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HYDRAULIC RESEARCH
at
COLORADO STATE UNIVERSITY

Compiled by
M. M. Skinner

Prepared for the 1963 issue of
National Bureau of Standards
"Hydraulic Research in the United States"

ENGINEERING RESEARCH

JUN 1973

FOOTHILLS READING ROOM

Civil Engineering Section
Colorado State University
Fort Collins, Colorado

December 1962

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INTRODUCTION

This is a summary of research projects which are underway, or which have been completed since December 1961.

REPORTING ORGANIZATION

The reporting organization is the Civil Engineering Section, Colorado State University, Fort Collins, Colorado. Professor Milton E. Bender is Section Chief. Reporting units included in this report are the Hydraulics Laboratory, The Fluid Dynamics and Diffusion Laboratory, Department of Atmospheric Science, Agricultural Research Service, and the Colorado Agricultural Experiment Station.

FORMAT

The following format is used in this report:

- (a) Title of project.
- (b) Name of organization for which the work is being done.
- (c) Name and title 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: (1) Experimental, theoretical, or field investigation, and (2) whether it is classified as basic research, applied research, design operation, development, for thesis (masters, doctoral, or otherwise).
- (e) A brief description of the project.
- (f) Present status.
- (g) Results.
- (h) Publications.

The above format follows that used in the publication, "Hydraulic Research in the United States," prepared annually by the National Bureau of Standards. The number preceding some of the titles of the projects is the number assigned by the National Bureau of Standards in previous publications.

PROJECTS

(55) SNOW COURSE MEASUREMENTS AND FORECAST ANALYSIS

- (b) Soil Conservation Service, Colorado Agricultural Experiment Station.
- (c) Mr. Jack N. Washichek, Snow Survey Supervisor.
- (d) Field investigations; applied research.
- (e) Systematic measurements of depth and water content of snow are being made at high elevations in Colorado and New Mexico mountain areas for the purpose of forecasting the runoff of the principal rivers in the interest of irrigation, power, domestic supplies, and other uses. The use of electrical resistance soil moisture units is being tested to determine a factor of soil moisture deficiency for water supply forecast purposes. Most of the major basins now have two or more soil moisture stations installed. A period of record must follow before any degree of correlation can be accomplished.
- (f) Active
- (g) Forecasts are now being issued at forty-four gaging stations in Colorado and New Mexico. As forecast procedures improve, additional streams will be forecasted and other areas of potential power and irrigation development will be investigated on the Colorado, San Juan, Animas and Arkansas Rivers.
- (h) Colorado Agricultural Experiment Station General Series Papers Nos. 765, 766, 767, and 768 covering monthly snow reports for all of Colorado and New Mexico.
 Nine small basin reports and one two-state bulletin covering the South Platte River watershed; Arkansas River watershed; Rio Grande watershed in Colorado; Rio Grande watershed in New Mexico; Dolores River watershed; San Juan and Animas River watershed; Gunnison River watershed; Colorado River watershed; Yampa, White and North Platte River watershed; Lower South Platte River watershed. Supplemental reports are issued January 1, May 15, and June 1.
 Summary of all historical data of snow surveys is in the press at the present time. Bulletins on surveys in Colorado after January 1, 1963 will be available.

(821) GROUND WATER FLUCTUATIONS AND THEIR RELATION TO PUMPING

- (b) Colorado Agricultural Experiment Station
- (c) Mr. M. M. Skinner, Assistant Civil Engineer.
- (d) Field investigation; applied research.
- (e) Semi-annual measurements of the depth to water table in approximately 565 observation wells are presently being obtained. The observation wells are primarily existing irrigation wells in the South Platte and Arkansas River Basins, the High Plains area of eastern Colorado and the San Luis Valley. Electrical Power and Natural Gas Consumption data are compiled and estimates of ground-water pumpage made. The purpose of the project is to detect areas of ground-water depletion and to develop relationships between gross pumpage and respective ground-water reservoir storage volume changes.
- (f) Active.
- (g) Ground-water levels of the spring of 1962 are generally up from the spring of 1961 in the South Platte and Arkansas River Basins and the

San Luis Valley. Considerable ground-water pumpage is beginning in the High Plains area of eastern Colorado with some increase in pumping lifts resulting. Reported, electrical-power consumption during 1961 by electrical pumping plants in Colorado amounted to approximately 98,000,000 kilowatt hours for 8765 pumping units.

- (h) "Colorado Ground-Water Levels - Spring 1962," by M. M. Skinner, Colorado State University Experiment Station, Civil Engineering Section, Fort Collins, Colorado.
 "Operating Characteristics of Ground-Water Reservoirs Occupying a Trench," by R. E. Glover and M. M. Skinner, Colorado State University, Civil Engineering Section, Fort Collins, Colorado.
 "Summary of Electrical Power Used by Irrigation Pumps in Colorado During 1961 as Reported by Power Companies," by M. M. Skinner, Colorado State University, Civil Engineering Section, Fort Collins, Colorado.

