CONFERENCE ON EVAPORATION
APRIL 12-13 1954

ABSTRACTS

Department of Civil Engineering

Colorado Agricultural and Mechanical College
Fort Collins, Colorado

CER No. 55-3

FOREWORD

At the suggestion of a number of persons interested in the engineering aspects of evaporation, the Civil Engineering Department of Colorado A & M College held a conference on this subject April 12 and 13, 1954. This conference was attended by representatives from colleges and Federal Agencies doing research work on this important subject. Following the conference, a brief résumé was issued by the college. Many persons felt, however, that they would like to have an abstract covering the technical material presented. This is in response to that demand.

Acknowledgment should be made to the efforts of H. J. Koloseus, Hydraulic Engineer, U. S. Geological Survey, who served as secretary to the conference and on whose shoulders fell the burden of a large share of the work involved in organizing and reporting this conference.

Scientists and Engineers Attending the Conference:

Representing the U. S. Geological Survey

Mr. G. E. Harbeck
Mr. G. Kolberg
Mr. O. Leppanen
Dr. B. N. Rolfe
Mr. H. J. Koloseus

Representing the U. S. Bureau of Reclamation

Mr. W. U. Garstka

Representing the U. S. Weather Bureau

Mr. M. A. Kohler

Representing the U. S. Department of Agriculture

Mr. C. Rohwer
Mr. A. R. Robinson
Mr. M. D. Hoover

Representing Stanford University

Prof. R. K. Linsley

Representing Texas A & M College

Dr. E. R. Lemon

Representing Kansas State College

Mr. N. P. Woodruff

Representing Colorado A & M College

Dean T. H. Evans
Dr. D. F. Peterson
Prof. H. W. Collins
Prof. E. W. Lane
Dr. P. N. Lin
Prof. J. E. Cermak
Mr. E. F. Schulz
Mr. A. C. Spengos

WIND TUNNEL EVAPORATION STUDIES AT COLORADO A&M COLLEGE

by J. E. Cermak

Lake Hefner Model Studies

Under sponsorship by the Bureau of Ships, Navy Department, and in cooperation with the U. S. Geological Survey, Colorado A & M College has conducted a model study of Lake Hefner. Wind tunnel investigations of the 1:2000 scale model have been conducted with the following objectives in mind:

1. To determine if wind structure over the prototype can be modeled or duplicated in the wind tunnel.
2. To determine if evaporation rates from the model may be used to predict evaporation rates from the prototype.

Results of the investigation have shown that wind structure (variation of horizontal mean velocity along the vertical) for neutral thermal conditions is similar for model and prototype above an elevation corresponding to the laminar sub-layer of the model. Measurements show that above the laminar sub-layer in the model and for the prototype, the mean wind velocity varies logarithmically with height. In general the prototype elevation corresponding to the thickness of the laminar sub-layer of the model is about 20 ft.

Measurements of evaporation rates indicate that the evaporation coefficient N is a unique function of the parameter R_* where

$$N = \frac{E}{\Delta C}\frac{\sqrt{A}}{\nu_e}$$

$$R_* = \frac{V_* \sqrt{A}}{\nu_e}$$

E = evaporation rate for unit area

A = area of evaporation surface

ΔC = difference between the ambient vapor concentration and the saturation concentration at surface temperature

ν_e = diffusion coefficient of water vapor into air

V_* = shear velocity $\sqrt{\tau_o/\rho}$ at an upwind location

τ_o = shear at air-ground interface and ρ = air density.

Because R_* for the prototype is about 2000 times larger than that for the model, no direct prediction of prototype has been possible. However, through use of the Reynolds analogy as modified by von Kármán, N for both the model and the prototype may be expressed with practical accuracy by derived equations.

Further studies have shown that upstream barriers have no appreciable effect upon the relationship between N and R_* if τ_0 is taken to be the shear which would occur if no barrier were present upstream and the same horizontal pressure gradient existed.

A practical implication of the investigation is the possibility of using the relationships between N , and R_* as given by Reynolds analogy to predict evaporation rates from existing and planned reservoirs. In order to make this application, an estimate of mean annual or monthly values of V_* , air temperature, and water surface temperature must first be made.

