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HYDRAULIC RESEARCH

at

COLORADO STATE UNIVERSITY

Compiled by
Richard A. Schleusener

ENGINEERING RESEARCH

JUN 1973

FOOTHILLS READING ROOM

Civil Engineering Section
Colorado State University
Fort Collins, Colorado

December 1961

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COLORADO STATE UNIVERSITY

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Prepared for the 1962 issue of
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Civil Engineering Section
Colorado State University
Fort Collins, Colorado

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INTRODUCTION

This is a summary of research projects which are underway, or which have been completed since December 1960.

REPORTING ORGANIZATION

The reporting organization is the Civil Engineering Section, Colorado State University, Fort Collins, Colorado. Professor Milton E. Bender is Section Chief.

FORMAT

The following format is used in this report:

- (a) Number and title of project.
- (b) Name of organization for which the work is being done.
- (c) Title and name of person to whom a request for further information should be addressed. The address in every case is: Civil Engineering Section, Colorado State University, Fort Collins, Colorado.
- (d) Nature of the project, whether theoretical or applied, experimental, laboratory, etc.
- (e) A brief description of the project.
- (f) Present status.
- (g) Results.
- (h) Publications

The format follows that used in the Hydraulic Research Bulletin prepared annually by the National Bureau of Standards. The number preceding the titles of the projects is the project number used within the Section.

PROJECTS

(104-307) METEOROLOGICAL OBSERVATIONS

- (b) Colorado Agricultural Experiment Station and U. S. Weather Bureau.
- (c) Assistant Research Engineer, Mr. Lewis O. Grant.
- (d) Field investigation; basic research.
- (e) Meteorological observations are being obtained to establish long-time records of climatological elements and to support current experiment station research which is weather dependent. The elements observed are: Maximum and minimum temperature and wet and dry bulb temperatures every two hours; soil temperatures at 3, 6, 12, 24, 36, and 72 inches; wind direction and velocity at 15 inches and 65 feet above ground; barometric pressure; evaporation from a free water surface; surface water temperature; precipitation; cloud cover; dew and frost.
- (f) Active.
- (g) Complete meteorological observations have been made throughout the year. Since April 1961 complete observations have been made at two sites in connection with a change in location of approximately 400 feet to the NNW. Record monthly precipitation was observed in March, and the accumulative precipitation through 15 November of 27.90 inches exceeds the 70 year record annual precipitation of 27.57 inches at Fort Collins

(104-310) STUDY OF CLOUDS AND SNOWFALL IN THE ROCKY MOUNTAINS, AND CHANGES RESULTING FROM THE ADDITION OF ARTIFICIAL ICE NUCLEI

- (b) National Science Foundation, Rocky Mountain Forest and Range Experiment Station, and the Climax Molybdenum Company.
- (c) Assistant Research Engineer, Mr. Lewis O. Grant.
- (d) Field investigation; basic research, applied research.
- (e) Various physical factors important in "Cold Cloud" orographic precipitation processes are being investigated under winter-time conditions in the high mountains of Colorado. This includes observations of airflow over the mountains, the characteristics of the "cold" orographic clouds rising over the mountains, the availability of suitable ice nuclei, the characteristics of individual snow particles falling from these clouds, snow water freezing characteristics, snowfall amounts, and the changes in these conditions when artificial ice nuclei are supplied.
- (f) Active.
- (g) Field equipment and procedures for use at high elevations in the Colorado Rockies have been developed. Observations of the daily accumulation of snowfall, atmospheric ice nuclei, and various other cloud and snow characteristics have been made over a large area

for seeded and unseeded days during two winter seasons. Significant increases in ice nuclei have occurred in the area of the observation network, on a number of the "seeded" days. Snowfall has been greater on the seeded days. The sample size is to be increased before determination of the statistical significance of this apparent increase in snowfall.

- (h) "Snowfall and Snowfall Accumulation near Climax, Colorado," by Lewis O. Grant and Richard A. Schleusener, to be published in the Proceedings of the April 1960 Western Snow Conference.
"Progress Report on Cloud Seeding in Central Colorado," by Lewis O. Grant, to be published in the Proceedings of the 16th Annual Meeting of the Colorado River Forecast Committee.

(105) GROUND WATER FLUCTUATIONS AND THEIR RELATION TO PUMPING

- (b) Colorado Agricultural Experiment Station.
- (c) Assistant Civil Engineer, Mr. M. M. Skinner.
- (d) Field investigation; applied research.
- (e) An extensive observation well network is being established capable of providing reliable information on the fluctuation of the ground-water table in each of the several ground-water basins in Colorado. Periodic measurements of ground-water table elevations are being made at each of the selected observation wells. Procedures are being developed for processing, cataloging, analyzing the resultant data by machine methods.
- (f) Active.
- (g) Due to an unusually large amount of rainfall during the summer months (1961) in eastern Colorado, the water tables in that area are generally up 2 to 3 feet over the 1960 fall measurements.

(106) DEVELOPMENT AND IMPROVEMENT OF WATER MEASURING DEVICES

- (b) Agricultural Research Service, Soil and Water Conservation Research Division and Colorado Agricultural Experiment Station.
- (c) Supervising Agricultural Engineer and Assistant Civil Engineer, Mr. A. R. Robinson.
- (d) Experimental laboratory research, field investigation; applied research operation and development.
- (e) This project has the general objective of developing and improving devices and techniques for the measurement of irrigation water. Specific objectives now in progress or recently completed are: (1) Design, evaluation and calibration of trapezoidal measuring flumes; (2) Re-evaluation of the submergence effects of Parshall measuring flumes and effect of variable angle of convergence; (3) Evaluation of vane-type flow meters.
- (f) Active.
- (g) Results from present tests indicate that the procedure for determining flow rates from submerged Parshall flumes can be simplified and made more accurately. Present indications are that trapezoidal measuring flumes have considerable merit over those of the Parshall type. Tests are continuing on different designs of these flumes. Tests on the vane-type flow meters indicate a probable accuracy under field operation of \pm 5 percent.