(2514) ALLUVIAL CHANNEL HYDRAULICS

- (b) U. S. Geological Survey.
- (c) Dr. D. B. Simons, Project Chief.
- (d) Laboratory investigation; basic research.
- (e) A laboratory study of resistance to flow, sediment transport and related problems in alluvial channels.
- (f) Active.
- (g) Five different bed materials ranging in size from 0.19 millimeters to 0.93 millimeters have been studied. The forms of bed roughness which occur and their relation to sediment transport and resistance to flow have been studied and described. The effect of large concentrations of suspended fine sediment (clay), the viscosity of the water and the specific weight and gradation of the bed material on the mechanics of flow and on sediment transport in alluvial channels have also been investigated.
- (h) "A Preliminary Study of the Effect of Gradation of Bed Material on Flow Phenomena in Alluvial Channels," by Niwat Daranandana, Ph.D. Dissertation, Colorado State University, May 1962.
 "Control Structures in Alluvial Channels," by Frederick C. Stepanich, M.S. Thesis, Colorado State University, October 1962.
 "An Investigation of Total Sediment Discharge in Alluvial Channels," by Feng-Ming Chang, Ph.D. Dissertation, Colorado State University, December 1962.
 "Electrokinetic-Probe Response to Vortex-Street Frequency," by Hsing Chuang, paper to be submitted to the Journal of Fluid Mechanics, Colorado State University Civil Engineering Report No. CER62HC55, September 1962.
 Discussion of Francis M. Henderson's paper "Stability of Alluvial Channels," by D. B. Simons, published in the Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 88, No. HY4, July 1962.
 Closure to "Forms of Bed Roughness in Alluvial Channels," by D. B. Simons and E. V. Richardson, published in the Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 88, No. HY4, July 1962.

(2760) METEOROLOGICAL OBSERVATIONS

- (b) Colorado Agricultural Experiment Station and U.S. Weather Bureau.
- (c) Mr. Lewis O. Grant, Assistant Research Engineer.
- (d) Field investigation; basic research.
- (e) Meteorological observations are being obtained to establish long-term 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 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.

(2770) TURBULENCE STUDIES IN LIQUID USING ELECTROKINETIC PHENOMENON

- (b) National Science Foundation.
- (c) Dr. J. E. Cermak, Professor of Engineering Mechanics and Civil Engineering.
- (d) Experimental research; basic research, doctoral thesis.
- (e) The primary objective of the study is to determine the interaction between velocity fluctuations produced by turbulence in the liquid flow and electrokinetic potential fluctuations generated at a liquid-solid interface. Knowledge gained by this study will be applied to developing techniques for measuring turbulence characteristics in liquids.
- (f) Active.
- (g) Probes constructed with electrode pairs have been used to measure the distribution of turbulence intensities (three components) and the turbulent shear stress across a diameter of a circular pipe. The distribution measured in water agree with those obtained by Laufer in air using a hot-wire anemometer.
- (h) "Electrokinetic Potential Fluctuations Produced by Turbulence in Fully Developed Pipe Flow," by H. Chuang. Ph.D. Dissertation. Colorado State University, Fort Collins, Colorado. May 1962.
 "Electrokinetic Potential Fluctuations Generated by Jet Impingement at a Solid-Liquid Interface," by L. Duckstein. Ph. D. Dissertation, Colorado State University, May 1962.
 "Electrokinetic Probe Response to Vortex-Sheet Frequency," by H. Chuang (Submitted to Journal of Fluid Mechanics) December 1962.

(2902) DEVELOPMENT AND IMPROVEMENT OF WATER MEASURING DEVICES

- (b) Laboratory project, cooperative with Soil and Water Division, Agricultural Research Service and The Civil Engineering Section, Colorado Agricultural Experiment Station.
- (c) Mr. A. R. Robinson, Agricultural Engineer.
- (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 presently in progress are: (1) Design, evaluation and calibration of trapezoidal measuring flumes, (2) Improvement of procedures

for determining effects of submergence on Parshall flumes, (3) Effects of operation of the Parshall flume, (4) Qualitative study of a suspension wire in a conduit and as a probe for drag and velocity measurements.

