shown in Table IIA, 233.93 mm of water fell on the watershed; 225.62 mm evaporated; 8.30 mm was stored; and 3.87 mm contributed to runoff. The estimated runoff (mm) is given for each month and plotted versus actual runoff in Figure I-A.

The value of this model comes not in its ability to duplicate actual runoff, but as a predictive tool. By varying precipitation rates, theoretical watershed response can be studied. This would give advance estimates of potential water supplies. Also the effects of watershed treatment can be studied. By varying the active soil layer the model will give runoff for a vegetated watershed or one that has been cleared. Returning to the basic assumptions, it was said that moisture would be drawn entirely from the root zone of the vegetation. If clearing, burning or spraying caused all vegetation to die, then evaporation would occur only from a 10 to 20 cm upper layer; hence more runoff should occur. Use of the model to predict runoff from a watershed before and after clearing or burning would give rapid and economical decision making options to a watershed manager. Simulation runs would in many cases do away with the need to perform an actual clearing or burning operation on a watershed to determine the amount of increased runoff. The model coupled with operations research type decision making provides a powerful watershed management technique.

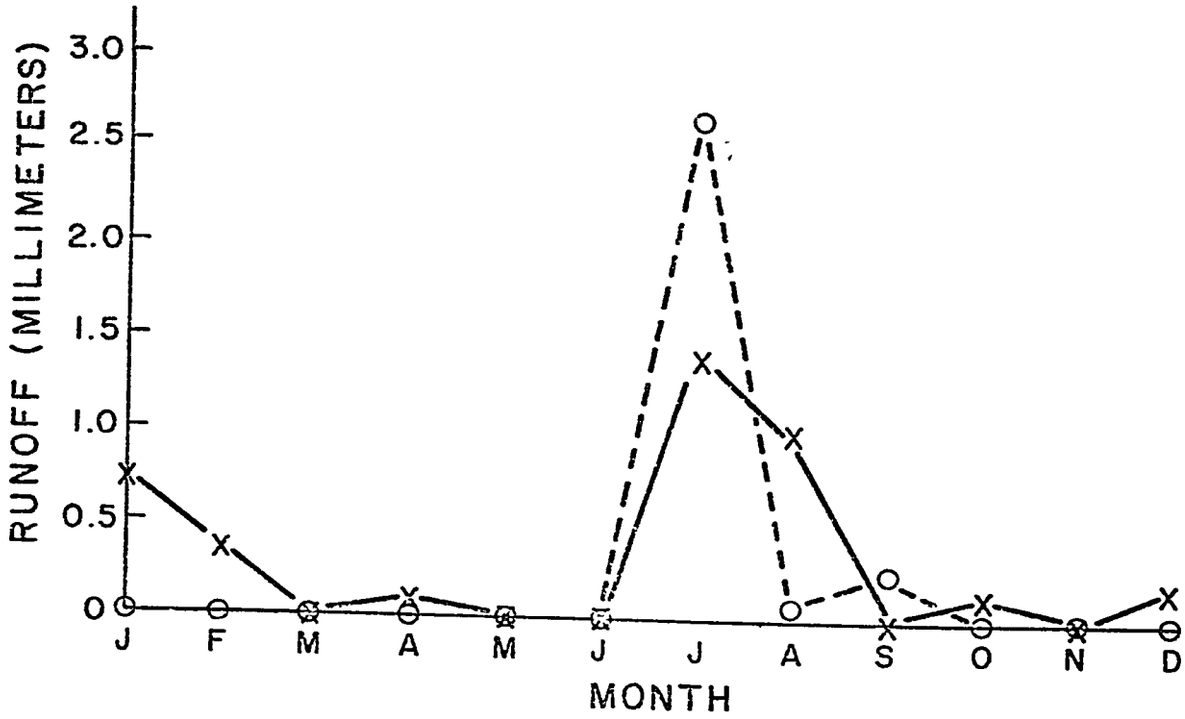


Figure I-A. Calculated vs. Actual Runoff from Walnut Gulch Watershed, Tombstone, Arizona.

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