- (h) "Study of the Cox Flow Meter (Modified Hall Pitot Tube)" by A. R. Robinson, report to Board of Water Commissioners, City and County of Denver, Colorado, January 1961.
 "Study of the Beaver Creek Measuring Flumes," by A. R. Robinson, report to Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, February 1961.
 "Evaluation Study of the Pendvane Flowmeter," by A. R. Robinson, prepared through the cooperation of the Applied Research Company, The Colorado Experiment Station and Agricultural Research Service, September 1961.

(107) SUPERCRITICAL FLOW

- (b) Experiment Station, Colorado State University.
 (c) Civil Engineer, Dr. V. M. Yevdjovich.
 (d) Theoretical, laboratory research; basic research, doctoral.
 (e) This project is planned to be carried out in three stages: (1) Review of the literature with the assessment of the actual status of knowledge in the field of supercritical flows in steep flumes; (2) Design of facilities and experiments to be carried out in hydraulic laboratory; and (3) Analysis of the experimental results.
 (f) Active.
 (g) The project started October 1961.

(108) SEALING OF CANALS AND RESERVOIRS WITH COLORADO CLAYS

- (b) State of Colorado.
 (c) Project Leader, R. D. Dirmeyer, Jr.
 (d) Laboratory research, field investigation; applied research, development.
 (e) The purposes of this project are: (1) To inventory the clay deposits in or close to major irrigated areas in Colorado. This inventory is to include both field and laboratory evaluations of the clays. (2) To develop methods of utilizing the locally-available clays in sealing leaky canals and reservoirs in Colorado.
 (f) Active.
 (g) Results to November 1961 include: (1) Laboratory testing of over 200 clay samples from 99 deposits in Colorado has been completed; (2) Field evaluations of approximately 96 installations of Colorado clay in canals and reservoirs have been completed.
 (h) "Sealing Rocky Ditches with Clay," by R. D. Dirmeyer, Jr., M. M. Skinner, and R. T. Shen, Colorado State University Circular, 16 pp., December 1961.

(109) GENESIS AREAS FOR HAILSTORMS IN THE HIGH PLAINS

- (b) Crop-Hail Insurance Actuarial Association, Chicago, Illinois.
 (c) Associate Research Engineer, Dr. Richard A. Schleusener.

- (d) Field investigation; applied research.
- (e) The position and movement of precipitation cells has been tracked by a 3.2 cm radar set located at New Raymer, Colorado, from 15 May to 15 August 1961. The cells that produced hail were identified from concurrent data from a special surface network. The location of genesis of these precipitation cells was related to terrain features and low-level wind flow.
- (f) Active.
- (g) It appears that regions of hail genesis can be identified from a "lift factor" computed from terrain differences and low-level wind flow. The "lift factor" gives a measure of the distance that a parcel of air would be lifted over terrain by the 8,000 foot wind.
- (h) "Hail Genesis Areas in and near Northeastern Colorado," by Richard A. Schleusener and Thomas J. Henderson, Atmospheric Science Technical Paper 21, Colorado State University, October 1961.

(110) GROUNDWATER MANAGEMENT

- (b) Colorado Experiment Station and Colorado Department of Natural Resources.
- (c) Assistant Civil Engineer, Mr. M. W. Bittinger.
- (d) Theoretical, field investigation; applied research.
- (e) The project consists of field studies to determine ground water reservoir characteristics. Management programs will later be applied to determine optimum operation techniques.
- (f) Active.
- (g) None to report at this time.

(111) ESTIMATING FLOOD FLOWS

- (b) U. S. Agricultural Research Service and the State of Colorado.
- (c) Professor of Civil Engineering, Dr. V. M. Yevjevich.
- (d) Basic research, doctoral.
- (e) Pearson type III curves are being fitted to flood hydrographs of small watersheds using three parameters: flood peak Q , flood volume V , and time lag t_0 , from the flood beginning to flood peak. The parameters Q , V , and t_0 are related to several variables of small watersheds, including precipitation characteristics and probability of specific rainfall intensities. Multiple regression analysis is used to determine the significant variables.
- (f) Active.
- (g) None to date.

(114) WATERSHED HYDROLOGY

- (b) Colorado Agricultural Experiment Station.
- (c) Associate Civil Engineer, Mr. E. F. Schulz.

- (d) Experimental, field investigation; applied research.
 - (e) The small watershed provides an opportunity to study the rainfall-runoff cycle in the absence of some of the complexities involved in studying larger watersheds. Some generalizations of the hydrologic characteristics of small watersheds are being developed and the region in Colorado where these generalizations are valid will be defined.
 - (f) Active.
 - (g) None as yet. Project was initiated in 1961.
- (763) THE CONSEQUENCES OF MODEL RESTRAINT ON RESULTS OF SEAWORTHINESS TESTS
- (b) David Taylor Model Basin, Navy Department, Washington 7, D. C.
 - (c) Associate Civil Engineer, Mr. E. F. Schulz.
 - (d) Experimental; applied research.
 - (e) Experimental measurements are being made of forces and moments acting on a completely restrained model being towed on different headings in a regular wave train.
 - (f) Completed.
 - (g) A five-foot model tanker was equipped with a six component force balance and fitted to a towing carriage. The model was towed at different speeds on different headings in a regular wave train. The variation of the oscillatory forces and moments resulting from the waves acting on the model were obtained.
 - (h) "Restrained Model Tests in Head Seas," by E. F. Schulz, prepared for David Taylor Model Basin, CER59EFS7, March 1959.
"Forces and Moments on a Restrained Model in Regular Waves," by E. F. Schulz, in preparation for David Taylor Model Basin, December 1961.
- (778) ATMOSPHERIC SURFACE LAYER PHENOMENON
- (b) National Science Foundation, Washington 25, D. C.
 - (c) Professor of Engineering Mechanics and Civil Engineering, Dr. J. E. Cermak.
 - (d) Experimental research; basic research, doctoral thesis.
 - (e) Measurements of mean velocities and mean temperatures together with turbulence intensities and correlations have been made over a smooth, plane, heated or unheated surface.
 - (f) Active
 - (g) Heating of the turbulent boundary layer at low Reynolds numbers has been found to produce the following effects: (1) Increase the coefficient of drag; (2) Increase the eddy viscosity; (3) Increase the correlation between vertical and horizontal velocity fluctuations.
 - (h) "The Turbulent Boundary Layer at Low Reynolds Number with Unstable Density Stratification Produced by Heating," by J. E. Cermak, Ph.D. Thesis, Cornell University, 1959.