- (f) Active.
- (g) A laboratory and field study on the problem of submergence on accuracy of the Parshall measuring flume was conducted and a report is in progress. The study indicates that submergence effects can be determined much more simply than with previous procedures used. The angle of convergence and point for measuring depth were varied for a model Parshall flume. Results indicate that the angle can be varied within limits without changing the standard stage-discharge relationship. Several sizes of trapezoidal flumes have been designed and calibrated under the entire range of operating conditions. Some of these are for the standard sizes of slip-form concrete ditches. Analyses based on energy and momentum principles have been used to study the operation of the flumes. The study of the suspension wire has demonstrated that drag measurements may be satisfactorily correlated with average velocity. As a probe, drag (and hence velocity) has been determined to within 0.001 feet of the channel floor. The device gave a favorable response in a heavy sediment load and tests show that the dynamic response in a turbulent field is very satisfactory (conducted by B. B. Sharp)
- (h) Discussion "Unification of Parshall Flume Data," by A. R. Robinson and Henry Liu. American Society of Civil Engineers, Journal of the Irrigation and Drainage Division, Vol. 88, No. IR-2, Part I, June 1962, pp. 112-114.
 "Conveyance, Control and Measurement of Irrigation Water on the Farm," by A. R. Robinson, C. W. Lauritzen, D. C. Muckel, and Jack Phelan. USDA Farmers Bulletin (in press).
 "Evaluation of the Vane-Type Flowmeter," by A. R. Robinson. Agricultural Engineering Journal, January 1963.
 "A Flow Measuring Device Depending on the Drag Developed on a Wire Suspended in Water," by B. B. Sharp. Report No. CER62BBS73, December 1962.

(3034) 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) Mr. D. W. Hubbell, Hydraulic Engineer.
- (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 foot 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.

(3037) TURBULENT SHEAR FLOW PHENOMENON

- (b) National Science Foundation
- (c) Dr. J. E. Cermak, Professor of Engineering Mechanics and Civil Engineering.
- (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 forming the floor of a wind tunnel.
- (f) Completed.
- (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. Characteristics of separation flow downstream from a plate set normal to the wind tunnel flow were insensitive to changing plate height relative to local boundary-layer thickness excepting when the plate height was of the order of the laminar "sub-layer" thickness or less.
- (h) "Mean Velocity Profiles for Flow Over a Plane, Smooth, Heated Boundary," by E. N. Earle. Masters Thesis, Colorado State University, Fort Collins, Colorado. May 1960.

(3395) FUNDAMENTAL STUDY OF A SUBMERGED THREE-DIMENSIONAL JET IMPINGING UPON A NORMAL PLANE

- (b) National Science Foundation.
- (c) Mr. George L. Smith, Assistant Civil Engineer, and Dr. Jack E. Cermak, Professor of Engineering Mechanics and Civil Engineering.
- (d) Experimental and theoretical; basic research and graduate thesis.
- (e) A study was made of an axisymmetrical jet of air impinging normally on a flat smooth plate. The mean velocity, the turbulent intensities and the turbulent shear stress were measured by means of a hot-wire anemometer in order to study the decay of the mean velocity, the growth of the boundary-layer thickness and the turbulent structure. A sensitive floating-element type shearmeter was designed and used. Data on skin friction obtained by direct shear measurements may be used to predict the distribution of the skin friction in similar wall jets. The objective of the program was to investigate systematically the effects on jet flow of the interaction between the free boundary and the solid boundary of varying roughness and configuration.
- (f) First phase, case of smooth boundary, completed. Investigation of effect of rough boundary has been initiated.
- (g) The characteristics of the whole boundary-layer is dominated by the effect of the free jet, and the wall influences the flow only in a very limited region close to the wall. This results in much higher turbulent intensities

and turbulent shear stress which increases the wall shear stress for this flow case as compared to two-dimensional uniform flow over a flat plate and smooth pipe flow. The ratio of turbulent intensities $\sqrt{w'^2}/\sqrt{u'^2}$ is in general not a constant across the boundary-layer which indicates non-applicability of Prandtl's assumption $u'\propto w'$ for this case.

- (h) "Axisymmetric Boundary-Layer of a Jet Impinging on a Smooth Plate," by Yeong-ging Tsuei, Ph. D. Dissertation, Colorado State University, August, 1962.

(3398) TURBULENT DIFFUSION IN SHEAR FLOW

- (b) National Institute of Health, Public Health Service, U.S. Department of Health, Education and Welfare, Washington, D.C.
- (c) Dr. J. E. Cermak, Professor of Engineering Mechanics and Civil Engineering.
- (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) Application of a hypothesis of Lagrangian similarity to particle motions in a turbulent shear flow near a solid boundary has yielded similarity parameters and relationships between them which correlate the wind-tunnel diffusion data and available diffusion data obtained in the atmospheric surface layer.
- (h) "Diffusion From a Point Source Within a Turbulent Boundary Layer with Unstable Density Stratification," by R. C. Malhotra, Ph. D. Dissertation, Colorado State University, June 1962.
"Lagrangian Similarity Hypothesis Applied to Diffusion in Turbulent Shear Flow," by J. E. Cermak. (Submitted to Journal of Fluid Mechanics) July 1962.