Evaporation from Smooth , Plane Boundaries

Through sponsorship by the Office of Naval Research, a systematic study of evaporation rates from smooth, plane boundaries has been conducted. The main objective of this study was to determine the effect of varying the dry approach length upstream from the evaporation surface. For a length of evaporation surface L the length of dry approach was varied in length from L/12 to L. Results of this study indicate that the relative length of approach need not be considered as an independent variable if N is expressed in terms of R_* . Furthermore, data from these studies are well represented by a relationship between N and R_* derived from Reynolds analogy.

PROVISIONAL RESULTS OF THE BRUNING EVAPOTRANSPIRATION STUDY

by O. E. Leppanen

In southeastern Nebraska the U. S. Geological Survey conducted a water-loss study to determine whether the evapotranspiration from a grass-covered surface could be accurately measured by use of mass-transfer and energy-budget techniques. The measurement program was in operation from May through September 1953 and March through June 1954. A water-budget control was used, moisture storage being determined by sampling. Almost continuous records of temperature and humidity were obtained at four levels above the surface as well as temperature variations in the ground and at the surface. A Cummings radiation integrator and Eppleys were used for energy-budget aspects. The data are now being processed.

THE FELT LAKE EVAPORATION PROJECT

by R. K. Linsley

Under the sponsorship of the U. S. Weather Bureau and with the active assistance of the U. S. Geological Survey, Stanford University is undertaking an evaporation study at Felt Lake situated on the Stanford Campus. Felt Lake is an off channel reservoir supplying water for irrigation and fire protection on the Stanford Campus. It is formed by a small earth dam across the mouth of a small valley. It is filled by diversion of flow through Los Trancos Canal from Los Trancos Cr. The lake is about 50 ft deep at maximum depth, 40 acres in area, and contains about 500 acre-feet of water. The local tributary area is approximately 70 acres and the normal annual rainfall is about 20 in., largely concentrated in the winter months (December through March).

The project will parallel on a more modest scale the work done at Lake Hefner. An accurate water budget will be maintained by careful records of lake level, inflow as measured with a V-notch weir, and outflow as measured with a venturi meter in the outlet line. The lake is situated on rock and soil of the Santa Clara formation which is highly impervious and no significant seepage is believed to occur. No attempt will be made to measure local inflow and days with significant rainfall will be neglected in computing the water budget.

A shore station on the west (windward) shore of the lake is equipped with a Class A pan, screened pan, BPI pan, and Colorado sunken pan in addition to rain gage, thermometers, and hygrothermograph. A raft station will be equipped to measure wind, temperature, humidity at 4 and 8 m. above the water surface, water surface temperature, and incoming and reflected radiation. Periodic measurements of the temperature distribution in the lake plus inflow and outflow temperatures will permit computation of an energy budget.

Observations on the shore station were started in January 1954. Because of instrumental difficulties the raft station is not operating as yet but is expected to be operating by July, 1954. Tentative plans contemplate termination of observations in June or July, 1955. Analysis will include comparison of pan and lake evaporation, energy budget comparison, and use of the Lake Hefner empirical equation. Additional studies may be made if the data suggest other approaches.

Processed data will be available to interested parties and a final report on the project will be published in some form. Because of delays in calibrating the inflow weir and the outflow venturi meter no comparative data are currently available.

The project is under the direction of Professor Ray K. Linsley, Dept. of Civil Engineering, Stanford University, Stanford, Calif.

THE LAKE MEAD PROJECT

by G. E. Koberg

The instrumentation program at Lake Mead was described briefly. The energy-budget method for determining evaporation was reviewed, and the methods used to evaluate each parameter in the energy budget were explained. The energy-budget results were summarized, and it was stated that the evaporation from July 1, 1952, through June 30, 1953, was 900,000 acre-feet, or 84 inches. The mass-transfer results were summarized, and the agreement between the two methods was excellent on an annual basis; however, on a monthly basis the mass-transfer method differed by as much as 25 percent from the energy budget. This deviation was probably due to the stability problem, which was very much more in evidence at Lake Mead than at Lake Hefner. The talk was concluded and color slides were shown by Mr. Garstka of the equipment used at Lake Mead.

EVAPORATION-SEEPAGE STUDIES IN THE CHEYENNE RIVER BASIN

by G. E. Harbeck, Jr.