"Separation Flow Downstream of a Plate Set Normal to a Plane Boundary,"
by H. S. Nagabhushanaiah, Ph. D. Thesis, Department of Civil Engineering,
Colorado State University, 1961.

(1412) INVESTIGATIONS TO DEVELOP WIND TUNNEL TECHNIQUES FOR
MEASURING ATMOSPHERIC GASEOUS DIFFUSION IN MODEL
VEGETATIVE SURFACES

- (b) Agricultural Research Service, U. S. Department of Agriculture.
- (c) Assistant Civil Engineer, Mr. E. J. Plate.
- (d) Laboratory research; basic research, applied research for thesis (doctoral).
- (e) Diffusion of a gas (ammonia) into and out of a model vegetated plane area contributing part of a wind tunnel test section floor is to be studied. Using a test section 80 ft long and 6 x 6 ft in cross-section the turbulent boundary layer in which diffusion occurs will be several times thicker than the vegetation height. Using the basic equations of fluid mechanics, an attempt will be made to establish criterion for application of the model data to prototype conditions. The criterion developed will be checked using field data being obtained at Cornell University by the Agricultural Research Service.
- (f) Active.
- (g) A study of diffusion from a line source into a boundary layer over a flat, smooth plate has been completed. Results show that the diffusion pattern can be separated into different zones, according to distances from the source in which different similarity laws are valid for the diffusion process.
- (h) "Diffusion from a Line Source in a Turbulent Boundary Layer," by Michael Poreh, Ph.D. Dissertation, October 1961.

(2004) ACCURACY OF SURVEYING INSTRUMENTS

- (b) Wild Heerburgg Investment Company, Main and Covert Streets, Port Washington, N. Y.
- (c) Professor of Civil Engineering, Mr. Milton E. Bender.
- (d) Experimental and laboratory research; applied research.
- (e) The purpose of this study was to determine the accuracy of theodolites. Particular attention was paid to systematic errors. The data have been collected but not yet analyzed.
- (f) Standby.
- (g) None.

(2021) SILT EXCLUDER FOR THE GUALANDAY HEADWORKS

- (b) Tipton and Kalmbach, Inc., Denver, Colorado.
- (c) Assistant Civil Engineer, Mr. S. S. Karaki.
- (d) Laboratory research; applied research.
- (e) A model study was made of a silt excluder at the headworks of the Gualanday Canal on the Coello River. The Coello River is located in Colombia, South

America. The Gualanday Canal has experienced considerable sediment problems and maintenance of the Canal has proved to be difficult and expensive. A different type of sediment excluder at the headworks was studied.

- (f) Completed.
- (g) The sediment excluder developed for the Gualanday headworks consisted of two tunnel sluices with a skimming weir to divert clear water flow into the Canal. Although developed for a particular installation, it could have application to other sites.
- (h) "Desilting Structure at the Gualanday Canal Headworks Coello Project, Colombia, South America," by S. S. Karaki, prepared for Tipton and Kalmbach, Inc., April 1961.

(2023) SILT EJECTOR MODEL FOR LINK CANALS

- (b) Tipton and Kalmbach, Denver, Colorado.
- (c) Assistant Civil Engineer, Mr. S. S. Karaki.
- (d) Laboratory research; applied research.
- (e) A network of large canals is being constructed in West Pakistan to divert waters of the Indus River and its tributaries to cultivated lands for irrigation. In order to maintain canals in regime it is necessary to remove sediment from the canals. The width of the canals ranges from 200 to 300 feet. Normal sediment ejectors are considered unsatisfactory for the new canals, hence new devices for sediment ejection are being investigated.
- (f) Active.
- (g) No conclusive results available to date, however, it appears that a curve in the canal to create secondary flow around the bend and utilizing the distribution of boundary shear on the bed may be an effective and economical means of transporting sediment to the inside of the curve. There the sediment which forms a shoal can be removed hydraulically.
- (h) "Model study of the Sediment Ejector for the Trimmu-Sidhnai Link Canal," by S. S. Karaki, Interim Report, prepared for Tipton and Kalmbach, Inc., Denver, Colorado, November 1961.

(2024) KREMASTA SPILLWAY MODEL

- (b) Engineering Consultants, Inc., Denver, Colorado.
- (c) Assistant Civil Engineer, Mr. S. S. Karaki.
- (d) Laboratory research; applied research.
- (e) The Kremasta Dam is located in Greece. Due to geologic conditions at the dam site it is necessary to construct an earth-fill dam with a side-channel spillway. The model study of the spillway is being conducted to study the spillway approach channel, supercritical chute, flip bucket design and tail water fluctuation at the power plant.

- (f) Active.
- (g) None.

(2203) MEASUREMENT OF ATMOSPHERIC OZONE WITH THE DOBSON SPECTROPHOTOMETER

- (b) Air Force Cambridge Research Center, L. G. Hanscom Field, Bedford, Massachusetts.
- (c) Assistant Research Engineer, Mr. Lewis O. Grant.
- (d) Basic research.
- (e) Measurements of the total amount and the vertical distribution of ozone with height are being made with the Dobson Spectrophotometer. Daily amounts of total ozone are being related to atmospheric circulation patterns.
- (f) Active.
- (g) Observations of total ozone and the vertical distribution with height have been made on a regular basis for days when sky conditions have been clear.
- (h) Observational data is being supplied to the U. S. Weather Bureau for publication.