(3400) HYDRAULICS OF SUB-CRITICAL FLOW IN SMALL, ROUGH CHANNELS

- (b) Colorado Agricultural Experiment Station and Agricultural Research Service, U.S. Department of Agriculture.
- (c) Mr. Norman A. Evans, Agricultural Engineer.
- (d) Theoretical, laboratory experiment.
- (e) The study was made in a tilting flume with rough channels formed in natural soil and stabilized with chemical spray.
- (f) Active.
- (g) Summary of three years work was prepared showing the character of flow resistance in small, hydraulically rough channels.
- (h) Sub-critical Flow in Small, Rough Channels, by E. G. Kruse, Ph.D. Dissertation, Colorado State University Library, 1962.

(3696) STUDY OF CLOUDS AND SNOWFALL IN THE ROCKY MOUNTAINS, AND CHANGES RESULTING FROM THE ADDITION OF ARTIFICIAL ICE NUCLEI

- (b) National Science Foundation and the Climax Molybdenum Company.
- (c) Mr. Lewis O. Grant, Assistant Research Engineer.
- (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 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. The sample size is to be increased before attempting to determine the statistical significance of this apparent increase in snowfall.

(3697) MEASUREMENT OF ATMOSPHERIC OZONE WITH THE DOBSON SPECTROPHOTOMETER

- (b) Air Force Cambridge Research Center, L. G. Hanscom Field, Bedford, Massachusetts.
- (c) Mr. Lewis O. Grant, Assistant Research Engineer.
- (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. Reports are submitted to Air Force Cambridge Research Center.

(3704) DEVELOPMENT AND USE OF COLORADO BENTONITE IN SEALING IRRIGATION CANALS AND RESERVOIRS

- (b) State of Colorado.
- (c) Mr. R. D. Dirmeyer, Jr., Project Leader.
- (d) Field Investigation; applied research and development.
- (e) The work consists of three stages: (1) Inventory of clay deposits in Colorado with emphasis on those potentially usable in sealing canals and reservoirs. (2) Laboratory evaluation of clays from (1) above.

(3) Field trials in canals and reservoirs with best clays found in (1) and (2) on the previous page and evaluation of sealing results (initial and with time).

(f) Active.

(g) Inventory and Testing--In excess of 240 samples of Colorado clays have been collected and tested in the laboratory.

Development of Deposits and Field Trials--Eight deposits have been developed commercially. Clays from these deposits have been used in about 100 trials in canals and ponds during the past three years.

(h) A final report of the three-year project is being prepared and is scheduled for completion by 7/1/63.

"Progress Report of Clay Sealing Investigations During 1961," by R. D. Dirmeyer, Jr. Colorado State University, Fort Collins, Colorado, CER61RDD8, January 1962.

(3708) 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) Dr. J. E. Cermak, Professor of Engineering Mechanics and Civil Engineering; and Mr. E. J. Plate, Assistant Civil Engineer.

(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.

(4098) HIGH LEVEL TURBULENCE

(b) U.S. Navy Weather Research Facility, Building R-48, Naval Air Station, Norfolk, Virginia.

(c) Dr. Elmar Reiter, Associate Professor.

(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) "On the Nature of Clear-Air Turbulence (CAT)," by Elmar R. Reiter, and Robert W. Hayman. Scientific Interim Report prepared for the Naval Research Facility Under Contract No. N 189(188) 538-28A. Atmospheric Science Technical Paper No. 28. CER62ERR11.
 "A Case Study of Severe Clear-Air Turbulence," by Elmar R. Reiter. Prepared for Navy Weather Research Facility under Contract N 189(185)55120A. AST Paper No. 30. CER62ERR20.
 "Die Feinstruktur der Strahlstroeme, I and II," by Von Dr. E. R. Reiter, Associate Professor of Atmospheric Sciences, Colorado State University, Fort Collins, Colorado. Die Umschau, Frankfurt A.M., 62(18,20): 575-577, 628-631; 1962.
 "The Atmospheric Micro-Structure and its Bearing on Clear-Air Turbulence (CAT)," by Elmar R. Reiter. Prepared for Navy Weather Research Facility under Contract No. 189(188)55120A, presented on September 10, 1962 at the 4th Conference on Applied Meteorology, Hampton, Virginia. CER62ERR62.
 "Nature and Observation of High-Level Turbulence Especially in Clear Air," by Elmar R. Reiter. To be presented at Joint Meeting of IAS and AMS in New York, Jan. 21, 1963. CER62ERR76.

(4099) WAKE CHARACTERISTICS FOR BODIES OF REVOLUTION

- (b) Department of Navy, David Taylor Model Basin, Washington 7, D.C.
 (c) Dr. J. E. Cermak, Professor of Engineering Mechanics and Civil Engineering, and Dr. L. V. Baldwin, Associate Professor.
 (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.