Studies are planned for the summer of 1954 to determine seepage and evaporation losses from selected stock ponds in the Cheyenne River Basin in Wyoming. Ponds underlain by different geologic formations will be used in order to study the effect of geologic conditions.

Seepage losses will be determined using a technique developed by W. B. Langbein. Pond stage will be measured at half hourly intervals over a period of approximately 24 hours, using several point gages that are direct-reading to the nearest 0.0001 foot. Measurements of air temperature, wet-bulb temperature, and water-surface temperature will also be made. A record of wind speed will be obtained. The total fall in stage in a 24-hour period includes both seepage and evaporation losses. That part of the total loss attributable to evaporation can be computed on the basis of the mass-transfer theory. It is assumed that evaporation is directly proportional to the product of the wind speed and the vapor-pressure difference and that evaporation in the absence of wind is negligible. The product of wind speed and vapor-pressure difference for periods of perhaps 2 hours in length is plotted against total fall in stage during that same period. The intercept on the stage axis thus represents the seepage loss.

Continuous records of water level and temperature, wind speed, air temperature, and humidity will be obtained at several ponds. Thermal surveys will be made at weekly intervals. Net incoming radiation will be measured using a Cummings Radiation Integrator. Weekly evaporation will be determined using both the energy-budget and mass-transfer methods.

SILVER HILL EVAPORATION PROJECT

by M. A. Kohler

Of recent years, the Weather Bureau has conducted numerous experimental projects at its Silver Hill Observatory, just across the District of Columbia boundary in Maryland. Part of the regular observational program for the Washington area is based at Silver Hill and, accordingly, the station is manned by commissioned personnel (21 hours per day, 7 days per week). The observatory grounds cover approximately 5-1/2 acres, and the site is believed to be meteorologically representative of the region. When it appeared that staff and workload requirements would permit, plans were made for initiation of a modest, experimental evaporation project.

Evaporation observations were begun June 10, 1953. The equipment was inoperative during the winter months, but observations were resumed on March 9, 1954. It is hoped that at least a portion of the equipment can be kept in operation throughout the coming winter.

The objectives of the project are many, and some are of a continuing nature. At such time as it becomes evident that sufficient data have been collected to achieve one objective, the observational program will be revised in accordance with existing staff and workload. Instrumentation and current observational procedure were established to serve the following objectives:

1. Determine pan-to-pan ratios for four of the more widely used types of pans -- Class A, Bureau of Plant Industry, Colorado (Sunken), and Screened (Sunken).

2. Study the effects of some non-standard operational practices, particularly with respect to the Class A pan.
3. Study the "splash-out" characteristics of the various pans.
4. Study practicability and advisability of shielding the Class A pan.
5. Provide further testing of the derived relation for estimating Class A evaporation from air temperature, dewpoint, wind and solar radiation (or percent sunshine).

In view of the fact that less than six months of data are available from the project, it is obvious that results to date necessarily border on speculation. Perhaps the most striking feature of last season's observations is the significantly and consistently lower evaporation from the sunken pans relative to the Class A than has been observed in other localities. Moreover, the magnitude of this difference seems to be greater the smaller the pan. Transfer of heat through the sides and bottom depend on the temperature gradient (water to air, or water to soil, as the case may be). This leads one to wonder if the lake-to-pan ratios for small sunken pans may not be more susceptible to climatic variation than is the Class A pan.

With respect to the Class A pan, air temperature is readily available and it now appears much of the climatic variation can be taken into account. Soil temperatures are not generally observed at evaporation stations and they are highly influenced by ground cover, soil moisture and soil type.

Studies soon to be reported in a research paper show rather conclusively that transfer of heat through the pan can account for appreciable variations in the pan coefficient -- as low as 0.6 in areas where pan water temperatures average much lower than air temperatures and as high as 0.8 where the reverse is true.

Original plans proposed the installation of a large stock tank (15 or more feet in diameter). Young and others concluded that evaporation from such a tank is representative of that from a small lake and, on this basis, pan to lake coefficients were to be derived for the site. The tank has not been installed, although we still hope to finance one in the near future.

PAN AND LAKE EVAPORATION AT LAKE MEAD

by M. A. Kohler

The two objectives of the Weather Bureau in the Lake Mead evaporation experiments were (1) to determine a pan coefficient by comparing observed annual pan evaporation with lake evaporation as computed by the energy budget and mass transfer methods, and (2) to test the accuracy of the Weather Bureau relation for computing pan evaporation from meteorological data.