(2206) WHITE SANDS WIND TUNNEL

- (b) White Sands Missile Range, White Sands, New Mexico.
- (c) Assistant Civil Engineer, Mr. E. J. Plate.
- (d) Laboratory research; design.
- (e) A low-speed wind tunnel was designed for use in calibrating and standardizing wind measuring instruments. The test section will be 4 x 4 x 4 ft in size and will have an air speed range from 1/2 to 70 mph. The variation in air speed for a given setting will not vary by more than ± 1 per cent in space or time excepting within the boundary layers formed on the walls. Turbulence levels will not exceed 0.2 per cent at any air speed.
- (f) Completed.
- (g) The wind tunnel has been designed, constructed, and installed.

(2208) CONSTRUCTION OF MICROMETEOROLOGICAL WIND TUNNEL

- (b) U. S. Signal Corps.
- (c) Assistant Civil Engineer, Mr. E. J. Plate.
- (d) Laboratory research; design.
- (e) A wind tunnel is being designed and constructed which will permit control of air speed (1-150 mph), air temperature (32-200⁰F) and relative humidity (5-95 per cent). The 6 x 6 ft square by 80 ft long test section will have provisions for heating and/or cooling about 30 ft of the floor. The facility is being designed to permit detailed study of turbulence and turbulent diffusion under various thermal conditions.
- (f) Active.
- (g) Design is completed. Construction is well on its way.

(2216) HIGH LEVEL TURBULENCE

- (b) U. S. Navy Weather Research Facility, Building R-48, Naval Air Station, Norfolk, Virginia.
- (c) Associate Professor, D.r. Elmar Reiter.
- (d) Field investigation; basic research.
- (e) By means of stereo-photography of high-level clouds a study will be made of wave-lengths of disturbances in the jet-stream region, which might account for clear-air turbulence.
- (f) Active.
- (g) Cameras have been calibrated and reduction procedures programmed for electronic computer.
- (h) "Die Feinstruktur der Strahlstroeme," by E. R. Reiter, Civil Engineering Department, Colorado State University, Atmospheric Sciences Tech. Paper No. 22, CER61ERR61.

(2218) WAKE CHARACTERISTICS FOR BODIES OF REVOLUTION

- (b) Department of Navy, David Taylor Model Basin, Washington 7, D. C.
- (c) Professor of Civil Engineering, Dr. J. E. Cermak.
- (d) Experimental research; basic research, doctoral thesis.
- (e) A study will be made of the relations between axially symmetrical bodies and the wakes produced by them for varying mean velocities and turbulence levels of the mean flow, both with and without momentum addition by means of a jet directed downstream from the body. Basic data will be obtained for establishing similarity criteria for turbulent and mean flow characteristics at large distances downstream from the body.
- (f) Active.
- (g) None.

(2402) CONSOLIDATION OF SOILS

- (b) National Science Foundation.
- (c) Professor, Dr. I. S. Dunn.
- (d) Theoretical, experimental and laboratory research; basic research, doctoral thesis.
- (e) The study consists of a mathematical analysis of the effect of viscoplastic resistance on the rate of pore pressure decrease and of an experimental program to verify the mathematical results and to investigate the effect of varied load increments on the time-consolidation relationship. The mathematical analysis will be carried out by adding visco-plastic resistance terms to the basic differential equation of consolidation developed by Terzaghi and solving the resulting equation either by standard methods or by analysis of a theoretical model. The solution of this system along with the laboratory consolidation curves will be used to produce the relationships between plastic resistance and related variables such as speed of deformation and percent of deformation.

- (f) Completed.
- (g) None.
- (2426) FUNDAMENTAL STUDY OF A SUBMERGED AND NONSUBMERGED THREE-DIMENSIONAL JET IMPINGING UPON A NORMAL PLANE
- (b) National Science Foundation.
- (c) Assistant Professor of Civil Engineering, Mr. George L. Smith.
- (d) Theoretical, experimental; basic research, doctoral thesis.
- (e) This is an analytical and experimental study of an axisymmetrical flow impinging normally on a smooth and rough flat boundary. The impinging jet can be divided into four zones: zone of establishment, zone of established flow in the vertical direction, deflection zone and zone of radial flow. Measurements of velocity profiles and turbulent intensities have been completed in the zone of radial flow for the case of the smooth boundary. A device for direct wall shear stress measurement has been designed, constructed and tested. The shear meter with static sensitivity of 10^{-6} lb. per sq. in. provides acceptable consistent data; however, its dynamic accuracy is poor because of the affect of vibration.
- (f) Active.
- (g) The turbulent intensities in the radial, vertical and circumferential directions have been measured. The local energy expressed by q^2/\bar{U}^2 is a minimum at the point of maximum velocity \bar{U}_m . The measured turbulent shear \bar{Uv} has been measured, and its extrapolation to the boundary is found to approximate the friction coefficient obtained by shear meter. The friction coefficient in the divergent flow was found to be much larger than the coefficient for the case of the two-dimensional jet.
- (2432) SHEAR STRESS AT A LIQUID-SOLID INTERFACE BY ELECTROKINETIC POTENTIAL
- (b) National Science Foundation.
- (c) Professor of Engineering Mechanics and Civil Engineering, Dr. J.E. Cermak.
- (d) Experimental research; basic research, doctoral thesis.
- (e) The primary objective is the determination of temporal fluctuations in shear stress at the fluid-solid interface in a pipe and jet flow. Fluctuation frequencies and relative amplitudes at different points along the pipe have been measured for a range of Reynolds numbers. The effect upon shear stress fluctuations of (1) pipe entrance disturbances (2) disturbances in turbulent flow (3) a periodic growth and decay of the laminar sublayer (as postulated by Einstein) will be investigated.
- (f) Active.
- (g) None.
- (h) "Electrokinetic-Potential Fluctuations Produced by Turbulence at a Solid-Liquid Interface," by Gilbert J. Binder, Ph.D. Thesis, 1961.