(4100) PATTERNS IN SEQUENCE OF ANNUAL RIVER FLOWS

- (b) National Science Foundation
 (c) Dr. V. M. Yevdjevich, Research Hydraulic Engineer.
 (d) Theoretical; basic research.
 (e) Three large samples, 140 river gaging stations from around the world, 450 river gaging stations from the western United States and western Canada, and several hundred precipitation stations from the western United States and western Canada have been used to study the non-randomness in the fluctuations of wet and dry years of river flows and precipitation.
 (f) Active.
 (g) The majority of the non-randomness of the sequence in wet and dry years of river flows may be explained by the carryover of water in river basins, by evaporation in river basins, by evaporation of the rainfall in the air between the cloud base and the ground (arid regions) and by non-homogeneity and inconsistency in hydrologic data.

- (h) "Climatic Fluctuation Studies by Using Annual Flows and Effective Annual Precipitation," by V. M. Yevdjovich, presented at the UNESCO Symposium on Climatic Changes, in Rome, Italy, October 1961.
"Fluctuations of Effective Annual Precipitation," by V. M. Yevdjovich, presented at the Western Snow Conference in Cheyenne, Wyoming, April 17, 1962.

(4101) UNSTEADY FREE SURFACE FLOW IN A LARGE STORM DRAIN

- (b) U.S. Bureau of Public Roads and U.S. Public Health Service.
- (c) Dr. V. M. Yevdjovich, Research Hydraulic Engineer.
- (d) Experimental and theoretical; basic research.
- (e) A 825-ft long, 36-in. diameter conduit, movable on 43 supports on a hillside, is used as the main experimental facility to simulate and record free surface waves in pipes. The same waves are computed by using a digital computer and then a comparison is made. The ultimate purpose is a development of a set of routing methods to suit the desired accuracy and the quality of the initial and boundary data.
- (f) Active.
- (g) The analytical study for directing the research is being completed.
- (h) "Unsteady Free Surface Flow in a Storm Drain," by V. M. Yevdjovich, general analytical study, a report to the U.S. Bureau of Public Roads Hydraulic Division, Engineering Research; Colorado State University, Fort Collins, Colorado, June 1961.

(4102) WIND FORECASTING TECHNIQUES

- (b) Federal Aviation Agency, Federal Aviation Facilities Center, Atlantic City, New Jersey, Attn: RD-140.
- (c) Dr. Elmar Reiter, Associate Professor.
- (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.
- (h) "Wind Forecasting Techniques for Input into an Automatic Air Traffic Control (ATC) System," Dr. E. R. Reiter, Atmospheric Science Technical Paper No. 37, CER62ERR51.
"Note on the Eddy Kinetic Energy Distribution in Relation to the Jet Stream," by Elmar R. Reiter. ATS Paper. Prepared in the course of research on upper-level winds under contract ARDS-450 with Federal Aviation Agency. CER62ERR68 ATSP40

(4105) HAIL GENESIS AREAS

- (b) Crop Hail Insurance Actuarial Association, Chicago, Illinois.
- (c) Dr. Richard A. Schleusener, Associate Research Engineer.
- (d) Field investigation, basic and applied research.
- (e) Regions of hailstorm genesis were determined by following thunderstorm precipitation areas with a three-centimeter radar set located at New Raymer, Colorado. The climatology of hailstorms and thunderstorms was determined by tracking these precipitation cells during the period 15 May 1962 to 31 July 1962.

- (f) The project is being continued.
- (g) The direction of hailstorms in the area was normally from the southwest in May, and changed to the northwest by late June or early July. It is noted that there is a concentration of hail genesis in the region just east of the Rocky Mountains, with more thunderstorm areas developing there than in a corresponding region about one hundred miles further east.
- (h) "Climatology of Hailstorms In and Near Northeastern Colorado 15 May to 31 July 1962 with comparative data for 1961," by Richard A. Schleusener and Thomas J. Henderson, Civil Engineering Report November 1962, Colorado State University. CER62RAS-TJH77.

(4106) GROUND-WATER RESERVOIR MANAGEMENT

- (b) Colorado Agricultural Experiment Station and Colorado Department of Natural Resources.
- (c) Mr. M. W. Bittinger, Associate Research Engineer.
- (d) Theoretical and field investigation; applied research.
- (e) It is the purpose to study the operating characteristics of ground water reservoirs in Colorado. Specific studies include (1) the inter-relationships of ground and surface water in alluvial valleys, (2) natural recharge from ephemeral streams, and (3) artificial recharge possibilities in the High Plains of Colorado.
- (f) Active.
- (g) (1) Statistical analyses of surface and ground water records for a section of the alluvial valley of the Arkansas Valley are being conducted, to determine significant components influencing river gain. (2) Studies in Kiowa Creek have shown influences of stream flows on water table levels. (3) Rainfall and runoff studies are being initiated in the High Plains Area.
- (h) "Statistical Techniques for Predicting River Accretion as Applied to the South Platte River" (Henderson-Fort Lupton), by R. A. Longenbaugh. Master of Science Thesis, Colorado State University Library, July 1963. 108 pp.
 "Natural Ground-Water Recharge from Kiowa Creek, 1961 Progress Report," by M. W. Bittinger, R. A. Longenbaugh, and E. F. Schulz, Colorado State University Mimeo. March 1962, 10 pp.
 "Managing Artificial Recharge Through Public Districts," by S. C. Smith and M. W. Bittinger. Paper presented at 1962 Winter Meeting of the American Society of Agricultural Engineers, December 1962, 16 pp.