In comparing pan and lake evaporation, it is necessary for consistency that the change in energy storage and advected energy for the lake be zero for the period or a correction must be made to the lake evaporation if these quantities are not zero. If we assume that transfer of heat occurs only at the surface of a lake, then the effect of advected energy and change in energy storage can be approximately evaluated by increasing the average water temperature and computing the increased evaporation, back radiation, and conduction of sensible heat. It can be assumed that solar radiation, long wave radiation from the sky, and vapor pressure of the air will not be appreciably affected by the increased water temperature. Preliminary computations at Lake Mead show that approximately 60% of the increased energy represented by an increase in annual water temperature will be dissipated by evaporation with the remaining 40% transferred by increase in back radiation from the water surface and conduction of sensible heat. This means that the observed lake evaporation must be corrected by algebraic addition of the factor 0.6 (change in energy storage minus advected energy) in order to compare with the lake evaporation computed by applying a coefficient to the pan evaporation. Since the 0.6 figure is an approximation and may actually vary from 0.55 to 0.65, depending upon the period selected to dissipate the excess energy, the correction should probably be made only for annual periods. This adjustment for the first full year (April 1, 1952 - March 31, 1953) at Lake Mead was -8.7 inches, and for the last full year (October 1, 1952 - September 30, 1953) was -8.6 inches.

Making these adjustments to the energy budget evaporation at Lake Mead gives values of 77.9 inches and 75.9 inches for the first and last 12-month periods, respectively. Since the observed pan evaporation for the corresponding periods was 108.6 inches and 112.4 inches, the computed pan coefficients are .72 and .68, respectively. On the basis of these figures, a coefficient of 0.70 for the Boulder City pan seems reasonable. Lake evaporation computed on the basis of this coefficient must be corrected, however, for the change in energy storage and advected energy.

Since the publication of the Lake Hefner Report, considerable time has been spent on investigation of variation of the Class A pan coefficient brought about by transfer of heat through the sides of the pan. Thus, in areas where water temperature tends to be higher than air temperature, the pan coefficient should be relatively high and vice versa for areas where water temperature is less than air temperature. Results of this study will be published soon in a Weather Bureau research paper. Applying this approach to the Boulder City Class A pan yields an estimated pan coefficient slightly less than 0.70.

EVAPORATION SUPPRESSION

by E. R. Lemon

A discussion was given concerning the mechanisms of mono-molecular layers of surfactants in free water surfaces. Various characteristics required of monolayers to suppress evaporation were reviewed. Following this, the results of laboratory studies on suppressing soil moisture evaporation were presented.

PROPOSED STUDY OF THE BOWEN RATIO

by H. J. Koloseus

The equation suggested by Bowen for the evaluation of the ratio of the heat lost by conduction to that lost through evaporation has been the subject of numerous discussions. The effect of spray, atmospheric stability, and radiative diffusivity on this ratio is not well understood. Since recourse is made to this ratio in the Energy Budget determinations of evaporation, a better understanding of its evaluation would be helpful. Therefore, a wind tunnel study of the Bowen ratio has been proposed.

A wind tunnel study is particularly suitable to this work because the influence of spray, stability, and radiative diffusivity can be controlled and evaluated more readily in a wind tunnel than in nature. Two possible approaches to the problem are:

1. Use of two insulated evaporation pans one of which contains water and the other a saline solution. The simultaneous use of two different solutions can be used to advantage to eliminate one of the variables of the energy equation.
2. Use a single insulated evaporation pan to which energy is supplied at such a rate as to maintain

a constant water surface temperature (steady state conditions).

Depending on the extensiveness of the program, it may be possible to ascertain:

1. The effect of various temperature differences between the air and the water on the Bowen ratio.
2. The effect of various vapor pressure differences between the air and the water on the Bowen ratio.
3. The effect of various ambient air velocities on the Bowen ratio.

The complexity of the undertaking increases as the effect of spray, stability, and radiative diffusivity on the Bowen ratio is studied.

Information regarding the Bowen ratio may be of industrial value where evaporation is used as a means of dissipating heat.