(2445) CHARACTERISTICS AND FORMATION OF HAIL

- (b) National Science Foundation.
- (c) Associate Research Engineer, Dr. Richard A. Schleusener.
- (d) Field investigation; basic research.
- (e) Basic information on hailfalls and precipitation is being obtained from a special network of cooperative observers and specialized instrumentation. Data on hail intensity, amounts, and structure of individual stones are being obtained to relate to the environment in which the storms form to obtain a better understanding of the hail formation process.
- (f) Active.
- (g) (1) Hail is favored in a broad-scale synoptic environment in which a 500 millibar "relative velocity maxima" moves through the latitude of hail occurrence. (2) Movement of precipitation cells which contain hail tends to be clockwise from the 500 millibar wind direction with a speed approximately that of the 500 millibar wind. (3) Information is available on frequency, duration, density and diurnal variation of hail. (4) The total quantity of ice that falls as hail, as well as the estimated impact energy per unit area from hail, appears to be closely related to crop damage.
- (h) "Hail Genesis Areas in and Near Northeastern Colorado," by Richard A. Schleusener and Thomas J. Henderson, Atmospheric Science Tech. Paper 21, Colorado State University, October 1961.

(2455) MODEL-PROTOTYPE RELATIONSHIPS FOR FLOW AND SEDIMENT TRANSPORT IN ALLUVIAL CHANNELS

- (b) National Science Foundation.
- (c) Hydraulic Engineer, Dr. D. B. Simons.
- (d) Theoretical, experimental and laboratory research; applied research.
- (e) Flume studies have been made to investigate variation in stage-discharge and sediment transport and deposition in the vicinity of several types of control structures using different sediments. Attempts have been made to correlate model prototype relations with regard to sediment size.
- (f) Completed.
- (g) The results illustrate the effect of size of bed material and form of bed roughness on control structures for alluvial streams. A non-silting structure with a fairly stable stage-discharge relation for a large range of sediment and water discharge has been developed. This work was done by Dr. J. D. Lawson, University of Melbourne, Australia.
- (h) "Flow Characteristics of Low Weir Structures in Alluvial Streams," by J. D. Lawson, Colorado State University Engineering Research Report in preparation.

(2456) ANALYTICAL STUDY OF LOCAL SCOUR

- (b) The U. S. Bureau of Public Roads.
- (c) Professor of Civil Engineering, Dr. V. M. Yevdjovich.

- (d) Theoretical, experimental laboratory research; basic research, doctoral thesis.
- (e) A study has been made of the scour around bridge piers and abutments using theoretical or laboratory experiments.
- (f) Completed.
- (g) By using dimensional analysis the maximum scour depth around the abutments is found to be an exponential of time, and the constants of the function are determined from experimental laboratory data in relation to dimensionless parameters in a more accurate way than it was done in previous works. The theoretical approach to the mechanics of scour around bridge piers and abutments is analyzed.

(2458A) ALLUVIAL CHANNEL HYDRAULICS

- (b) U. S. Geological Survey.
- (c) Hydraulic Engineer, Dr. D. B. Simons.
- (d) Theoretical, experimental and laboratory research, basic research.
- (e) This is a study of the mechanics of flow in alluvial channels.
- (f) Active.
- (g) Five different bed materials ranging in size from 0.19 mm to 0.93 mm have been studied. The forms of bed roughness ranging from ripples to antidunes have been described and related to sediment discharge and resistance to flow. The effects of large concentrations of fine sediment (clay) and temperature on sediment discharge and form of bed roughness has also been investigated.
- (h) "Flume Studies Using Median Sand (0.95 mm)" by D. B. Simons and E. V. Richardson, U. S. Geological Survey Water Supply Paper 1498A, 1961.
 "Sonic Depth Sounder for Laboratory and Field Use," by E. V. Richardson, D. B. Simons and G. J. Posakony, U.S. Geological Survey Circular No. 450, 1961.
 "The Variable Depth-Discharge Relation in Alluvial Channels," by D. B. Simons, E. V. Richardson and W. L. Haushild, U. S. Geological Survey Professional Paper 424D, 1961.
 "The Significance of Fall Velocity and Fall Diameter of Bed Material," by W. L. Haushild, D. B. Simons and E. V. Richardson, U. S. Geological Survey Professional Paper 424D, 1961.
 "Qualitative Effects of Temperature on Flow in Alluvial Channels," by D. W. Hubbell and K. Al-Shaikh Ali, U. S. Geological Survey Professional Paper 424D, 1961.
 "Forms of Bed Roughness in Alluvial Channels," by D. B. Simons and E. V. Richardson, Hydraulics Division Journal, ASCE, May 1961.
 "Sediment Transport in Alluvial Channels," by A. A. Bishop, Ph.D. Dissertation, Colorado State University, July 1961.

- (2458B) DISTRIBUTION AND CONCENTRATION OF RADIOACTIVE WASTE IN STREAMS BY FLUVIAL SEDIMENT
- (b) U. S. Geological Survey, for Reactor Development Branch of the Atomic Energy Commission.
 - (c) Hydraulic Engineer, Mr. D. W. Hubbell.
 - (d) Theoretical, experimental and laboratory research, field investigation; basic research, applied research.
 - (e) Natural streams provide a convenient and effective medium for the disposal of low-level radioactive wastes. When radionuclides are introduced in streams they may become fixed on sediment particles. As a result, waste disposal depends, in part, on the transport and dispersion of the sediment. Project activity includes field and laboratory studies on the application and development of transport and dispersion theory for bed and suspended load. In addition, some phases of the dispersion of liquid contaminants are being studied.
 - (f) Active.
 - (g) An experiment in which polyethylene particles were released from a point source at the water surface of an 8 ft wide alluvial channel having small dunes was performed to provide data on lateral diffusion. One field experiment and two laboratory flume experiments have been conducted on the dispersion of contaminated bed load particles. In the experiments sand labelled with radioactive isotopes has been released on the channel bottom, then traced with underwater radiation-detection equipment.
 - (h) "Uptake and Transport of Radionuclides by Stream Sediments," by W. W. Sayre, H. P. Guy and A. R. Chamberlain, in preparation as a U. S. Geological Survey Professional Paper.
- (2461) UNSTEADY FLOW IN STORM DRAINS, GENERAL AND ANALYTICAL STUDY
- (b) U. S. Bureau of Public Roads.
 - (c) Professor of Civil Engineering, Dr. V. M. Yevdjovich.
 - (d) Theoretical; basic research.
 - (e) The project consisted of an analytical study of unsteady free surface flow in a storm drain, considering the study as the initial step for a basic research program in developing new methods for storm flood routing in drains, using a digital computer.
 - (f) Completed.
 - (g) The basic partial differential equations, and especially their initial and boundary conditions, for unsteady free surface flow are discussed and analyzed as the basis for the experimental hydraulic and numerical digital computer investigations.
 - (h) "Unsteady Free Surface Flow in a Storm Drain, General and Analytical Study," by Vujica M. Yevdjovich, Colorado State University Engineering Research Report CER61VMY38, June 1961.