(4108) WATERSHED HYDROLOGY

- (b) Agricultural Experiment Station, Foothills Campus
- (c) Dr. V. M. Yevdjevich, Research Hydraulic Engineer and Mr. E. F. Schulz, Associate Civil Engineer.
- (d) Theoretical and experimental; basic research.
- (e) The research is being initiated in three directions; gathering of the data on several hundred hydrographs and hyetographs for floods from small watersheds; design of a large hydraulic model to investigate rainfall-runoff relationship; and theoretical research for relating variables describing hydrographs, river basins, and hyetographs for floods from small watersheds.

- (f) Active in the very initial stage.
- (g) "Design Hydrographs for Very Small Watersheds from Rainfall," by B. M. Reich. Ph.D. Dissertation.
"Some Effects of Glaciation on Water Yield," by E. H. Hansen. Master of Science Thesis.
"Normal Monthly and Annual Precipitation for Eastern Colorado," by G. L. Smith and E. F. Schulz. CER62GLS48.
"A Graphical Procedure to Estimate Potential Evapotranspiration by the Penman Method," by E. F. Schulz. CER62EFS49.

(4109) METEOROLOGICAL CONDITIONS AFFECTING DENVER AIR POLLUTION

- (b) Yetter Foundation, administered by Denver U.S. National Bank.
- (c) Dr. Herbert Riehl, Professor of Atmospheric Science.
- (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 are operating during pollution periods. The air sampling is carried out in conjunction with the project by the City of Denver.
- (f) Completed.
- (h) "A Study of Denver Air Pollution," by Herbert Riehl and Loren W. Crow. A report on research conducted under a Grant by the Helen Dean Yetter Foundation to Colorado State University. June 1962.

(4110) TURBULENT AIR MOTION IN THE HIGH ROCKIES IN RELATION TO THE WATER YIELD OF UPPER WATERSHEDS

- (b) Colorado Agricultural Experiment Station.
- (c) Dr. Herbert Riehl, Professor of Atmospheric Science.
- (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 1962-63 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) Project temporarily postponed while wind equipment is being redesigned.

(4111) THE ROLE OF THE ROCKY MOUNTAINS IN THE GENERAL CIRCULATION OF THE ATMOSPHERE

(b) U.S. Navy Numerical Weather Prediction Facility, Monterey, California.

(c) Dr. Herbert Riehl, Professor of Atmospheric Science.

(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 percent--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.

(4112) THE DISCHARGE OF MAJOR WESTERN RIVERS IN RELATION TO THE GENERAL CIRCULATION OF THE ATMOSPHERE

(b) Office of Naval Research, Department of the Navy.

(c) Dr. Herbert Riehl, Professor of Atmospheric Science.

(d) Basic research.

(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.

(h) Publications in progress.

(4113) WEATHER PATTERNS AND CIRCULATION OF THE TROPICS

- (b) U.S. Weather Bureau.
- (c) Dr. Herbert Riehl, Professor of Atmospheric Science.
- (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.
- (h) "Some Observations of Low-Level Wind Variation in the Vertical in Tropical Cyclones", by Arthur C. Pike. A report on research conducted under contract No. CWB-9918 between the U.S. Weather Bureau and Colorado State University. February 1962. Engineering Report 62-12. "Estimating the Effect of Cloudiness on Incoming Solar Radiation," by Arthur C. Pike. A report on research conducted under contract No. CWB-9918 between the U.S. Weather Bureau and Colorado State University. May 1962. Engineering Report 62-33. "Radiation Measurements over the Caribbean During the Autumn of 1960," by Herbert Riehl. Published in Journal of Geophysical Research, Vol. 67, No. 10, pp. 3935-3942. March 1962. Engineering Report 62-13.

(4114) GRAVEL FILTER FOR TILE DRAINS

- (b) Colorado Agricultural Experiment Station.
- (c) Mr. Norman A. Evans, Agricultural Engineer.
- (d) Applied; experimental
- (e) Gravels classed as "pit-run" have been tested in a sand tank model with very fine sand as the aquifer.
- (f) Active.
- (g) Criteria for selecting very non-uniform gravels as fillers for very fine sand have been established.
- (h) "Criteria for Gravel Filter Design," by C. des Bouvrie, Master of Science Thesis, Colorado State University Library, 1962.

(4115) INFLUENCE OF INORGANIC WATERSHED COVERS ON MOISTURE EXCHANGE IN A VERTICAL DIRECTION ACROSS THE SOIL-AIR INTERFACE

- (b) Colorado Agricultural Experiment Station, a contributing project of the Western Regional Research Project W-73.
- (c) Dr. A. T. Corey, Professor of Agricultural Engineering
- (d) Applied and basic research.

- (e) This project is a study of the effects of inorganic covers (especially gravel mulches) on the hydrologic processes of evaporation and infiltration of moisture across the soil-air interface and the relationship of these processes to water yield.
- (f) Active.
- (g) It has been demonstrated by both laboratory and field experiments that gravel mulches substantially reduce the rate of evaporation from bare soils and promotes an increased accumulation of water in the soil.
- (h) "Influence of Inorganic Watershed Covers on Moisture Exchange in a Vertical Direction Across the Soil-Air Interface," Colorado Contributing Project, W-73, Progress Reports Nos. 1 and 2, Colorado Agricultural Experiment Station, October 1961 and October 1962.

STRUCTURE OF TURBULENCE IN TURBULENT SHEAR FLOW

- (b) Department of the Army.
- (c) Dr. J. E. Cermak, Professor of Engineering Mechanics and Civil Engineering, and Mr. E. J. Plate, Assistant Professor.
- (d) Experimental research; basic research, doctoral theses.
- (e) The effects of surface roughness and surface heating or cooling upon the structure of turbulence in boundary layer flow will be determined. The flows investigated will be those existing on the heated or cooled floor of a wind-tunnel test section 6 x 6 ft in cross section and 80 ft long. Space-time correlations, joint probability densities, spectra and intensities of the turbulent velocities and temperatures will be obtained by hot-wire techniques and special analog computers employing magnetic tape input.
- (f) Active.

WIND-WAVE RESEARCH FACILITY

- (b) National Science Foundation.
- (c) Mr. E. J. Plate, Assistant Professor.
- (d) Laboratory development.
- (e) The research facility consists of a tilting water channel approximately 35 feet long and 2 feet by 2 feet in cross section with a closed upper space about 2 feet by 2 feet in cross section to permit controlled air flow over the water. Studies of wind-wave generation and growth and interfacial transfer phenomena will be made possible with this water channel-wind tunnel combination.
- (f) Active.
- (g) Construction is in progress.

TURBULENCE DATA ANALYSIS SYSTEM

- (b) Department of the Army and National Center for Atmospheric Research.
- (c) Dr. L. V. Baldwin, Associate Professor.
- (d) Laboratory development.
- (e) The system employing magnetic tape input is designed to yield the following information: (1) spectra (10^{-3} to 10^4 cycles/second), (2) joint probability densities, (3) root-mean-squares, and (4) space-time correlation.

- (f) Active.
- (g) Installation is near completion.

MODELING OF AIR-FLOW PATTERNS AT CANDLESTICK BALL PARK

- (b) Metronics Associates Inc., Menlo Park, California.
- (c) Dr. J. E. Cermak, Professor of Engineering Mechanics and Civil Engineering; and Mr. E. J. Plate, Assistant Professor.
- (d) Experimental; applied research.
- (e) The applied study utilizes a 1:800 scale model of the local topography and the Candlestick Ball Park Stadium placed in a 6 by 6 foot wind tunnel. Verification of the modeling technique is being accomplished as a first phase of the study by comparing model wind patterns with prototype wind patterns obtained by field measurements. The second phase of the model study will consist of modifying both topography and stadium to obtain minimum wind disturbance in the ball park.
- (f) Active.
- (g) The first phase of the study has been completed with the result that model wind patterns have been found to be sufficiently representative of field behavior to permit proceeding to the second phase with confidence.

PREPARATION AND ANALYSIS OF CLIMATOLOGICAL DATA OF IMPORTANCE TO AGRICULTURE IN COLORADO

- (b) Colorado Agricultural Experiment Station, a contributing project of the Western Regional Research Project W-48.
- (c) Dr. A. T. Corey, Professor of Agricultural Engineering.
- (d) Applied.
- (e) This project has as its objectives: (1) To provide climatological data for a representative network of Colorado stations in a form suitable for weather analysis; (2) To obtain summaries of distributions of meteorological parameters pertinent to agriculture; (3) To devise and utilize statistical and computer methods for estimates of the probabilities of significant weather conditions; e.g., weekly rainfall totals and dates of critical spring and fall temperatures.
- (f) Active, continuing.
- (g) Work on objective No. 2. has almost been completed.
- (h) Colorado Contributing Project, W-48, Progress Report No. 1, Colorado Agricultural Experiment Station, September 1962.

PERMEABILITY AND CAPILLARY PRESSURE RELATED TO MEDIA PROPERTIES

- (b) National Science Foundation.
- (c) Dr. A. T. Corey, Professor of Agricultural Engineering.
- (d) Experimental and theoretical basic research.
- (e) The study involves an investigation of a tentative theory describing how the functional relationship between relative permeability and relative capillary pressure is related to measurable properties of porous media.
- (f) Active, continuing.