(2466) CURB OPENINGS

- (b) U. S. Bureau of Public Roads.
- (c) Assistant Civil Engineer, Mr. S. S. Karaki.
- (d) Experimental; applied research.
- (e) Laboratory data on prototype-size highway sections were taken to determine the efficiency of curb opening drains on highway pavements. The Bureau of Public Roads is using the data to compile design curves for highway engineers.
- (f) Completed.
- (g) None.
- (h) "Depressed Curb Opening Inlets - Supercritical Flow - Experimental Data," by S. S. Karaki, prepared for U. S. Department of Commerce, Bureau of Public Roads, June 1961.

(2474) SNOWFALL AND THE EFFECTS OF CLOUD SEEDING ON SNOWFALL IN COLORADO ROCKIES

(See Project 104 - 310)

(2478) WIND TUNNEL MODELING OF ATMOSPHERIC DIFFUSION

- (b) National Institute of Health, Public Health Service, U. S. Department of Health, Education and Welfare, Washington, D. C.
- (c) Professor of Engineering Mechanics and Civil Engineering, Dr. J. E. Cermak.
- (d) Experimental research; basic research, doctoral thesis.
- (e) The objective of this project is to determine the influence of geometrical factors (land surface roughness, topography, structures), and thermal and aerodynamical factors (turbulence intensity and scale) upon atmospheric diffusion of heat and mass. "Laws of modeling" or "similitude parameters" are sought by obtaining detailed data under various conditions in the wind tunnel and by comparing them with similar data now existing for the atmospheric prototype.
- (f) Active.
- (g) None.
- (h) "Diffusion from a Point Source Within a Turbulent Boundary Layer," by Mr. Kersi Davar, Ph.D. Thesis, 1961.

(2482) HYDROLOGIC ASPECTS OF THE UPPER COLORADO RIVER BASIN

- (b) Upper Colorado River States.
- (c) Professor of Civil Engineering, Dr. V. M. Yevdjovich.
- (d) Theoretical; applied research.
- (e) By using the distributions of the first serial correlation coefficient of several stations, and distribution of ranges, the patterns in the sequence of annual river flows of the Upper Colorado River Basins are studied.
- (f) Completed.

- (g) The sequence of annual effective precipitations on the Upper Colorado River Basin is very close to random. A depletion model by man-made changes is derived. The sequence of annual river flows is close to random, except that the non-homogeneity in data and the water carryover from one water year to another create a dependence of successive values of river flows.
- (h) "Some General Aspects of Fluctuations of Annual Runoff in the Upper Colorado River Basin," by Vujica M. Yevdjovich, Colorado State University Engineering Research Report CER61VMY54, October 1961.

(2483) ANALYSIS OF PRECIPITATION DATA IN THE UPPER COLORADO RIVER BASIN

- (b) State of Colorado.
- (c) Associate Research Engineer, Dr. Richard A. Schleusener.
- (d) Theoretical; basic and applied research.
- (e) None.
- (f) Completed.
- (g) A sample of daily precipitation and temperature data from 30 weather observing locations in and near the Upper Colorado River Basin have analyzed by computer techniques. Frequency of precipitation at multiple time intervals for each location are presented. Major storms with an average recurrence interval of less than once per year have been found to contribute significantly to runoff from the Upper Colorado River Basin. Moisture sources for the basin are primarily from the Gulf of Mexico in summer, and from the Pacific Ocean during other seasons.
- (h) "Analysis of Precipitation Data in the Upper Colorado River Basin," by Richard A. Schleusener and Loren W. Crow, Civil Engineering Report CER61RAS52, October 1961.

(2486) HAIL CLOUDS AND THEIR ENVIRONMENT

- (b) National Science Foundation.
- (c) Associate Research Engineer, Dr. Richard A. Schleusener.
- (d) Field investigation; basic research.
- (e) The occurrence of hailstorms is being related to the synoptic environment, using conventional meteorological data, and to the local environment, using radar, and stereo camera pairs to examine the structure of clouds and precipitation region.
- (f) Active.
- (g) Analysis of data is now being accomplished.
- (h) "Characteristics of Hailstorms in the Colorado State University Network, 1960-61," by Richard A. Schleusener and Lewis O. Grant, Proceedings of the Ninth Weather Radar Conference, pp. 140-145, October 1961.

(2487) ARTIFICIAL ICE NUCLEI

(See Project 104 - 310)

(2499) UNSTEADY FLOW IN A LONG STORM DRAIN

- (b) U. S. Bureau of Public Roads.
- (c) Professor of Civil Engineering, Dr. V. M. Yevdjevich.
- (d) Theoretical, experimental and laboratory research; basic and applied research.
- (e) A long model conduit is being designed for hydraulic experiments of unsteady free surface flow in a storm drain. The model studies furnish the hydraulic boundary conditions for flood wave studies on a digital computer. The second group of experiments is simulation of storm flood waves through the conduit. The flood routing of the same waves by numerical integration of differential equations on a digital computer will enable comparison of numerical and hydraulic experimental flood routing. The purpose of the project is the development of methods for computing flood movement through storm drains by the use of a digital computer.
- (f) Active.
- (g) None.