- (g) A theory showing how the variables capillary pressure, liquid and gas permeability are related to degree of saturation has been developed. The experimental results to date appear to verify the theory. The most important property of granular porous media in respect to the functional relationship between relative permeability and relative capillary pressure seems to be the presence or absence of secondary porosity (structure).
- (h) "Hydraulic Characteristics of Porous Media," R. H. Brooks and A. T. Corey, Annual Research Report 1960, 1961.

TRANSPORT OF PARTICLES THROUGH UNSATURATED SOILS

- (b) Department of Health, Education, and Welfare, Bureau of State Service.
- (c) Dr. A. T. Corey, Professor of Agricultural Engineering.
- (d) Applied; experimental.
- (e) The objective of this research is to determine to what extent the transport of solid particles by water flowing through soil may be affected by the degree of saturation of soil. The term "soil" is interpreted broadly as including sands and gravels as well as agricultural soils. The solid particles to be considered in this study will be of sizes and shapes corresponding to that of viruses.
- (f) Project was only recently funded and is just getting started.

MORPHOLOGY OF WHITE RIVER, MOUNT RAINIER, WASHINGTON

- (b) U.S. Geological Survey, Water Resources Division, General Hydrology Branch.
- (c) Mr. Robert K. Fahnestock, Geologist, U.S. Geological Survey
- (d) Field investigation; basic research.
- (e) To determine the processes of valley train formation and the influences of a glacier on the stream form.
- (f) Active.
- (h) "Dynamics of Stream Braiding as Shown by Means of Time Lapse Photography," by R. K. Fahnestock, (Abs) Geol. Soc. America Bull., v. 70, No. 12, Pt. 2, p. 1599, 1959.
 "Morphology and Hydrology of a Glacial Stream," by R. K. Fahnestock, Ph.D. Thesis, Cornell University, 1960, (Abs) Geol. Soc. America Bull., v. 71, no. 12, pt. 2, page 1862, (Abs) Dissertation Abstracts, v. 21, no. 6.
 "Significance of a Braided Channel Pattern," by R. K. Fahnestock, (Abs) Geol. Soc. America Bull., v. 71, no. 12, pt. 2, p. 1862, 1960.
 "Competence of a Glacial Stream," by R. K. Fahnestock, U.S. Geological Survey Professional Paper 424-B, p. B211-213, 1961.
 "Morphology and Hydrology of a Glacial Stream, White River Below Emmons Glacier, Mount Rainier, Washington," by R. K. Fahnestock, U.S. Geological Survey Professional Paper 422A, in press.

SEDIMENT TRANSPORT AND FLUVIAL MORPHOLOGY OF THE RIO GRANDE NEAR EL PASO, TEXAS

- (b) U.S. Geological Survey, Water Resources Division, General Hydrology Branch.
- (c) Mr. Robert K. Fahnestock, Geologist, U.S. Geological Survey.
- (d) Field investigation; basic research.

- (e) A reach of canalized river 100-ft wide and another 200-ft wide have been selected for comparison. Discharges from 100 to 1300 cfs are available in the form of irrigation releases from Caballo Reservoir. Preliminary maps of bed form and bottom velocity have shown marked variations with time, sediment transport, width, water temperature, and discharge. Measurements of variables in these and additional reaches will allow comparison with flume data and provide a better basis for prediction of bed behavior in natural and artificial channels.
- (f) Active.

MORPHOLOGY OF STREAMS OF THE OLYMPIC PENINSULA, WASHINGTON

- (b) U.S. Geological Survey, Water Resources Division, General Hydrology Branch.
- (c) Mr. Robert K. Fahnestock, Geologist.
- (d) Field investigation; basic research.
- (e) The objectives of the study are to determine the characteristics of streams of the Olympic Peninsula, the processes taking place within the channel and to relate these characteristics and processes to morphology of the stream valley.
- (f) Active.

WATER CYCLE (General Hydraulic Characteristics of Western North America).

- (b) Office of Naval Research.
- (c) Dr. V. M. Yevdjovich, Research Hydraulic Engineer.
- (d) Theoretical; basic research.
- (e) By using a large sample of 450 homogeneous river gaging stations in western North America and several hundred precipitation stations, the regional correlation of wet and dry years, as well as their simultaneity, is being investigated.
- (f) Active.
- (g) Both large samples are in a final stage of processing with standardized variables of annual flows, effective annual precipitation and annual precipitation obtained.

MECHANICS OF LOCAL SCOUR

- (b) Department of Commerce, Bureau of Public Roads, Hydraulic Research Division.
- (c) Mr. S. S. Karaki, Associate Civil Engineer.
- (d) Theoretical and experimental; basic research.
- (e) A theoretical study of the mechanics of local scour is under way to develop basic equations for determining local scour. Basic experiments will be undertaken simultaneously to assist theoretical development.
- (f) Active.
- (g) Just started.