(2503) WIND FORECASTING TECHNIQUES

- (b) Federal Aviation Agency, Federal Aviation Facilities Center, Atlantic City, New Jersey, Attn: RD-140.
- (c) Associate Professor, Dr. Elmar Reiter.
- (d) Theoretical, experimental; basic and applied research.
- (e) Automatic forecasting techniques for high-level winds which can be used by an automatic air traffic control system shall be devised and tested.
- (f) Active.
- (g) None.

(2506) PATTERNS IN SEQUENCE OF ANNUAL RIVER FLOWS

- (b) National Science Foundation.
- (c) Professor of Civil Engineering, Dr. V. M. Yevdjevich.
- (d) Theoretical; basic research.
- (e) The series of annual river runoff and the series of annual effective precipitations are analyzed by using the probability distribution of ranges and runs. The effect of the selection of beginning of a water year and of inconsistency and non-homogeneity in annual flow data on statistical parameters of above series also will be studied.
- (f) Active. This research project was in its initial stage in October 1961. It is a continuation of the research, carried out on the same subject and sponsored by the U. S. National Bureau of Standards (1958-1959), and the U. S. Geological Survey (1959-1960).

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CER 61-73

D. B. Simons

ADDENDUM

Reports of research which follow were omitted from the first printing of CER61RAS73.

Projects 125, 213, 219, 248 and 109-303 are conducted within the Agricultural Engineering Section, Colorado State University, Fort Collins, Colorado. Professor Norman A. Evans is Section Chief.

(125) DRAINAGE OF IRRIGATED LANDS

- (b) Colorado Agricultural Experiment Station and Agricultural Research Service, U. S. Department of Agriculture.
- (c) Irrigation Engineer, Norman A. Evans.
- (d) Theoretical and applied.
- (e) An empirical equation for predicting water yield from tile drain systems in Northeastern Colorado was developed by correlation analysis on field data. Theoretical and laboratory studies of drainage properties of soils have developed a promising method for relating the significant flow properties (permeability, capillary pressure, saturation) for flow above the water table.
- (f) Active.
- (g) Gas permeability as a function of capillary pressure and saturation can be used to predict liquid permeability as a function of capillary pressure or of saturation.
- (h) "Hydraulic Characteristics of Porous Media," by R. H. Brooks and A. T. Corey, AE39ATC16, November 1961.

(213) GRAVEL FILTER FOR TILE DRAINS

- (b) Colorado Agricultural Experiment Station.
- (c) Irrigation Engineer, Norman A. Evans.
- (d) Applied, experimental.
- (e) A sand box model is used in which gravel filters may be tested with any aquifer material of interest. Very fine sand of uniform size is now being used. Gravels of non-uniform size distribution similar to "pit-run" material are being tested.
- (f) Active
- (g) A tentative criteria for gravel based on ratio of mean particle size of aquifer to mean particle size of gravel and standard deviation of gravel particle sizes has been developed.
- (h) "Criteria for Gravel Filter Design," by A. R. Qazi, M. S. Thesis, Colorado State University Library, 1961.

(219) EVAPORATION FROM POROUS MEDIA

- (b) Colorado Agricultural Experiment Station.
- (c) Irrigation Engineer, Arthur T. Corey.
- (d) Theoretical, experimental.

- (e) Effect of surface characteristics on evaporation from porous media at or near saturation are studied in controlled environment chamber.
- (f) Active.
- (g) A 50 percent reduction in evaporation from saturated media is possible if pores in the surface 1/2 inch are larger than the largest pores of the media.
- (h) Influence of inorganic watershed cover on moisture exchange across the soil-air interface, Progress Report, AE34ATC13, 1961.

(248) HYDRAULICS OF SUB-CRITICAL FLOW IN SMALL, ROUGH CHANNELS

- (b) Colorado Agricultural Experiment Station and Agricultural Research Service, U. S. Department of Agriculture.
- (c) Irrigation Engineer, Norman A. Evans.
- (d) Theoretical, laboratory experiment.
- (e) Tilting flume with rough channels formed in natural soil and stabilized with chemical spray. Channel shape and roughness is varied.
- (f) Active.
- (g) Method of characterizing surface roughness was developed. An empirical analysis of flow in the laminar range produced a formula for predicting flow resistance, criteria for determining the transition between laminar and turbulent flow, and criteria for the boundary roughness necessary to affect laminar flow.
- (h) "The Influence of a Rough Boundary on Laminar Flow," by C. W. Huntley, M. S. Thesis, Colorado State University, 1961.
"Hydraulics of Subcritical Flow in Small, Rough Channels," by E. G. Kruse, USDA-ARS 41-43, October 1960.

(109-303) SNOW SURVEY

- (b) Colorado Agricultural Experiment Station, Soil Conservation Service, several Rocky Mountain States.
- (c) Snow Survey Leader, Jack N. Washichek.
- (d) Applied.
- (e) Snow course measurements are taken and forecasts of annual runoff are made for all the drainage basins of the state.
- (f) Active.
- (g) Forecasts are made approximately April 1 for the forthcoming spring and summer.

METEOROLOGICAL CONDITIONS AFFECTING DENVER AIR POLLUTION

- (b) Yetter Foundation, administered by Denver-U. S. National Bank.
- (c) Professor of Atmospheric Science, Dr. Herbert Riehl.
- (d) Field, applied, basic.
- (e) Denver pollution has been steadily growing but has not yet attained extreme proportions. It will be a novel feature of this investigation that the causes and history of pollution periods will be measured and analyzed with view toward providing the basis for a sound city ordinance, before the situation has become very severe.

With instrumentation furnished by the Taft Center of Sanitary Engineering, National Institute of Health, five stations recording detailed wind and temperature fluctuations have been set up in the Denver area. With collaboration of the U. S. Weather Bureau, the U. S. Air Force, and private industry six additional stations take records, so that a total of 11 stations is operating during pollution periods. The air sampling is carried out in conjunction with the project by the City of Denver; equipment also has been furnished by the Taft Center.

- (f) Active. The first day of observations was on 15 December 1961.
- (g) None as yet.

(113A) TURBULENT AIR MOTION IN THE HIGH ROCKIES IN RELATION TO THE WATER YIELD OF UPPER WATER SHEDS

- (b) Colorado Agricultural Experiment Station.
- (c) Professor of Atmospheric Science, Dr. Herbert Riehl.
- (d) Field, basic and applied.
- (e) The structure of the turbulent wind eddies, which produce the exchange of momentum between atmosphere and ground in the high mountains, is completely unknown. Yet these eddies have sufficient force for the most part to blow the snow away from the mountain slopes above timberline. This snow in part drifts into high-altitude basins where it accumulates in depth augmenting the summer water supply; in part it drifts on slopes where it readily evaporates. Much interest has been shown in the possibility of channeling the drift so that a substantially higher fraction goes into the basins. Technologically this appears to be feasible. But any construction is dependent on knowledge of the turbulence spectrum, especially on the first day following snowfall.

In order to determine this spectrum, a first installation containing electronic wind and temperature measuring instruments is being installed on Quandary Peak (14,250 feet) in the central Colorado Rockies. It will be maintained there during the 1961-62 winter. Other sites will be chosen in subsequent years. The measurements will yield detailed information on the structure of turbulence, when very fast air currents interact with major topographic features.

- (f) Active.
- (g) None as yet.

(2212) THE ROLE OF THE ROCKY MOUNTAINS IN THE GENERAL CIRCULATION OF THE ATMOSPHERE

- (b) U.S. Navy Numerical Weather Prediction Facility, Monterey, California.
- (c) Professor of Atmospheric Science, Dr. Herbert Riehl.
- (d) Basic.

(e) The Rocky Mountains are a solitary obstacle in the path of the westerly winds which cannot be circumvented like the Himalayas. A large fraction of the exchange of angular momentum between air and ground -- estimated as high as 50 per cent -- takes place in the small mountain region. The processes are direct surface stress from interaction between the high-velocity currents of the upper air and the high mountains, and a torque produced due to the pressure differential between eastern and western mountain slopes. The purpose of the project is (a) to determine the actual atmosphere-ground momentum exchange and its variation in time; (b) to determine the effect of this exchange on weather in and to the lee of the mountains; (c) to determine the importance of the momentum exchange on large-scale weather conditions around the hemisphere; and (d) to find an improved model of the surface stress term for numerical prediction purposes.

- (f) Active.
- (g) None as yet.

(2217) THE DISCHARGE OF MAJOR WESTERN RIVERS IN RELATION TO THE GENERAL CIRCULATION OF THE ATMOSPHERE

- (b) Office of Naval Research.
- (c) Professor of Atmospheric Science, Dr. Herbert Riehl; and Professor of Civil Engineering, Dr. V. M. Yevdjovich.
- (d) Basic.

(e) The discharge of major western rivers (Colorado, Columbia, Sacramento, Rio Grande) has fluctuations with the order of magnitude of the mean annual discharge itself. These fluctuations are brought about mainly by variations in winter precipitation yield and by variable evaporation. Heavy precipitation may result from seasonal conditions favorable for the recurrence of cyclones over headwater areas; the occurrence of occasional very heavy storms may also be random. On the other hand, high evaporation, requiring weeks of abnormally dry and warm conditions, must be a manifestation of general circulation anomalies of longer duration. The objective of the study is (1) to separate the 'systematic' and 'random' components of the precipitation, and (2) to determine the controls for the systematic anomalies of precipitation and evaporation. Such controls may

be deviations of air-sea heat exchange from average in the tropical Pacific, deviations of the Asiatic monsoon circulation from the mean, and departures of strength and location of the Siberian winter cold pool from normal.

- (f) Active.
- (g) None as yet.

(2454) WEATHER PATTERNS AND CIRCULATION OF THE TROPICS

- (b) U. S. Weather Bureau.
- (c) Professor of Atmospheric Science, Dr. Herbert Riehl.
- (d) Basic.
- (e) Part of the project deals with hurricanes, another part with general characteristics of weather in the tropics. Hurricane investigation is concerned (1) with the energy cycle of the mature storm, especially the role played by air-sea interaction in maintaining the center; (2) with the balance of forces in these storms and the nature and importance of frictional forces in a fully turbulent vortex; (3) with the formative stage of hurricanes; and (4) with the ocean-air heat exchange and recovery of ocean temperatures subsequent to hurricane passage.

Other studies are concerned with the variability of radiative emission from the atmosphere as a function of height; with the thermal modification of air passing over the tropical ocean under various types of general weather conditions; and with the interaction between tropical disturbances of less than hurricane intensity with their environment at large using line integral approaches.

- (f) Active.
- (g) Air in the surface layer approaches hurricane centers at much greater inflow angles (up to 45 degrees) than previously thought. As a result, the whole absorption of heat from the ocean, which maintains the core, and the transfer of angular momentum to the ocean, take place in a very short time; this leads to a new examination of transfer processes at the interface and the meaning of the roughness parameter at very high wind speeds. The balance of forces computation has shown that large frictional forces are active throughout the depth of the vortex; the hypothesis is being tested that these are due to vertical rather than lateral turbulence.

On radiation, results of over 100 soundings made with the Suomi-Kuhn radiometer show that the long wave emission in the trade wind belt falls far short of that estimated previously in theoretical calculations, and that a heat source due to this type of radiation exists above 30,000-foot altitude.

- (h) On the Balance of Forces in Hurricanes, by William M. Gray, Atmospheric Science Reports, Colorado State University. To be published in the Quarterly Journal of the Royal Meteorological Society.